


# CLIMATE FOCUSED AGRICULTURAL VOCATIONAL EDUCATION

# Climate Focused Agricultural Vocational Education

*Editor*

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**Atatürk Horticultural Central Research Institute**

**Publication No: 114**

**YALOVA-2024**

*The European Commission's support for the production of this publication does not constitute an endorsement of the contents, which reflect the views only of the authors and the Commission cannot be held responsible for any use which may be made of the information contained therein.*

Funded by the European Union

Content of this book is prepared for the project "Climate Focused Agricultural Vocational Education (CLIAVE)" which is an Erasmus+ project funded by the European Union. Original content can be reached from www.cliave.net. As an alternat way to reach the learning modules offline and to reach more people we created this book. But we suggest checking learning modules from our project web page as more content may be add over time.

This e-book follows the open access model and aims to contribute to the free sharing of knowledge.

This book has been published by Atatürk Horticultural Central Research Institute

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Layout by Murat Korucuk

Publication No: 114

ISBN: 978-625-94899-5-7

Some photographs used in this book for decorative purposes were created with artificial intelligence.

In the face of climate changing, to adapt our agricultural practices has never been more critical. "Climate Focused Agricultural Vocational Education" is a text that seeks to empower current and future generation of students and agricultural professionals with the knowledge and tools necessary to mitigate the impacts of climate change on agriculture. This book serves as a comprehensive guide, detailing innovative methods and sustainable practices that can reduce carbon footprints, enhance biodiversity, and secure food production in harmony with the Earth's ecosystems. As we embark on this journey, we invite readers to engage with the content, apply the techniques, and become part of a global movement towards a more resilient and environmentally conscious agricultural landscape. Together, we can cultivate a future where both our planet and with it we the people thrive.

Emre Bilen

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MODULE 1

# Climate Resilient Cropping Systems

## Jaroslav BERNAS, Petr KONVALINA, Jaroslav NEUMANN

## Outline

•Introduction, Parameters and Advantages of Climate Resilient Cropping Systems
•Climate Change and Its General Impact on Agriculture
•Sustainable Farming Strategies and Climate Resilient Cropping Systems
•Tillage Systems Under Climate Resilient Cropping Systems and Crop Rotation, Cover Crops and Pre-Crops Effect
•Marginal Crops Growing for Food Production
•Alternative Crops Growing for Biomass Production
•Intercropping and Agroforestry
•Ecosystem Services Within Climate Resilient Cropping System

## Introduction

Human activities, particularly fossil fuel combustion and land use changes, drive current climate change, increasing greenhouse gas concentrations. This influences temperature and precipitation patterns, affecting agriculture, particularly in tropical regions. Climate change poses a severe threat to agriculture and food security. As we approach a global population of 9.8 billion by 2050, the declining productivity of major crops exacerbates concerns. Agriculture faces climate change impacts worldwide, potentially offsetting advancements in crop improvement and management practices. Instability in crop yields can have economic repercussions. Soil fertility, carbon sequestration, microbial activity and crop growth are diminishing due to intensive input use and intensive cultivation strategies in general. Also, drought, intense precipitation, higher temperatures, soil contamination and more pests and pathogens are becoming regular problems. Changes in temperature and precipitation patterns make crops more susceptible to biotic and abiotic stresses. Monoculture practices in modern agriculture increase crop vulnerability to diseases and pests. Historical examples highlight the risks of limited crop diversity. In contrast, traditional agriculture practices persist in many developing countries, focusing on biodiversity and minimal inputs. The emphasis on organic farming, diversification and minimizing inputs is growing, promoting sustainability and agroecosystem resilience. Diversifying crops, agroforestry and generally adjusting cultivation practices are vital strategies. The footprint of agriculture on the planet is substantial, with arable land covering about 12% of the Earth's surface. Sustainable agriculture strategies, such as reducing tillage, play a critical role in maintaining biodiversity within agroecosystems. Climate resilient agriculture and climate resilient cropping systems seek to sustainably use natural resources for crop production, focusing on long-term productivity while adapting to climate fluctuations. Climate resilience involves robustness, adaptability and transformability in agricultural practices, promoting ecosystem health and biodiversity. Climate-resilient cropping systems have the potential to withstand stressors like drought and pests and play a critical role in global agriculture. Many agricultural technologies and approaches dealing with drought-resistant or pest-resistant crop varieties already offer solutions. Although climate resilient crops provide numerous benefits, small-scale farmers may hesitate to adopt them due to risk aversion and profitability concerns. Climate change profoundly affects agriculture, food security and the environment. To address these challenges, adopting climate resilient cropping systems, developing climate resilient crops and preserving biodiversity are vital steps.

# INTRODUCTION, PARAMETERS AND ADVANTAGES OF CLIMATE RESILIENT CROPPING SYSTEMS

Climate change has reduced the productivity of major crops in many regions of the world [13], which may cause great problems by the year 2050, when the population on Earth should reach about 9.8 billion. With the estimated population 30 years from now and decreasing productivity of agriculture, farmers will be challenged to secure global food security [21] and if farmers want to meet the upcoming increase in demand for meat and dairy products when those demands lead inevitably to even further use of natural resources which may affect the climate, they will need to adjust their farm management, for example, sowing dates, the use of intermediate crops and the use of more resistant crops to a specific climate [23].

No agriculture system is immune to climate change. Even though there are genetically improved plants and management practices that give farmers improvements in yields and sustainability, climate change may easily offset all of this mentioned above [8]. For example, climate variability is the main cause of changes in yields in the Midwestern United States [8]. The instability of yields may result in economic swings for consumers and producers. After all, this can be seen by looking 10 years back when the drought in 2012 caused a 53% increase in the price of corn relative to the previous 5-year average price [2].

At this time, we can see a decrease across the world in soil fertility, as well as carbon sequestration, microbial activity and crop growth. Those and other negative effects on our environment are supported by the low diversity and high intensity of inputs that farmers put into agroecosystems. Another problem, one that is also disturbing, is the predicted increase in the occurrence of drought, intense precipitation, higher temperatures and contamination of soils by salts and heavy metals when all of this will inevitably lead to increased occurrence of pests and pathogens, which will take its toll on crop yields [15].

Climate changes are significantly affecting agriculture and food production. Climatic conditions such as wind, drought, high temperatures and floods have a great impact on food safety and poverty reduction. However, this is especially the case in highly water-dependent countryside communities. With upcoming climate changes, lower yields from staple crops are expected due to lower productivity [9].

## Climate Resilient Agriculture

Climate resilient agriculture is a form of farming that aims for the sustainable use of natural resources that are at our disposal through crop production systems. The main goal is to increase the productivity of farms in the long term and at the same time while maintaining the income of the farm under climate variabilities.

Climate resilience is the ability to keep up with agricultural structures while ensuring their functions with constantly changing climatic conditions. Farmers can support climate resilience by improving the robustness, adaptability and transformability of agricultural practices 16. Robustness is meant the capacity of the agricultural system to be able to deal with climate extremes. Adaptability is meant as the capacity to change agricultural practices like marketing and risk management to reduce the impacts of climate extremes while maintaining the structure of the system. Transformability is meant the capacity to change the structure and function of the system in response to climate change 16. Overall, the aim of improving climate resilience does not include only increasing the productivity of crops while the climatic conditions are changing but also improving the ecosystems and their biodiversity while minimizing environmental degradation 20.

## Climate resilient cropping system

Climate resilient crops (CRCs) were bred for a specific purpose, to cope with biotic and abiotic stress, for example, drought, where there are numerous ways how to fight drought through water management. For example, water-friendly technologies like a furrow irrigated raised bed, rainwater harvesting, cover crop method, micro irrigation, etc. When drought occurs and with-it high temperatures, a relatively safe way how to get satisfactory yields is the use of different kinds of technologies based on crop water estimation, adoption of water conversation methods, changing the fertilizer and watering schedules, etc.

For example, the drought-resistant varieties of rice grown in India have yielded approximately about 1 t/ha higher than common varieties when undergoing drought stress. Rice is not the only crop that is affected greatly by drought or floods. Maize and wheat are also sensitive to these stresses. Drought is responsible for up to 20% loss in yield in maize. Drought-tolerant varieties of Maize can yield up to 2-3 t/ha than common varieties that will yield up to 1 t/ha in the same conditions [25].

Another reason why CRCs were bred is water resistance. For example, the introduction of short-duration varieties of pea, soybean, wheat and sorghum in India led to increased yields significantly [24]. It is important to say that a large part of the territory where these crops are grown suffers from submerging due to floods and almost 80% of the rice-growing territory in Eastern India is suffering from excess water or drought, depending on rainfall pattern and thus making farmers completely dependent on the environment. By using a flood-tolerant rice variety, that can manage up to 17 days of complete water submerging and with a yield of 3 t/ha, farmers can reduce their dependency on environmental factors [22].

There are more reasons why to use CRCs, such as high temperatures, salinity and shorter vegetation period, as well as to cope with pests. Another purpose because CRCs were bred is to improve water retention in soil, improve soil quality and erosion reduction. Climate resilient crops (CRCs) have a higher tolerance to biotic and abiotic stresses compared to commonly grown crops [3].

*Table 1. Advantages and disadvantages of intensive and extensive farming activities 18*

| Intensive | Extensive |
|---|---|
| **Advantages** | |
| Rational land use | Preservation of natural landscape |
| Global food security | Preservation of wildlife habitats |
| Cheaper food products | Better quality and safer food products |
| Growing revenues for food export | More people involved in agricultural activities |
| Faster work using the modem equipment | Government supported activity |
| Doesn't need a lot of manual work | Lower additional cost (no need to buy mineral and other chemical fertilizers) |
| **Disadvantages** | |
| Technical equipment operation cost | More expensive food products |
| Additional cost of fertilizers, chemicals | More care for crops and animals grown |
| Capital replaces the labour, less people arc involved in agricultural activities | More hand work needed |
| Need for specialists with higher qualification | Large agricultural land areas needed |
| Damage to environment, landscape, soil, water | Lower productivity |

The main purpose of these crops is to maintain the yield under stress conditions compared to crops that are commonly grown. Thanks to the properties CRCs have, farmers will get the means to adopt their farm management and sustain quality, yields and financial stability. Climate-resilient crop systems aren't only about using water, temperature, or salt tolerant varieties of crops, but it goes beyond the issue of biodiversity, alternative farming systems, conversation agriculture and more [4].

Despite the benefits CRCs provide, adoption by small-scale producers ought to be mentioned, but in some cropping systems, it might not be as high as expected [6, 14]. Due to high risk and profitability

concerns caused by switching to new and different ways of managing an agroecosystem, farmers are more likely to be timid in accepting and trying different ways, even though they know that these methods are more sustainable and environmentally friendly than their current approach.

## Alternative farming systems

At this time, there are a few ways how farmers can manage their fields other than conventionally. For example, they can use alternative agricultural systems that are better than conventional farming as far as climate resilient crop system is concerned [17]. Alternative management systems may include no-till, reduced tillage practices, crop rotation, the use of cover crops, decreasing usage of inorganic inputs, etc. Research shows that these alternative systems of farming might have the potential to mitigate environmental pollution and greenhouse gas emissions while improving water and soil quality [1].

Current knowledge suggests that climate changes will affect biotic (pests, pathogens) and abiotic (solar radiation, water temperature, water) factors in crop production, which will lead to threatening crop sustainability and production [14]. That is why farmers should also focus on biodiversity and try to diversify their agroecosystems because more diverse systems will perform better in changing environments. Potential benefits for farmers are shown in Table 2.

*Table 2. Examples of diversification in agricultural systems and the potential benefits for farmers under climate change, adopted from 14*

| Type of Diversification | Nature of Diversification | Benefits |
|---|---|---|
| Increased structural diversity | Makes crops within the field more structurally diverse | Pest suppression |
| Genetic diversity in monoculture | Growing mixed varieties of a species in a monoculture | Disease suppression<br>Increased production stability |
| Diversity field with non-crop vegetation | Growing weed strips or vegetation banks in and alongside crops | Pest suppression |
| Crop rotations | Temporal diversity through crop rotations | Disease suppression<br>Increased production |
| Polycultures | Growing two or more crop species and wild varieties within the field, spatial and temporal diversity of crops | Disease suppression<br>Climate change buffering<br>Increased production |
| Agroforestry | Growing crops and trees together, spatial and temporal diversity | Pest suppression<br>Climate change buffering |
| Mixed landscapes | Development of larger-scale diversified landscapes with multiple ecosystems | Pest suppression<br>Increased production |

## Conversion agriculture

Conversion agriculture is defined by FAO (Food and Agriculture Organization) as an approach to managing agroecosystems for improved and sustained productivity while increasing profits and food security and, at the same time, preserving and enhancing the resources and environment. 3 basic principles constitute, along with other complementary practices, conversion agriculture [11].

•Principle 1 is about minimal tillage or no-till, which goes hand in hand with the practice of no-till sowing and direct sowing of planting material into untilled soil. This causes minimal soil disturbance from any operation.

•Principle 2 is about the maintenance of a permanent mulch cover on the ground surface, which means the farmer needs to implement retaining crop biomass on the field.

•Principle 3 is about the diversification of crop species, which requires to use of annuals and perennial crops, cropping system rotation and the right mix of legume and non-legume crops.

These three principles are the foundation of conversion agriculture, which means if a farmer is applying one or two of these principles in his agroecosystem, he isn't conversion agriculture compliant. The purpose of conversion agriculture is to increase biological biodiversity and biological processes in agroecosystems. Tillage shouldn't be used, or it should be at least reduced to an absolute minimum. External inputs, like inorganic and organic fertilizers, should be applied optimally and in quantities that will not affect biological processes in soil [11]. While being compliant with all principles of conversion agriculture, farmers will be able to improve overall farm management, mainly in raid-fed areas. With other well-known practices, for example, integrated pest, water and nutrient management, conversion agriculture is the base system farmers should choose if they want to intensify their production while keeping it sustainable [10]. The development of conversion agriculture in Europe is summarized in Table 3.

*Table 3. Extend of conversion agriculture adoption (000 ha) in Europe in 2008/09, 2013/14 and 2015/16 11*

| Country | CA Area 2008/2009 | CA Area 2013/2014 | CA Area 2015/2016 |
|---|---|---|---|
| Spain | 650.00 | 792.00 | 900.00 |
| Italy | 80.00 | 380.00 | 283.92 |
| Finland | 200.00 | 200.00 | 200.00 |
| France | 200.00 | 200.00* | 300.00 |
| Cormany | 354.00 | 200.00 | 146.00 |
| United Kingdom | 25.00 | 150.00 | 362.00 |
| Slovakia | 10.00 | 35.00 | 35.00# |
| Portugal | 28.00 | 32.00 | 32.00# |
| Switzerland | 9.00 | 17.00 | 17.00# |
| Hungary | 8.00 | 5.00 | 5.00 |
| Ireland | 0.10 | 0.20 | 0.20 |
| Moldova | - | 40.00 | 60.00 |
| Greece | - | 24.00 | 24.00# |
| Netherlands | - | 0.50 | 7.35 |
| Belgium | - | 0.27 | 0.27 |
| Romania | - | - | 583.82 |
| Poland | - | - | 403.18 |
| Estonia | - | - | 42.14 |
| Czech Republic | - | - | 40.82 |
| Austria | - | - | 28.33 |
| Lithuania | - | - | 19.28 |
| Ooatia | - | - | 18.54 |
| Bulgaria | - | - | 16.50 |
| Sweden | - | - | 15.32 |
| Latvia | - | - | 11.34 |
| Denmark | - | - | 2.50 |
| Slovenia | - | - | 2.48 |
| Luxemburg | - | - | 0.44 |
| Cyprus | - | - | 0.27 |
| Total | 1564.10 | 2035.97 | 3557.20 |
| % difference | | 30.1 since 2008/2009 | 127.4 since 2008/2009<br>74.7 since 2015/2016 |

The main reasons to accept conversion agriculture are better farm economy due to a reduction of inputs, like water, fertilizers, agrochemicals, time and fuel, flexible technical possibilities for fertilizer application and weed control, equal or higher yields, greater yield stability [12], higher protection of soil from water and wind erosion [19], higher fertilizer retention and higher water retention with better water management in drought areas [5].

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# CLIMATE CHANGE AND ITS GENERAL IMPACT ON AGRICULTURE

The current global climate change phenomenon is primarily attributed to the combustion of fossil fuels (coal, oil, natural gas) and the alteration of land use, leading to the mineralization of organic matter. These activities, driven by human exploitation of fossil resources, deforestation and the conversion of land for agriculture, have resulted in a significant increase in carbon dioxide ($CO_2$) levels. This rise in $CO_2$ concentration contributes to global warming by impeding the reflection of sunlight, thereby causing more heat to be trapped in the Earth's atmosphere. Furthermore, molecules such as methane ($CH_4$) and nitrous oxide ($N_2O$) have an even greater impact, with methane having a global warming potential twenty times higher than that of $CO_2$ and nitrous oxide's potential being up to 300 times greater [10].

Agricultural production heavily relies on climate conditions, making it highly susceptible to the effects of climate change. Consequently, significant changes have been observed in various agricultural sectors over the past decade, prompted by the potential effects of climatic changes. Research in this field primarily focuses on understanding the physical implications of climate change on crops, livestock and the associated economic consequences [3]. Agriculture, due to its scale and sensitivity to weather parameters, is considered the most vulnerable sector in the face of climate change, resulting in substantial economic impacts. Climatic events such as temperature and rainfall variations have a significant influence on crop yields. Tropical regions are generally more affected by climate change, as crops in these areas are already closer to their optimal temperature ranges, making them more susceptible to high-temperature stress [8].

Agriculture and climate change are interconnected in various ways, as climate change serves as a major cause of both biotic and abiotic stresses that negatively impact agricultural regions. Climate change affects agricultural activities through alterations in annual rainfall patterns, average temperatures, occurrences of heatwaves, changes in weed and pest populations, modifications in microbial communities, fluctuations in atmospheric $CO_2$ levels, ozone depletion and shifts in sea levels [11].

Predictions concerning the future global trends for greenhouse gas emissions from agriculture largely depend on physical and economic parameters that strongly influence total emissions. These parameters include the cost of fuel, economic development, the evolution of livestock numbers, increase in productivity, new technology, availability of water, deforestation and consumer attitudes and diet [10]. Current scientific models predict substantial environmental changes caused by increased emissions of greenhouse gases. These changes will affect agriculture both in positive and negative ways. The forecast increases in global temperature between 1.4℃ and 5.8℃ will result in alterations in precipitation patterns. Extreme weather events (droughts, floods) are expected to occur more frequently. Seasonal variations in weather events may pose risks to traditional crop production methods either due to water constraints or a surplus of water and erosion. Soil stability will become crucial to store water in the soil profile, resisting severe weather events and minimizing soil losses [10]. In general, soil erosion is caused by the action of water and wind on arable lands but also by frost and animals. Depending on topographic features, the soil may be lost entirely from a field or redeposited within it. The coarse fraction of the soil (sand and stones) is transported short distances, whereas the finer silt, clay and organic matter can be moved well away from the site. This causes the remaining soil to become progressively coarser-grained and less fertile [13]. Vulnerable regions such as tropical and subtropical areas and high mountain regions are expected to suffer the most from climate change [10]. The situation is generally more serious in less developed countries where agroecosystems are already fragile, investment in agriculture is limited and climate change is predicted to have its most devastating effects [12].

Projected climate changes are also most likely to affect the development and survival of pathogens. It is predicted that the climate or weather pattern change will increase the susceptibility of crops to various pests, diseases and weeds pressure, which can decrease yield levels in general. Moreover, pests and diseases are more prevalent in humid and warmer regions. The other parameters, such as

humidity, wind speed, temperature and rainfall, can also impact crop yields. Plant-water relations are highly susceptible to changes in temperature and precipitation. Physiological changes are more likely to be affected by extreme changes in these parameters than by changes in mean climate. Plants' response to climate change varies according to the plant species and developmental stage. There are species-specific thresholds for different crops. Their responses, such as elongation of roots, disturbance in growth angle of roots and reduction in yield, vary among different species of plants [8]. During the climate change, precipitation patterns will change, with some areas becoming wetter but some leading agricultural regions becoming drier. Despite these patterns being challenging to predict, the climate model predictions are more uncertain for precipitation than temperature. However, the recent droughts in many parts of the world underscore the crucial role of changes in rainfall. Even if total annual precipitation is unchanged, agriculture may be harmed by changes in the seasonality or intensity of rainfall [4].

With the rise of environmental legislation and increased public interest in protecting the environment, the significance of effective environmental management in agriculture is now widely acknowledged. While the agricultural sector is slowly responding to these challenges, there is a growing voluntary movement towards better environmental practices in farming. The main environmental impacts associated with agriculture are primarily linked to pesticides and their residues, nitrogen compounds and emissions, livestock management, soil erosion and nutrient losses that contribute to eutrophication. It's important to note that environmental impacts are not limited to chemical or biochemical measurements alone. Visual and aesthetic impacts, such as the appearance of the landscape, as well as socio-economic considerations like the implications for rural communities, pose more complex challenges to quantify [13].

Reaching a consensus on the interpretation, definition and measurement of sustainability presents significant challenges. However, the increasing awareness of the environmental consequences associated with conventional farming systems has prompted a shift towards alternative approaches that explicitly address the externalities of farming. These alternatives strive to minimize negative effects, such as the impact of pesticides on wildlife or the impact of fertilizers on water supplies, by implementing changes within the farming system itself. While organic farming is often presented as the primary alternative to conventional production systems, it is not the only option. Within the realm of sustainable and alternative practices, other approaches like low-input, biodynamic and regenerative systems are gaining recognition. For example, low-input sustainable agriculture has received significant research funding and support in the United States, focusing on reducing the use of certain agrochemical inputs without completely eliminating them. It is important to highlight that many countries have established distinct standards, certification procedures and legislative frameworks that differentiate organic farming from other sustainable agriculture approaches. These distinctions are primarily for marketing purposes [14].

## Environmental Impact of Agriculture

Despite the constant advancements in technology, our society remains heavily influenced by the landscape, climate, hydrology, soil and organisms [9]. The interaction and reliance on the landscape are fundamental factors that must be taken into account when considering the potential for sustainable development, as our current landscape management practices are far from sustainable. One of the most pressing issues we face today and will continue to face in the coming decades, is the problem of food production. Throughout thousands of years, this problem has been addressed by converting forests, pastures and wetlands into arable land and intensifying agricultural practices.

The cultivation of crops stands as the sole viable source of food for human beings. As the global population continues to grow, the demands on our food supply will inevitably increase, leading to a rise in agricultural inputs. However, this increase in inputs is likely to create even greater environmental challenges from an agricultural standpoint than what we currently experience. While agriculture is essential for sustaining human life, how we treat nature will face significant challenges

in the years to come. It will become increasingly crucial to limit the pressures arising from carbon dioxide emissions, biodiversity degradation and water loss caused by intensive agricultural practices [5].

## Expanding the Agricultural Area

Today, expanding agricultural areas by cultivation is increasingly difficult. Over the past 50 years, production has increased mainly through intensification per unit of land combined with a relatively slowly growing land base [2]. Most areas in temperate zones are already used for agricultural purposes. Deforestation, especially the cutting down of rainforests to produce soy or palm oil, has major and undeniable environmental consequences in terms of biodiversity loss and global warming.

## Soil degradation

Soil is the basic unit of the ecological system and is largely a non-renewable resource. However, unfortunately, its degradation is a permanent and constant companion of agriculture and one of its most serious environmental problems. The biggest causes of soil degradation are monocultures, mineral extraction, uncontrolled grazing, deforestation, inappropriate tillage, water erosion and incorrect application of agrochemicals. One of the solutions to prevent soil degradation is the afforestation of arable land or the transition from arable land to meadows, however, in a state where the demand for meat is increasing [6].

## Demand for meat products

During the last 50 years, the global consumption of meat per person has doubled from about 20 kg per person per year in 1960, 2011 meat consumption was already more than doubled and for the year 2050, the assumption is more than 50 kg per person per year [1]. This problem will worsen over time as the population and incomes increase. Meat, eggs and dairy products will likely increase consumption, which will pressure the land to grow more corn, soybeans and other crops needed to feed livestock. For example, in China, the production and consumption of pork increased dramatically. When compared to 1979, the consumption of pork increased five times on average per inhabitant of China. This demand alone in China has resulted in the taking of forests and their conversion to arable land and the massive conversion of pastures to arable land in Argentina, which has created a very high pressure on the land itself and its degradation, where such significant and extensive changes cannot be sustained in the long term.

## Climate Change Adaptation in Crop Production

Establishing a precise definition of adaptation is crucial from the outset. One suitable definition could be: that adaptation refers to actions that mitigate the negative impacts or enhance the positive effects of climate change [7]. Temperature fluctuations and variations in rainfall patterns are the primary factors indicating environmental stresses, encompassing both positive and negative outcomes, with the negative effects being particularly concerning [11]. Due to the wide range of interests in adaptation, numerous definitions of climate adaptation have emerged. The Intergovernmental Panel on Climate Change (IPCC) defines adaptation as adjustments made in natural or human systems in response to actual or anticipated climate-related stimuli or their effects, aimed at minimizing harm or capitalizing on beneficial opportunities. Climate adaptation can also be defined as any action that sufficiently improves societal welfare to offset losses related to climate change. However, the problem with broad definitions is that they lose their significance when it comes to assessing the impacts of greenhouse gas emissions [7].

Even slight climate change poses significant challenges for agriculture. Unlike other industries, which can often implement relatively quick solutions in response to climate change, agriculture operates

differently. It relies on natural processes that depend on specific proportions of nutrients, temperatures, precipitation and other conditions. Agriculture worldwide has been optimized based on local climate conditions through decades of experimentation. Favorable conditions for crop growth include preferred average temperature and precipitation ranges, as well as precise timing and extreme value information [4]. While various changes in agricultural management and technologies, such as shifts in crop phenology and improved drought and heat tolerance, can enhance crop productivity, they do not necessarily represent true adaptations [7]. Adaptation to climate change is necessary but not sufficient. If global warming continues at the current rate, adaptation will become increasingly impossible within a matter of decades. A long-term solution must involve the rapid reduction of emissions to limit the extent of future climate change [4].

Ensuring productivity in crop production is of utmost importance. Crop yield and production are just two among many possible impact metrics, with social and economic outcomes also being widely considered. Any agricultural changes that enhance overall wealth and reduce vulnerability to extreme situations can be regarded as climate-adaptive [7]. Addressing the climate crisis in agriculture requires adaptation through the development of heat-resistant and drought-resistant crops and cultivars, as well as an urgent reduction of greenhouse gas emissions to minimize future climate-related damages [4]. Truly impactful actions in agriculture are relatively rare, contrary to how they are often portrayed or assumed [7]. According to Reynolds and Ortiz [12], sustainable and resource-conserving crop management technologies offer significant benefits under climate change.

These approaches include, for example:

1. Reduced tillage combined with crop residue retention can protect crops against severe climatic events, for example, by increasing water content in the soil,

2. In addition, by improving the overall soil environment for root growth, such practices can support to fulfill of the yield potential of improved cultivars,

3. Diversification of cropping systems helps to control soilborne diseases.

There are also longer-term benefits, which, for example, include the following:

4. Reduced environmental impact through the precision in applying N and water in case of irrigation and reduced use of diesel fuel related to agrotechnological operations.

5. Support the soils less prone to becoming degraded even as climate change increases the need for more intensive cultivation in still productive regions.

To better evaluate the impacts of climate change and identify more effective agricultural innovations for future climates, there is a need for consistent treatment of climate adaptation. It is important to acknowledge that some of the best agricultural innovations in the coming decades may not have direct adaptation benefits and should still be given attention [7]. In line with this, Reynolds and Ortiz [12] suggest implementing the following crop-oriented technical solutions to enhance food security:

•Implementing crop and land management practices that maximize sustainable productivity using available natural resources while realizing the full genetic potential of cultivars.

•Employing livestock management and breeding strategies to reduce greenhouse gas emissions.

•Focusing crop breeding efforts on developing crops adapted to the harsher environments anticipated from climate change models.

•Conducting systematic evaluation of genetic resources to better target their utilization in cultivar improvement.

•Investing in target agroecosystems, considering factors such as cultivation, climate, biotic conditions and soil characteristics, to evaluate different models of genetic adaptation systematically.

•Integrating research techniques such as remote sensing for precise phenotyping, networks of field operations and state-of-the-art molecular techniques to establish more accurate links between genome analysis and adaptive responses of crops.

•Determining the theoretical limits of resource-use efficiency in cropping systems (including nutrients, water and light) to establish realistic research goals for estimating potential productivity in future climate scenarios, considering crop response and potential adaptation to extreme climatic events.

•Monitoring and modeling the spread of diseases and pests in response to climatic factors to minimize crop losses and reduce the risk of epidemics.

•Establishing research consortia that bring together expertise and research platforms to solve common problems.

In conclusion, narrowing the gap between current and achievable yields can help mitigate the risk of food shortages [12]. The widespread interest lies in the potential of adaptation to reduce negative impacts or enhance the positive effects of climate change. It is essential to quantify the risks associated with greenhouse gas emissions reduction to evaluate costs and benefits properly. Additionally, there is a need to identify actions and investments that can improve prospects for food production and enhance food security [7].

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# SUSTAINABLE FARMING STRATEGIES AND CLIMATE RESILIENT CROPPING SYSTEMS

The intensification of agricultural production, which took place in the last century in the countries of the current European Union, seriously worsened today's efforts for sustainability in the agricultural sector. One example of agricultural intensification can be the excessive input of nutrients into the environment. Despite some restrictions related to the volume of fertilizer application that took place a few years ago, the consequences of the intensive use of fertilizers persist to this day [1]. From the point of view of fertilizers and nutrients contained in them and from the point of view of their entry into the environment, reducing their excess in terms of improving the state of the environment is one of the most fundamental problems of the common agricultural policy [2]. It turns out that protective measures related to the transition to organic farming, such as more diverse sowing practices, the use of biological pesticides, conservation tillage, etc., increase the uptake of fertilizers by plants [3] and reduce the runoff of surface water, which is essential to maintain nutrients in the soil and reduce the need for imported fertilizers [4]. Due to the fact that organic farming is an alternative farm management system that combines various conservation measures and manure fertilization; while prohibiting the application of mineral fertilizers, farmers can see an increase in the resistance of their business to external economic shocks that mineral fertilizer prices can cause or completely avoid their lack.

The strategy of sustainable agriculture is significantly influenced by legislation at the regional and European level. Most of these regulations take the form of binding directives that can have a strong influence on the adoption and development of sustainable agriculture strategies. Knowledge of current legislation is important to understand the differences in approaches to sustainable agriculture in Europe compared to other areas. It is very important to try to create sustainable development strategies because temperature and water availability are key factors in determining plant growth and yield. These are factors that will also change with the changing climate and their predicted changes are not optimistic. The climate changes that humanity fears today may cause changes in the invasiveness dynamics of pests, pathogens and weeds and only for the worse.

Instability caused by climate and weather will undoubtedly affect the level of food supply and access to it, alter social and economic stability and regional competitiveness. In this regard, adaptation is seen as a key factor that will shape the future severity of climate change impacts on food production. Climate change will affect food production worldwide due to increased pressure from weeds [5], pests and pathogens [6]. The most debatable, due to climate change, are the frequency of extreme events such as floods, droughts, changes in precipitation, temperature differences and associated changes in food systems on a global scale of pathogens [7]. The manifestation of the above-mentioned is expected only in the second half of the 21$^{st}$ century, which does not change the importance of taking protective measures today and moving, for example, towards sustainable agriculture strategies and crop cultivation systems resistant to climate change.

## Monocultures-Unmodern Cultivation in Modern Agriculture

A big problem in today's agriculture is monocultures, where their share continues to increase worldwide. About 80% of the 1.5 billion hectares are used for the purpose of monocultures of several cereals and several species of animals. Wheat, corn, rice and potatoes alone account for roughly 60% of the world's plant food sources and just 14 animal species provide 90% of all animal protein [8]. The variety of crops per unit of arable land is still decreasing today.

A good example that monocultures are not a suitable solution for today's modern agriculture is, for example, the epidemic of corn blight (Helminthosporium maydis) in the USA in 1970. The epidemic of corn leaf blight in the USA resulted in a crop loss estimated at a 15% reduction in corn yield or a loss of one billion dollars [9]. The epidemic in the USA is not the only example that demonstrates the

reduction in the diversity of cultivated plants and how this reduction threatens world food production [10]. The Irish potato famine, between 1845 and 1852, was the result of extensive planting of a genetically uniform clone (a single variety called Lumpers) and an outbreak of potato blight (*Phytophthora infestans*) which caused an 80% reduction in yield. As a result, millions of Irish people starved to death and another two million emigrated. The Great Bengal Famine in India in 1943 was caused by a devastating disease (*Cochliobolus miyabeanus*) that nearly destroyed rice production. More than a century ago in France, grapevines were completely eradicated by *Phylloxera vertifoliae* until a resistant cultivar was introduced from the USA [11].

## Traditional Agriculture as a Path to Diversification and Sustainability Standards

In many developing countries, traditional agriculture still persists, i.e. agriculture that uses practices, methods and techniques that are passed down from generation to generation and often involves a large amount of manual labor and the use of simpler tools that help improve biodiversity and support the resilience of agroecosystems [12]. For example, in constantly coping with extreme weather events and climate variability, farmers living in Africa, Asia and Latin America have developed and/or inherited complex agricultural systems managed in a sophisticated manner. These systems have enabled small farming families to meet their subsistence needs in the midst of environmental variability without depending on modern agricultural technologies [13].

Nowadays, despite the general modernization of agriculture, the trend of organic farming, diversification of agricultural production, emphasizing biodiversity and minimizing inputs into the system is increasingly occurring, which gives these ecosystems resistance to environmental and economic changes [14]. Among the strategies that will make it possible to preserve agricultural production in the coming years, to increase its resistance to climate changes, pathogens and pests, are the protection and restoration of ecosystems, the sustainable use of soil and water resources, agroforestry, diversification of farming, adjustments to cultivation practices and the inclusion of stress-resistant crops [15].

## Biodiversity in the Agroecosystem

The level of existing biodiversity can mean the difference between a system being stressed or somewhat resilient to stress. In order for an agroecosystem to function and provide environmental services, it is necessary that the number of organisms in a given agroecosystem be diverse [16]. If the agroecosystem does not have high biodiversity, its ability to respond to external changes decreases [17]. Two types of biodiversity can be distinguished in an agroecosystem, namely functional diversity, which refers to the diversity of organisms and the ecosystem services they provide, which ensure its functioning [18]. The second is diversity, which creates diversity in responses to environmental change among species and these species have the same function in the agroecosystem and thereby ensure its function. If an agroecosystem contains both types of these diversities, it can be assumed that it will be resistant to external influences [19]. Biodiversity provides a large number of ecosystem services beyond food production, including nutrient recycling, regulation of microclimate and hydrological processes, suppression of undesirable organisms or phytoremediation. Because biodiversity-mediated restoration processes and ecosystem services are largely biological, their persistence depends on maintaining biological integrity and diversity in agroecosystems.

## Challenges and Strategies for Sustainable Agriculture

Agricultural expansion and intensification have a profound effect on our atmosphere as well. These atmospheric changes, or climate change will affect global food security [20]. Prior to the early 19$^{th}$ century, the $CO_2$ concentration was around 250 ppm or lower. In 2013, the concentration continuously

increased to a level of approx. 400 ppm (Figure 2-d). With $CO_2$ emissions being the main contributor to the greenhouse effect, the average global temperature has increased by more than 1°C since 1850 (Figure 2-e). If the deterioration of the climate is not controlled, it may become irreversible and this situation will continue to worsen, especially due to the higher frequency of forest fires, which will also result from the ever-increasing temperature. As a result of the ever-increasing temperature, the glaciers in the Arctic will melt faster, which will subsequently lead to an increase in $CO_2$ emissions and a further increase in temperature. Although the melting of glaciers does not directly contribute to the increase in $CO_2$ emissions, it can indirectly contribute to the increase in emissions. When glaciers melt, they release large amounts of fresh water into the surrounding oceans. This influx of fresh water can disrupt ocean circulation patterns, which in turn can change the distribution of nutrients and carbon in the ocean. Disruption of ocean circulation can lead to a reduction in the amount of carbon dioxide that the ocean is able to absorb from the atmosphere. This in turn can lead to an increase in the concentration of $CO_2$ in the atmosphere, which contributes to climate change.

This warming will cause a poor distribution of rainfall, worsening floods and droughts and in some areas will have detrimental effects on crop growth, such as reduced germination and seed multiplication, increased incidence of diseases and pests [20, 21, 22].

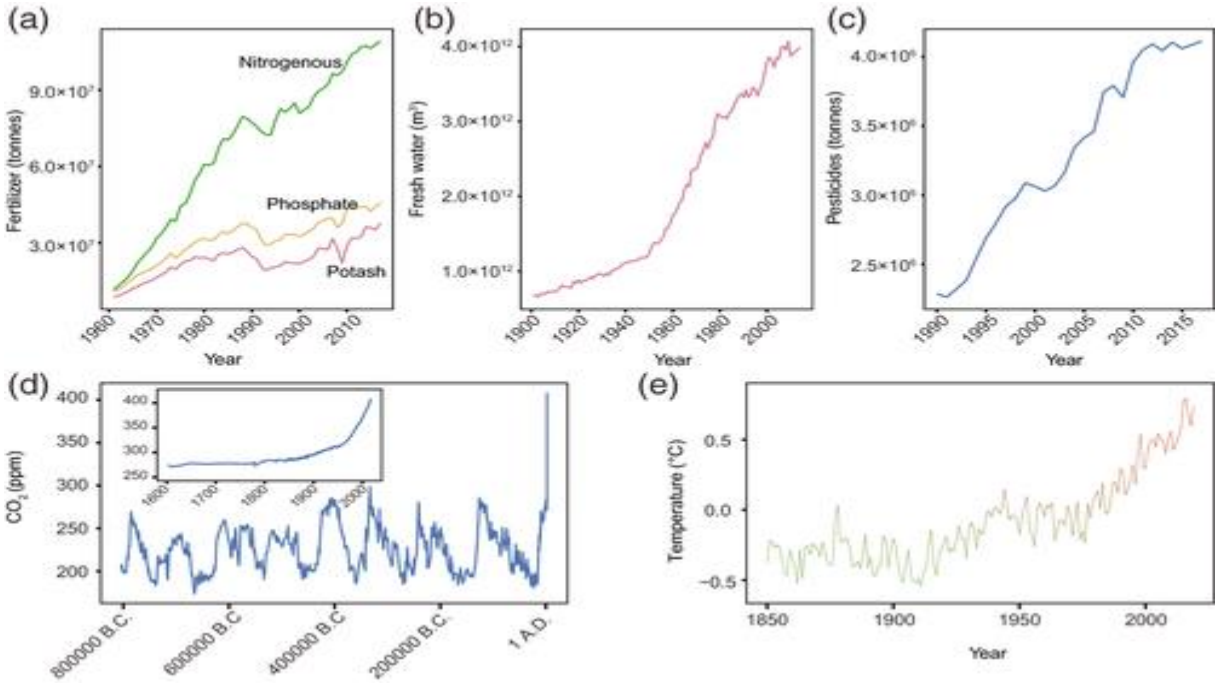



*Figure 1. Fertilizer, water and pesticide use and environmental change throughout history [23]*

a) Consumption of nitrogen, phosphate and potassium fertilizers,

b) Water consumption,

c) Consumption of pesticides,

d) Changes in $CO_2$ concentration,

e) Global average temperatures,

## Requirements for sustainable agriculture

Agroecology as a concept currently has the greatest potential to secure access to the realization of the right to adequate food, such as availability, accessibility, adequacy and sustainability of food. Agriculture must also not compromise the ability to meet future needs at the expense of biodiversity and natural resources. Agriculture must be developed in a way that increases the incomes of small

farmers and consumers from poorer backgrounds, because hunger is mainly caused by poverty and not by lack of food. In the future, the only system that will be able to face all of today's incipient problems, especially connected with the climate, will be a system that will be focused on a high level of diversity, productivity and efficiency [24]. Due to the increasingly expensive inputs (e.g. in the form of fuel or agrochemicals), the constant limitation of nitrogen supplies and the rapidly changing climate, such a system will be increasingly difficult to create. This big challenge, which is becoming more and more real, will probably have to be solved with the help of new technologies that will be friendly to the environment and will also take into account the ever-shrinking areas of arable land. One of the options to proceed in the future is to increase the efficiency of production according to Figure 2.

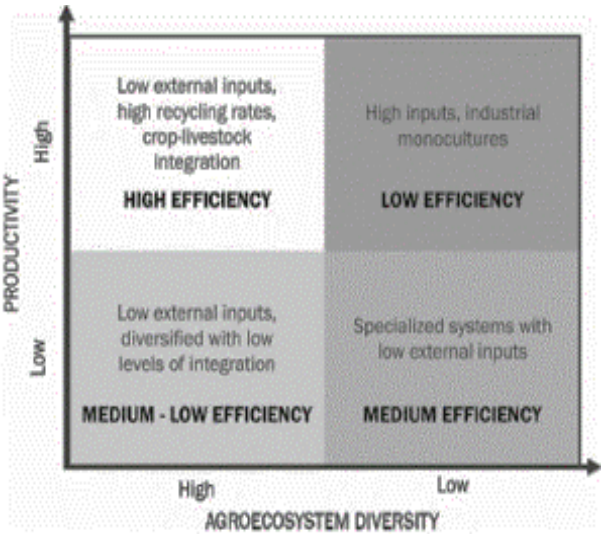



*Figure 2. Agroecosystems of the future [24]*

The transformation of agricultural production so that it not only produces an abundant amount of food, but also becomes a major contributor to global protection and biodiversity is one of the greatest challenges of the 21st century [25].

## Sustainable development standards

For example, the concepts adopted by Iniveler, BLobal Bioenergy Partnership and Rainforest Alliance are pioneering in terms of sustainability, where Unilever has adopted a series of measures related to the principles of agricultural sustainability and requires its suppliers to comply with these principles [26].

Other initiatives that aim to create a common whole, including economic, environmental and social metrics, because thanks to data from these sectors it will be possible to find out whether a given agricultural system is really managed in a sustainable way, are the Global Bioenergy Partnership [27]. The main requirement of this initiative is to find ways in the company to implement the sustainability plan and at the same time how to evaluate the goals and methods used in the company that work across the environmental and economic spheres.

The use of standards and their subsequent checks, when the checks do not have to be carried out by the state, but directly by the customer in the form of audits, can support the sustainability of agriculture and the resilience of the given agroecosystem [25].

For example, the Rainforest Alliance [28] has developed a series of standards that cover environmental, social, labor and agronomic farm management. Rainforest Alliance certification is built on three pillars of sustainability: environmental protection, social justice and economic viability. Trends expected on farms in tropical areas that adhere to the standards include less soil erosion, reduced pollution and waste generation, better habitat for wildlife, reduced risks to human health and improved conditions for workers.

## Green agriculture as the key to sustainability

There are many ways to achieve new models of biodiverse, resilient, productive and resource-efficient agriculture, such as:

1. Use of conservation practices involving minimal or no tillage,

2. Sustainable intensification (increase profitability and efficiency of production,

3. Transition to organic farming,

4. Use of agroecological systems, viz. Table 1.

These are only some of the possible ways to fight climate change in agriculture and every farmer who applies any of the above methods in his business contributes to a better future for all people in all countries.

These farming practices are similar in principle but very different methodologically, such as high versus low land inputs, market-driven versus non-market-driven agriculture, large monoculture areas versus biodiverse small farms.

Here are a number of attributes that an agricultural system should contain in order to be considered sustainable in the long term. However, there are many ways to assess agricultural systems in terms of sustainability. The basis must be to agree on the attributes for sustainability assessment and apply them in all systems that stand for sustainability.

Basic attributes of sustainable agriculture [25]:

1. Use of local crop varieties and livestock breeds to increase genetic diversity and improve adaptation to changing biotic and environmental conditions,

2. Avoid the unnecessary use of agrochemicals and other technologies that have an adverse impact on the environment and human health (e.g. heavy machinery),

3. Efficient use of resources (nutrients, water, energy, etc.), reduced use of non-renewable energy and reduced dependence of farmers on external inputs,

4. Use of agroecological principles and processes such as nutrient cycling, biological nitrogen fixation, allelopathy, biological control, etc.,

5. Productive use of human capital in the form of traditional and modern scientific knowledge and skills to innovate and the use of social capital through the recognition of cultural identity, participatory methods and farmer networks to strengthen solidarity and the exchange of innovation and technology to solve problems,

6. Reduce the ecological footprint of production, distribution and consumption processes, thereby minimizing greenhouse gas emissions and soil and water pollution,

7. Promoting practices that increase the availability of clean water, carbon sequestration, biodiversity conservation, soil and water conservation, etc.,

8. Strengthening the adaptive capacity and resilience of the agricultural system by maintaining the diversity of the agroecosystem,

9. Recognition and dynamic preservation of agricultural heritage systems that enable social cohesion and a sense of pride and promote a sense of belonging and reduce migration.

## Sustainability Strategy

A sustainability strategy could theoretically be easily achievable, or come fairly close to it. At the same time, preserving the possibility for every inhabitant of the world to buy food would not be difficult at

all. If buyers, especially the largest ones, required their suppliers, in this case farmers, to adhere to specific principles, rules and principles while maintaining prices, it would be possible to achieve sustainability in agriculture faster than is the case today. However, it would be ideal if part of the standards would be set by the government of the given state, or a state grouping, which would ensure the unification of all involved farmers, exactly as is the case with organic farming. Of course, it is very important to educate the population on the issues of today's agriculture, because the moment the population is very well acquainted with this issue, it will arouse interest in regulated production and products from sustainable farming systems. Just as vegan products are, these products from sustainable production could be equally or more in demand.

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# TILLAGE SYSTEMS UNDER CLIMATE RESILIENT CROPPING SYSTEMS AND CROP ROTATION, COVER CROPS AND PRECROPS EFFECTS

Agriculture leaves a significant footprint on the earth's surface. According to the United Nations (FAO), arable land is approximately 1.53 billion hectares, which is about 12% of the earth's land. Grasslands cover approximately 3.38 billion hectares, which is about 26% of the earth's land. This combined area of agricultural land represents about 38% of the earth's surface, making agriculture the industry that uses the largest amount of land on the planet. The remaining land is occupied by deserts, mountains, tundra, cities, ecological reserves and other areas unsuitable for agriculture [1]. In recent decades, global crop production has increased substantially along with agricultural land. FAO reports a 47% increase in production between 1985 and 2005 (ref.18), while the increase in agricultural land is only 2.4%. However, despite the impressive increase in crop yields between 1985 and 2005, between 1965 and 1985, the increase in production was even 56%, which may indicate that crop yields are increasing more slowly today than before and it is a matter of time before yield growth completely stops [1]. However, one of the ways to constantly improve plant yields is to focus on the biodiversity of the agroecosystem. Biodiversity is the basis of agriculture, as it includes all species of plants, animals and microorganisms within the agroecosystem [2]. Biodiversity provides valuable genetic resources for further crop breeding. Crops that are used today have ancestors in wild species or varieties that have been selectively crossed or hybridized [2]. Perry [3] stated that biodiversity has an essential role in the provision of ecological services, such as preventing soil erosion and/or microclimate regulation. Altieri [4] added that biodiversity contributes to ecosystem services by recycling nutrients or regulating pest populations. However, these ecosystem services can only be preserved or maintained if biodiversity is preserved in the agroecosystem [4]. If there is a loss of biodiversity in an agroecosystem, very high maintenance inputs can be expected, simply because the loss of biodiversity in an agroecosystem will cause the system to lose its self-sustaining capacity.

One of the ways to maintain biodiversity, or to further improve it, is reduced tillage. Currently, it appears that changes in soil cultivation and crop rotation practices have a great influence on the composition of soil fauna, including pests but also useful organisms. Tillage has a significant impact because it changes the chemical and physical properties of the soil. Research by Stinner and House [5] shows that the response of pest populations to reduced tillage varies quite a bit. Reduced tillage indirectly shapes the species composition of the soil microbiome by contributing to soil moisture retention and modulating soil temperature [6]. The species composition of the microbiome associated with reduced tillage will create an environment that can be antagonistic to pathogens through competition [7].

## Environmental Implications of Plough Tillage

Intensive tillage and the use of heavy machinery have produced mixed opinions at best in today's knowledge [8]. Soil erosion has become a global problem with increasing demand for primary soil resources and is a major risk to agricultural productivity and sustainability. As such, plowing exacerbates wind and water erosion, which is becoming an increasing problem today as more and more emphasis is placed on agricultural intensification. Plowing disrupts the soil structure and exposes it to intense rainfall and high wind speeds, which directly leads to erosion [8].

Erosion is a very significant cause of soil degradation, along with others, such as soil carbon loss, nutrient depletion, soil compaction, soil acidification, or salinization [9]. The problem of erosion, especially the water one, is not only about the washing away of topsoil, which in itself represents a big problem, but water erosion has other negatives, such as the floating of pesticides into the groundwater, which can infect water courses and threaten these ecosystems as well.

In recent years, reduced tillage practices have become increasingly widespread, which have the potential to increase soil mass, improve carbon sequestration and thus potentially contribute to

mitigating climate change [10, 11, 12]. Reduced tillage results in an increase in the amount of organic matter and less compaction of the soil, which results in improved physical properties and thereby, for example, improving the ability of the soil to absorb precipitation and retain water, which can later be used for crops [13, 14, 15].

*Table 1. Summary of the four-production systems C-IT conventional intensive agriculture, C-NT conventional no-tillage agriculture, O-IT organic intensive agriculture, O-RT organic low-tillage agriculture*

| **Management Practices** | **C-IT** | | **C-NT** | | **O-IT** | | **O-RT** | |
|---|---|---|---|---|---|---|---|---|
| **Tillage** | **Plough (20 cm) Rotary Harrow (5 cm)** | | **-** | | **Plough (20 cm) Rotary Harrow (5 cm)** | | **Disk Harrow Rotary Harrow (<10 cm)** | |
| **Weed Control** | **Post-Emergence Herbicides** | | **Glyphosate, Post-Emergence Herbicides** | | **Mechanical (Harrow, Hoe)** | | | |
| Fertilization | Mineral ($NH_4$-N/$NO_3$-N) | | | | Organic (Cattle Slurry) | | | |
| **Management Intensity** | **C-IT** | | **C-NT** | | **O-IT** | | **O-RT** | |
| Cover cropping | C | CC | C | CC | C | CC | C | CC |
| Energy use (liter fuel $ha^{-1}year^{-1}$)* | 54 | 61 | 18 | 22 | 47 | 55 | 25 | 32 |
| Relative scaling* | 0.9 | 1.0 | 0.5 | 0.4 | 0.8 | 0.9 | 0.4 | 0.5 |
| N supply (kg N $ha^{-1}year^{-1}$)** | 100 | 100 | 100 | 100 | 69 | 69 | 69 | 69 |
| Relative scaling* | 1.0 | 1.0 | 1.0 | 1.0 | 0.7 | 0.7 | 0.7 | 0.7 |
| Pesticide (kg.$ha^{-1}$ active substance)*** | 2.7 | 2.7 | 5.6 | 5.6 | 0.0 | 0.0 | 0.0 | 0.0 |
| Relative scaling* | 0.5 | 0.5 | 1.0 | 1.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| **Averaged Intensity Score** | 2.4 | 2.5 | 2.3 | 2.4 | *1.5* | 1.6 | 1.1 | 1.2 |

Management intensity is estimated for each production system using three anthropogenic inputs (energy use, weed control and fertilization). These factors have also been used in various studies evaluating the intensity of agricultural land use [16, 17]. Energy consumption is measured as L of fuel per ha per year. Includes primary processing soil, preparation network beds, sowing, fertilizing, spraying and mechanical weight loss weeds. Seeding (all systems) and mulching (except C-NT) were included next controlling surgery for treatment covering crops [18].

The most important factor in determining the quality of soil is soil organic matter. Schlesinger [19] states that the loss of soil carbon in maize fields is a result of intensive processing land, which leads to increased emissions of greenhouse gases. Reicosky and Lindstrom [20] evaluated help portable dynamic chamber short-term impact plow and miscellaneous processing of land for emissions oxide of carbon, when carbon is in high measure released from the soil over time two to three weeks after processing soil. In systems with low processing, soil loosens carbon lower and the smallest losses of carbon from the soil are after no-till processing soil. Reicosky and Lindstrom [20] and Reicosky [21], [22] concluded that intensive processing methods of land, in particular plowing to a depth of 0.25 m, affect this initial soil flow differently and suggested more gentle techniques of land management such as preservative processing soil.

The context between global warming and the amount of $CO_2$ in the atmosphere increased interest in saving soil carbon in systems of agricultural production, which led to the need to understand how processing soil affects the emission of greenhouse gases (carbon dioxide, methane, oxide stuffy). Kimble et al. [23] stated that appropriate processing of soil can contribute to the reduction of emissions of greenhouse gases because agricultural soil plays an important role in the sequestration of carbon. Reasonably, land management organic matter plays a key role in the maintenance of fertility soil, physical Properties of soil and biological activities when these factors are necessary for the production of food and quality of life environment. That's why it would be appropriate to implement no tillage procedures, which will reduce the emission of sulfurous oxide [24, 25]. Oxide stuffy has about 310 times larger potential for global warming up than oxide carbon [26] and must be included in the calculations of greenhouse gases because oxide nitrogen is associated with the use of nitrogenous

fertilizer and the level of nitrogen in the soil is affected by the processing soil as well as carbon [27, [28, 29].

## Crop Rotation, Cover Crops and Precrops Effect

Soil health depends on a complex community of interacting organisms, including bacteria, fungi, protozoa, arthropods and earthworms. Plant residues are the source of nutrition for these organisms. Microbially mediated decomposition of plant residues releases energy and nutrients, enabling these soil organisms to provide essential ecosystem services [30, 31].

Studies comparing organic and conventional farming practices have been conducted to understand the dynamics of the soil food chain and to determine whether organic matter inputs have advantages over inorganic sources, which currently represent the largest inputs to agricultural land [32, 33, 34], [35]. Supporting the development of resilient systems is increasingly important today, if only because the livelihood of communities depends on these systems [1].

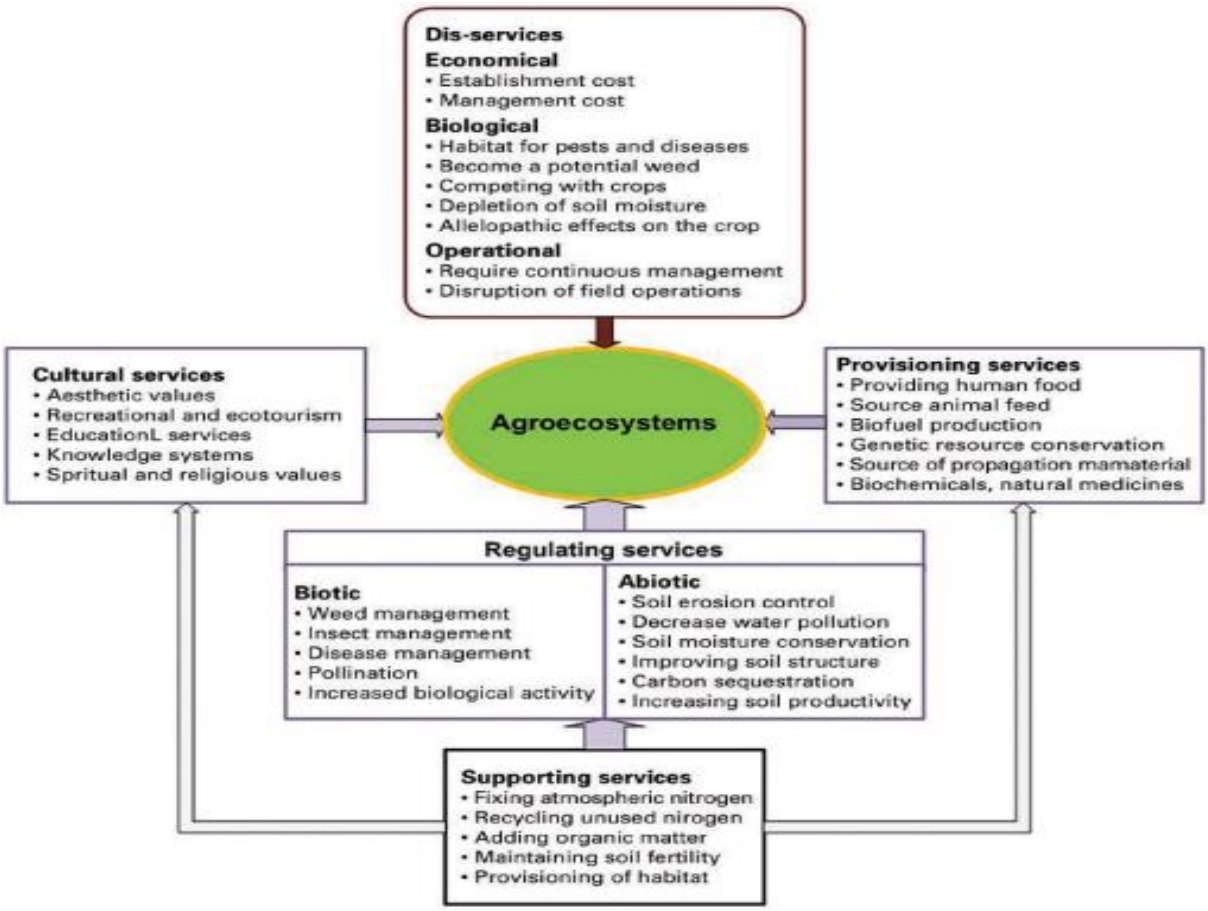



*Figure 1. Pros and cons that cover crops provide in an agroecosystem. The size of the arrows indicates the degree of contribution 50*

Resilient systems, improved soil health and other extremely important factors in tillage can be improved through crop rotation. The definition of crop rotation is a systematic or repetitive sequence of crops grown over several harvest seasons. The choice of crops is mainly influenced by the ecology of the agroecosystem and the economics of agricultural production [36] and is not determined by the farmer, or at least he should not determine it. Crop selection depends on edaphic, biotic and climatic factors. Pearson [36] introduced the term "comparative advantage", where this designation is related to the adaptation of a crop to the environment, differences in the necessary inputs to produce a given crop and market influences. This can directly affect sowing practices and, therefore, crop rotation because if the economic advantage is high enough for several crops, the farmer will prioritize this and,

therefore, not grow monocultures. Cover crops are part of climate resilient systems. These are defined as plants grown primarily to cover soil to protect it from soil erosion and nutrient loss [37, 38]. Cover crops can be classified in both temperate and tropical climates [39, 40]. Cover crops are recognized for their ability to contribute to various agroecosystem services [41]. Agroecosystem services are complex concepts involving various interacting elements that are spatially and temporally interconnected, making it challenging to separate the effects of individual elements from the overall system [42]. Agricultural ecosystems, intended primarily for the production of food, feed, fiber and industrial raw materials, receive and provide agroecosystem services [43].

Crop rotation has been a recommended practice for plant disease control [44]. Different crop species grown in sequence disrupt disease cycles. For example, in Australia, planting narrow leaf or blue lupine reduced common root rot infection rates in wheat compared to continuous wheat monoculture [45]. Crop rotation is particularly effective for nematode control. In Alabama, rotation with corn resulted in consistent increases in soybean yield compared to continuous soybean under conventional tillage, primarily due to the treatment of soybean cyst nematodes [46]. Tillage practices can interact with crop rotation in disease management. In some cases, conservation tillage systems combined with crop rotation have resulted in improved disease control and increased yields compared to continuous cropping and conventional tillage [46, 47]. However, the interactive effects of rotations and tillage systems on disease organisms may differ [48, 49].

Cover crops are primarily grown to absorb nitrogen from the soil, effectively reducing nitrogen loss through leaching, a form of water erosion [51, 52]. Intercropping efficiency is closely related to the depth of root systems rather than root density [51, 52]. When green manure crops are integrated into the soil through tillage, they often accelerate the mineralization of organic nitrogen. This acceleration can lead to a temporary mismatch between the release of mineral nitrogen, which becomes prone to losses and the actual nitrogen demand of crops. Such asynchrony can come from a variety of sources, including the addition of inorganic nitrogen fertilizers, animal manure, green manuring, or natural mineralization of soil nitrogen.

In some cases, cover crops exhibit preemptive competition, taking up nitrates from soils that would otherwise be at risk of leaching and making them available to succeeding crops [53]. Preemptive competition is observed, especially during the late spring growth of non-legume cover crops and in regions characterized by a low risk of leaching, such as dry areas. In such situations, optimizing intercropping strategies over several years can be beneficial in terms of maximizing N availability for cash crops.

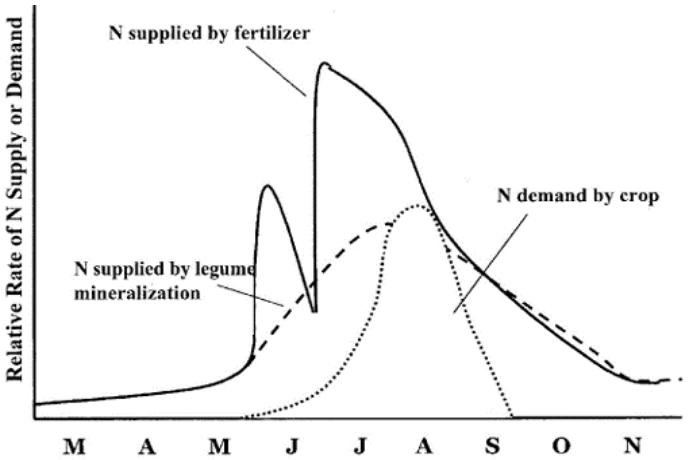



*Figure 2. Asynchrony between nitrogen supply from fertilizers or green manure and nitrogen demand by subsequent crops 54. M = March, A = April, M = May, J= June, J = July, A = August, S = September, O = October, N = November*

## Conclusion

In conclusion, agriculture has a significant impact on the earth's surface, cultivated land covers approximately 12% of the planet's surface and pastures occupy about 26%. This combined agricultural area represents about 38% of the earth's surface, making agriculture the largest land-using sector. However, despite substantial increases in crop production over the past few decades, there are signs that crop yields are growing more slowly than before. Limited tillage practices have gained importance as a means of improving soil health and mitigating environmental problems associated with intensive tillage, such as soil erosion and carbon loss. Crop rotation, cover crops and pre-crop selection are essential components of climate-resilient agricultural systems. Crop rotation breaks disease cycles and can improve overall soil health. Cover crops, on the other hand, help reduce nitrogen loss through leaching and can provide several ecosystem services. Considering growing concerns about climate change and sustainable agriculture, it is increasingly important to adopt agricultural practices that promote soil health, reduce environmental impacts and increase the resilience of agricultural systems. The integration of limited tillage, strategic crop rotation and the use of cover crops is a promising approach to achieving these goals, ultimately contributing to more sustainable and climate-resilient agriculture. However, it is essential to realize that the effectiveness of these practices may vary depending on local conditions and must be adapted to specific agroecosystems to achieve the best results.

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# MARGINAL CROPS CULTIVATION FOR FOOD PRODUCTION

Climate change significantly impacts agriculture in Central Europe, affecting crop yields, soil health, water availability and pest and disease management. The region is experiencing rising temperatures, changes in precipitation patterns and more frequent extreme weather events, such as droughts and floods. Table 1 shows the changes in temperatures, precipitation and vegetation period in Central Europe over the past century, based on data from several scientific studies:

*Table 1. Changes in climate over the past century in Central Europe*

| Climate Variable | Change Over the Past Century | Reference |
|---|---|---|
| Mean Annual Temperature | Increased by 1.5-2.0°C | [14] |
| Winter Temperature | Increased by 2.0-3.0°C | [5] |
| Summer Temperature | Increased by 1.5-2.0°C | [14] |
| Precipitation | Increased in winter, decreased in summer | [14] |
| Extreme Precipitation Events | Increased in frequency and intensity | [14] |
| Vegetation Period | Extended by 10-30 days | [24] |

The main problems caused by climate change in plant production are mainly caused by changes in the distribution of precipitation and increasing temperatures. This then affects other factors, such as the risk of soil erosion, leaching of nutrients, changes in weed communities and the occurrence of previously rare diseases or pests. An overview is given in Table 2.

*Table 2. Main problems caused by climatic change in crop production*

| Problem Caused | Description | Reference |
|---|---|---|
| Heat Stress | High temperatures can cause heat stress in cereal crops, leading to reduced photosynthesis, stunted growth and lower yields. Heat stress can also increase the incidence of pests and diseases, further reducing crop productivity. | [21, 11] |
| Drought Stress | Changing rainfall patterns can result in drought stress, which can cause reduced water availability for cereal crops. Drought stress can lead to reduced yields, poor grain quality and crop failure. | [21, 11] |
| Extreme Weather Events | Climate change increases the frequency and intensity of extreme weather events, such as floods, storms and hail. These events can damage crops, reduce yields and lead to crop failure. | [11, 28, 8] |
| Changes in Pests and Diseases | Climate change is causing changes in the distribution and behavior of pests and diseases, making them more difficult to control. This can result in increased crop damage and reduced yields. | [11] |
| Soil Degradation | Changing weather patterns can cause soil erosion, nutrient depletion and other forms of soil degradation. This can reduce soil fertility, leading to lower yields and reduced crop quality. | [11, 28] |
| Reduced Water Availability | Changing weather patterns can lead to reduced water availability, which can cause water stress in cereal crops. This can lead to reduced yields, poor grain quality and even crop failure | [11] |

## Strategies in Crop Production to Reduce the Negative Impact of Climate Change

Climate-resilient agriculture involves implementing various strategies that aim to help farmers adapt to the changing climate and improve their crop production despite the challenges posed by climate change. These strategies can be employed in climate-resilient agriculture to improve crop production and help farmers adapt to the changing climate.

•**Diversification of crops and use of drought-tolerant crops:** Farmers can diversify their crop production by growing crops tolerating different climatic conditions. This will ensure that other crops can still thrive if one crop fails due to unfavorable weather conditions.

•**Growing of crops or varieties mixtures:** Crop mixtures can also adapt to changing climate conditions by selecting crop combinations that are better suited to the local climate or by using mixtures that are more tolerant to specific stresses such as drought, heat, or flooding.

•**Conservation agriculture:** This involves practices such as reduced tillage, cover cropping and intercropping, which help to conserve soil moisture, reduce soil erosion and increase soil fertility.

•**Efficient irrigation:** Efficient irrigation systems such as drip and sprinkler irrigation can help farmers conserve water and reduce the water needed for crop production.

•**Soil management:** Proper soil management practices such as soil testing, fertilization and organic matter can help improve soil quality, which can improve crop yields.

•**Crop rotation:** Farmers can rotate crops to help manage pests and diseases and improve soil health.

•**Agroforestry:** This involves integrating trees into farming systems, which can provide shade, reduce soil erosion and improve soil fertility.

•**Use of weather information:** Farmers can use weather information to make informed decisions about planting and harvesting times and other farm management practices.

•**Use of improved seed varieties:** Farmers can use improved seed varieties that are resistant to pests and diseases and are adapted to local climatic conditions.

In the next part of the text, attention is paid diversification of crops and use of drought-tolerant crops and the growing of crops or varieties mixtures. The other mentioned methods are part of other chapters.

## Diversification of Crops and Use of Drought-Tolerant Crops: The Importance of Cereals for Agriculture in Conditions of a Changing Climate

Climate change poses significant challenges to cereal crop production, including increased temperatures, changing rainfall patterns and more frequent extreme weather events. In general, cereals are the most adaptable group of crops to climate change. However, some cereal crops are better adapted to these changing conditions than others. Here are some examples of cereals that are good in the conditions of changing climate:

•**Einkorn wheat (*Triticum monococcum* L.):** Studies have shown that einkorn wheat has more drought tolerance and plasticity than other modern wheat varieties. This is caused mainly because the root system of plants is deep and that allows them to access water from deeper soil layers, making it less dependent on rainfall. Additionally, einkorn wheat has a thick wax layer on its leaves and stems, which helps to reduce water loss through transpiration. According to many studies, einkorn wheat has been found to have a higher yield under drought conditions than other wheat species [32].

•**Emmer wheat (*Triticum diccocum* (Schrank.) Schuebl.):** *Triticum dicoccum*, or emmer wheat, is an ancient species cultivated for thousands of years. Due to some plant characteristics, it is known for its ability to tolerate drought conditions and plasticity. The root system of plants has an extensive root system that can access water from deeper soil layers, making it less dependent on rainfall. Studies have shown that this deep root system allows emmer wheat to maintain growth and yield under drought conditions [36]. Emmer wheat has a thick wax layer on its leaves and stems, which reduces water loss through transpiration. This wax layer also helps to protect the plant from high temperatures and other environmental stresses [34]. Emmer wheat can also adjust its osmotic potential by accumulating Osmo protectants, such as proline and soluble sugars, in response to drought stress. This helps to maintain cellular water balance and prevents dehydration [18]. Plants also can regulate stomatal closure in response to water stress, which helps to reduce water loss through transpiration.

Due to this stomatal regulation, emmer wheat can maintain high photosynthetic rates under drought conditions [36]. Emmer wheat is a promising crop for regions with limited water resources and may be a valuable tool in addressing water scarcity and climate change issues.

•**Spelt (*Triticum spelta* L.):** *Triticum spelta*, also known as spelt wheat, is another ancient wheat species historically cultivated. It is also known for its ability to tolerate drought conditions and plasticity. Spelt wheat has an extensive root system that can penetrate the soil deeply and absorb water from different soil layers. Studies have shown that spelt wheat has a greater root length density than other wheat species, which helps it to access water from deeper soil layers and maintain growth under drought conditions [31]. Like emmer wheat, spelt wheat has a high wax content on its leaves, which reduces water loss through transpiration. Studies have shown that this wax layer helps spelt wheat to maintain its water status and prevents dehydration under drought conditions [7]. Another aspect is an osmotic adjustment. In response to drought stress, plants can accumulate Osmo protectants, such as proline and soluble sugars. This helps to maintain cellular water balance and prevent dehydration [7]. Practical is also the ability to regulate stomatal closure in response to water stress, which helps to reduce water loss through transpiration [31].

•**Millet (*Panicum milliaceum* L.):** Millets are cereal crops highly adapted to hot and dry conditions, making them an excellent choice for areas with limited water availability. Millets require significantly less water than cereal crops such as maize or wheat. Millets have a fibrous root system that can penetrate the soil deeply and access water from different soil layers [30]. Helpful is also the ability rolling of leaves as a response to drought stress. This mechanism helps to maintain water status and prevent dehydration under drought conditions [2]. Millets can also adjust their osmotic potential by accumulating Osmo protectants, such as proline and soluble sugars [19]. Effectively, it also can regulate stomatal closure in response to water stress, which helps to reduce water loss through transpiration [3].

•**Sorghum (*Sorghum bicolor* L.):** Sorghum is a warm-season cereal crop widely cultivated for its grain and forage. Sorghum is traditionally grown in arid areas of the African continent. Sorghum's extensive root system can access water from deeper soil layers, making it less dependent on rainfall [19]. Plants can roll their leaves in response to water stress, which helps to reduce water loss through transpiration [2]. In response to drought stress, sorghum can adjust its osmotic potential by accumulating Osmo protectants, such as proline and soluble sugars [29]. Sorghum can also regulate stomatal closure in response to water stress, which helps to reduce water loss through transpiration. Due to this stomatal regulation, sorghum can maintain photosynthetic rates under drought conditions [22]. Sorghum is a promising crop for regions with limited water resources but requires relatively high temperatures for vegetation. In European conditions, ripening is inevitable only in the warmest areas. It is also beginning to establish itself as a green fodder crop, where the problems of certainty of ripening are eliminated.

•**Buckwheat (*Fagopyrum exculentum* Moench.):** Buckwheat is a pseudo-cereal crop adapted to cooler temperatures and can tolerate various soil types. It is also relatively resistant to pests and diseases, making it a low-input crop. Although it is generally considered a crop that requires moist soils, there is evidence that some varieties can be relatively drought-tolerant. Buckwheat has a fibrous root system that can penetrate the soil deeply and access water from different soil layers [26]. Plants can roll their leaves in response to water stress, which helps to reduce water loss through transpiration [37]. The ability to adjust osmotic potential helps to maintain cellular water balance and prevent dehydration [39]. Buckwheat has been found to have relatively high water-use efficiency, meaning it can produce more biomass per unit of water used than other crops [10]. Overall, buckwheat has some potential for drought tolerance, but more research is needed to identify the specific varieties and conditions under which it performs best under drought conditions.

•**Quinoa (*Chenopodium quinoa* Willd.):** Quinoa is a hardy cereal crop that can tolerate extreme temperatures, from freezing to high heat. It also requires less water than other cereal crops and is highly resistant to pests and diseases. Quinoa requires much less water than other crops, making it

well-suited to areas with low rainfall and limited irrigation. It can survive with as little as 250-300 mm of rainfall per year, while many other crops require at least 500-600 mm [4]. Quinoa is traditionally grown in the Andean region of South America, characterized by arid conditions [15]. It has been cultivated for centuries in areas where other crops cannot grow due to a lack of water. Quinoa is known for its ability to efficiently use water, as it has a small leaf area and a deep root system that allows it to access water from lower soil layers [38]. Quinoa has a unique strategy for drought escape, where it rapidly matures and produces seeds before the onset of drought conditions [4]. Overall, quinoa's drought tolerance and adaptability to arid and semi-arid regions make it a promising crop for sustainable agriculture in the face of climate change and increasing water scarcity.

•**Barley (*Hordeum vulgare* L.):** Barley is an exciting crop because it is traditionally grown in the Central European region. It is a crop well-suited to cooler temperatures and can tolerate various soil types. It is also relatively drought-tolerant and requires less water than other cereal crops such as maize or wheat. Drought tolerance in barley can be achieved through traits such as deep root systems, reduced leaf area and increased water use efficiency [9]. Barley can also exhibit a range of adaptive responses to climate change, including changes in the timing of developmental stages, shifts in distribution and phenology and alterations in growth and physiological processes [27]. Barley has a relatively deep root system, which allows it to access soil moisture from deeper layers [23]. Barley can also increase its drought tolerance by regulating gene expression, such as the expression of the DREB1 transcription factor gene [13]. Mentioned characteristics of barley cause the plants to tolerate a range of climate conditions, including high temperatures and drought stress [6].

Mentioned cereal species are better adapted to the changing climate conditions and can be grown with less water and fewer inputs, making them ideal for areas with limited resources. These crops are also suitable to be grown in organic farming. Farmers can enhance their food security and improve their resilience to climate change by promoting cultivating these climate-resilient cereal crops.

In addition to the mentioned properties, which predetermine the mentioned cereals for cultivation in a changing climate, it is also possible to use their second advantage, which can support their cultivation. These are types of cereals that have proven nutritional benefits. Apart from hulled wheat (einkorn emmer, spelt), these are gluten-free foods.

*Table 3. Specific production quality of hulled wheat species and barley*

| Parameter | Einkorn wheat | Emmer wheat | Spelt | Barley |
|---|---|---|---|---|
| Protein content | Usually around 15%, genotypes with the content exceeding 20% can also be found | High, even in organic farming conditions without industrial N fertilizers (usually 15-20%) | High, usually 14-19% | 9-12%, contain some essential amino acids, including lysine, threonine and tryptophan |
| Prospective products | Non-yeast product (biscuits, Arabic bread, cereal rice) | Non-yeast bread, breakfast cereals, extruded products, pasta | Bread, baking products, pasta, extruded products and ready-to-cook foods, spelt beer, spelt coffee | Porridge, tea, beer |
| Weaknesses | Low baking quality (low swelling capacity of proteins) | Running gluten of poor baking quality, unsuitable for yeast baking products | No considerable weaknesses | Low customer interest in barley products |
| Strengths | Higher carotenoid content | Higher nutritional value (when compared with common wheat) | Good baking quality, better technological processibility | High content of beta-glucans |
| Product availability | Einkorn wheat products can be bought in many countries (Austria, Germany, France, Italy, etc.) | Whole (dehulled) grains of emmer wheat, or even emmer wheat flour and pasta, are available | Broad range of products available | Broad range of products available |

The main advantage of hulled wheat species is the high protein content in the grain, which, even under organic farming conditions, reaches 15% or more. From a nutritional point of view, the high content of protoplasmic protein fractions is positive. Eincorn and emmer are unsuitable for making classic yeasted products, therefore, they are used in the food industry to prepare other products, such as pasta. More information is provided in Table 3. The most common barley product is beer. However, barley is an underappreciated raw material from the point of view of food processing because a wide range of products can be prepared from it. Naked forms of barley are most suitable for food processing.

The crops listed in Table 4 have the advantage that they are all usable for gluten-free products. These are traditional crops from which many traditional food products are produced. However, many of them are unknown to consumers in Europe, so it is important to take this fact into account when marketing them. The main disadvantage of quinoa is its high price.

*Table 4. Specific production quality of hulled wheat species*

| Parameter | Millet | Sorghum | Buckwheat | Quinoa |
|---|---|---|---|---|
| Protein content | Usually 10-12% | Range between 10-12%, don´t contain all essential amino acids | Usually 10-13%, high lysine content | High protein content around 14%, easy digestible |
| Prospective products | Porrige, flatbreads, pilaf, beer | Porrige, couscous, beer, syrup. | Noodles, porridge, tea, groats | Grain, flakes, pasta, popcorn |
| Weaknesses | Antinutrients content, specific flavor, difficult processing of grain | Bitter flavor, the potential of difficult digestibility, processing. | Specific flavor, allergic potential and difficult processing | Potential risk of saponins and antinutrient content |
| Strengths | Gluten free | Gluten free | Gluten free | Gluten free |
| Product availability | Limited availability in Europe | Limited availability in Europe | Broad range of products available | Broad range of products available |

## Growing of Crops or Varieties Mixtures: Possibilities of Using Mixed Cultures to Increase Resistance to Climate Change

Crop mixtures, or intercropping, involve planting two or more crops together in the same field. This farming practice can help mitigate the negative impacts of climate change on crop production by increasing biodiversity and reducing the risk of crop failure. Here are some ways crop mixtures can be used as a tool against the negative impacts of climate change:

•**Diversifying crop production:** Intercropping allows for the cultivation of different crops in the same field, which can increase the resilience of the cropping system to climate change impacts. For example, a study conducted in China found that intercropping maize with soybean increased yield stability and reduced the risk of crop failure compared to monoculture.

•**Enhancing soil health:** Crop mixtures can improve soil health by increasing the diversity of soil microorganisms and enhancing nutrient cycling. This can improve soil fertility and increase crop productivity, which can help farmers adapt to changing climatic conditions. For example, a study conducted in Brazil found that intercropping maize and beans improved soil fertility and increased crop yield compared to monoculture.

•**Managing pests and diseases:** Intercropping can also help manage pests and diseases by disrupting pests' habitats and reducing the spread of diseases. This can reduce the need for chemical pesticides and fungicides, which can have negative environmental impacts. For example, a study conducted in Canada found that intercropping wheat and peas reduced the incidence of common root rot compared to monoculture.

Here are some examples of crop mixtures used in Central Europe to mitigate the negative impacts of climate change on crop production. Winter wheat and field beans were tested in Germany. Intercropping winter wheat and field beans has been found to improve soil fertility and increase crop

yield compared to monoculture. The mixture also reduced the risk of nitrogen leaching and improved nutrient uptake efficiency [20]. Rye and legume intercropping were tested in Poland. Intercropping of rye with legumes such as vetch, peas, or clover has improved soil structure and fertility, reduced erosion and increased yield stability [35]. In Hungary, experiments with intercropping corn and soybeans have been found to increase yield stability, improve soil fertility and reduce the risk of insect and disease infestations [1]. Austrian scientists conducted research in intercropping winter wheat with clover has improved drought tolerance, as clover helps maintain soil moisture and reduce evapotranspiration. This mixture improves soil structure and fertility [12]. In Germany, Barley and legume (pea or faba bean) intercropping was tested. Noted was increased yield stability and drought tolerance compared to monoculture [16]. Maize and beans intercropping were tested in Switzerland and has been found to increase drought tolerance and improve soil health by enhancing nutrient cycling and soil organic matter [33]. More examples, including the stated effect and a link to the author, are given in Table 5.

*Table 5. Examples of benefits of intercropping*

| Benefit | Mechanism | Example | Reference |
|---|---|---|---|
| Diversifying crop production | Increases resilience of cropping system | Winter wheat/field bean intercropping in Germany | [20] |
| Enhancing soil health | Improves soil structure and fertility | Rye/legume intercropping in Poland | [35] |
| Managing pests and diseases | Reduces risk of infestations | Corn/soybean intercropping in Hungary | [1] |
| Improving drought tolerance | Maintains soil moisture and reduces evapotranspiration | Winter wheat/clover intercropping in Austria | [12] |
| Improving drought tolerance | Provides additional nutrients to the system | Barley/legume intercropping in Germany | [16] |
| Improving drought tolerance | Enhances nutrient cycling and soil organic matter | Maize/bean intercropping in Switzerland | [33] |
| Improving drought tolerance | Increases soil water use efficiency | Sorghum/Sudangrass intercropping in Hungary | [25] |
| Increasing carbon sequestration | Improves soil health and mitigates climate change | Maize/Soybean intercropping in Germany | Chyba! Nenalezen zdroj odkazů. |

Varietal mixtures, involve growing a greater diversity of wheat varieties in a mixture can provide several benefits in the face of climate change and help maintain yield stability:

•**Climate resilience:** With a changing climate, extreme weather events such as droughts, heat waves and heavy rainfall are becoming more frequent [17]. Growing a mixture of wheat varieties with different traits can help increase resilience to such events. For example, some varieties may have deeper root systems that can access water from deeper in the soil, while others may have traits that enable them to tolerate heat or drought better.

•**Pest and disease resistance:** Growing a mixture of wheat varieties can reduce the risk of pest and disease outbreaks. When multiple varieties are grown together, pests and diseases are less likely to spread and can be more easily controlled.

•**Yield stability:** Growing a mixture of wheat varieties can help ensure more stable yields over time. Because different varieties have different growth patterns and responses to environmental conditions, some varieties may perform better in one year while others may perform better in another. By growing a mixture of varieties, farmers can better ensure that they have a good crop in any given year.

•**Nutrient efficiency:** Some wheat varieties are better adapted to specific soil conditions or nutrient levels. Growing a mixture of varieties can help ensure that all soil nutrients are used effectively, leading to more efficient nutrient use and potentially higher yields.

•**Enhanced biodiversity:** Growing a mixture of wheat varieties can contribute to increased biodiversity on the farm. By diversifying the crop, farmers can provide a habitat for a broader range of plant and animal species, which can help maintain a healthy and balanced ecosystem.

•**Reduced environmental impact:** Growing a mixture of wheat varieties can reduce the environmental impact of farming by reducing the need for synthetic inputs such as fertilizers and pesticides. The diversity of the crop can help control pests and diseases naturally, reducing the need for chemical interventions.

•**Improved soil health:** Growing a mixture of wheat varieties can improve soil health by promoting the growth of beneficial soil microorganisms. Different varieties may have different root structures and secrete different compounds that can help promote soil microbial diversity and activity.

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# ALTERNATIVE CROPS GROWING FOR BIOMASS PRODUCTION

## Importance of Alternative Energy and Forage Crops

Biomass from alternative energy and forage crops is a universal source of energy through which it is possible to produce both heat and electricity, as well as fuels in a gaseous, solid and liquid state [23] or produce valuable forage biomass for animals at the farm [31]. Biomass, among which the alternative crops for energy belong, is considered a renewable energy source (RES) and has long had huge potential for mitigating the effects of global warming [34].

Of particular importance is the multifunctionality of biomass, which includes food production, energy and feed sources, biodiversity conservation and social services in society. It also brings new opportunities for managing and researching strategies in forestry, agriculture, agroforestry and pasture to mitigate global warming [11] or [28] and positively contribute to relation to the climate resilient cropping system.

The importance of alternative crops for biomass production can be summarized in accordance with three main pillars: social, environmental and economic. In the case of social benefits, energy crops could benefit the production of indigenous renewable energy, which in turn increases energy security and improves trade balances. This will lead to the creation of alternative sources of employment in rural areas. Production of energy crops could lead to the creation of farmers' associations/cooperatives. Energy crops growing could improve the education, training and assistance services provided for farmers. From the perspective of the economic benefits, the production of energy crops can lead to the development of new and profitable markets (biofuels, chemicals, materials, foods, feeds, etc.) that could provide farmers with new sources of income and employment. Incorporation of energy crops can promote the development of regional economic structures and can create higher-value coproducts. From the perspective of climate resilient cropping systems, the environmental benefits are crucial because the production of dedicated lignocellulosic biomass crops (energy crops in this case) has the potential to provide a range of benefits for water quality improvements, phytoremediation and treatment of wastewater and sludges, carbon emission reductions (GHG), and biodiversity. Even the soil degradation problems could also be reduced when perennial herbaceous and short-rotation trees are grown. Thanks to the implementation of energy crops into the growing system, the pressure on finite natural resources can be reduced. Energy crops can significantly promote the use of marginal lands and can support wildlife, natural habitats and overall agrobiodiversity [41].

## Alternative Energy and Forage Crops Potential in Relation to the Threat of Drought

One of the main threats to agriculture is drought. Drought can significantly affect the composition and functioning of all cropping systems and needs to be responded to appropriately. Alternative energy or forage crops can bring certain solutions. Drought is often considered a major threat to ecosystems in global climate change. Water stress limits biomass yields more than all other biotic and abiotic factors combined. The frequency and extent of the regional dry season are constantly increasing. Recently predicted scenarios of more frequent dry spells and heat waves for Europe and the Mediterranean region have come true [40], and so have most climate change scenarios that predicted increasingly extreme precipitation fluctuations, i.e., longer dry spells alternating with large precipitation totals [13], or scenarios predicting increased water consumption for agriculture. One of the most common reactions of crop roots to drought is an increase in root length. This reaction is typical for annual plants, especially for agricultural crops [5]. A plant's chances of surviving extreme drought stress are greater the longer it can delay a dangerous reduction in the water potential of the protoplasm (ability to delay desiccation) and the more the protoplasm can dry out without damage (ability to tolerate desiccation).

It is also important that tolerance to different soil moisture (drought) also depends on the stage of plant development [13]. A lower demand for water should rather be understood as the ability of the given species to survive even in conditions with a limited supply of moisture, regardless of the amount of production. In drought-resistant plants, we find that they have open stomata even when there is a lack of water. Some plants roll up and fold their leaves (as some of the energy grasses) [22]. A number of alternative energy crops are included in cropping systems precisely because of drought resistance or the low water requirement [24] or [18]. A distinction must be made between soil drought, characterized by a lack of physiologically available water in the soil and atmospheric drought. Atmospheric is particularly dangerous because it sets in in a short period of time and crops usually cannot adapt to it. The resistance of plants to lack of water is not the same throughout the growing season. It decreases the most in the so-called critical periods.

## Drought resistance

Plants (mainly agricultural crops) can also be bred for drought resistance. Drought resistance is a property that allows plants to endure a period of drought (water deficit in the soil) or a period of high temperatures and associated air dryness without significant deterioration of development and reduction of production. Species that are inherently drought-resistant or generally have low water availability requirements can also be selected for plant production systems. This refers precisely to the selection of alternative energy crops suitable for energy or forage purposes [24] or [18]. Drought resistance and high temperature resistance and their combinations are advantageous for arid regions, but they do not have such applications in regions with highly variable weather, only as part of broad adaptability [5]. Drought resistance is a complex property, as it depends on a number of circumstances and factors: the amount and strength of the root system, the ratio of above-ground and underground mass, the morphological and anatomical peculiarities of stems and leaves that can affect the water management of crops, the regenerative capacity and speed of development, etc. The genetics of drought resistance are very complex due to the many factors that condition or influence it [15]. Drought resistance is a complex trait and it is, therefore, difficult to test it, unlike a number of other traits, only in field conditions, where a number of different stressors act and the reproducibility of results in individual years is difficult. Tolerance and resistance to drought in general, species and varieties of individual crops are based on different physiological laws [5]. Testing drought resistance is methodically quite difficult. Rather, laboratory methods are chosen by comparing the formation of mass (dry matter) in drought conditions and in irrigation conditions, in climate chambers, or indirect methods are also used. In field conditions, the production achieved by new breeding or varieties in dry areas (vintages) and in areas with a normal course of the year is compared.

## Alternative energy crops

There are already selected potential crops for bioenergy production for European environmental areas suitable for energy purposes, meeting the requirements of the bioenergy industry efficiently. Not all crops possess the necessary attributes and therefore, suitable plants and practices must be identified for each agroecological zone, with continuous improvement to reduce pre-treatment, cultivation and conversion costs. Among the potential crops for bioenergy production within different European environmental zones belongs: Maize, Mustard seed, Hemp, Linseed, Castor bean, Clover or alfalfa, Sugarbeet, Oil seed rape, Sunflower, Potato, Wheat, Other cereals, Sorghum, Cardoon, Giant reed, Reed canary grass, Miscanthus, Switchgrass, Eucalyptus and Poplar and willow. These crops vary in terms of yield, agri-environmental ranking and geographical suitability [28].

## Annual Versus Perennial Energy Crops

The choice of the most suitable alternative energy crops is crucial, especially in terms of strategic and effective replacement of the traditional ones and reduction of greenhouse gas emissions [39]. Selected

alternative crops should have a high yield and energy potential, along with only minimal environmental impacts [6]. The decision based on the annual or perennial crop implementation can also be opened. Total energy efficiency (i.e., the ratio of energy input to energy gain) is higher for perennial crops than for annual (depending on yields and intensity of cultivation) [21, 3]. The positive environmental effects mainly from the plantations of perennial crops due to the soil coverage and higher $CO_2$ sequestration [9, 10] and biodiversity promotion [8]. In general, they have a better impact on the environment than traditional annual crops and are associated with higher biomass yields, better yield stability of clean energy and lower environmental impacts [12]. The area that will then be defined for growing alternative energy and forage crops should be based primarily on yield potentials, production intensity and the type of technology used [6, 3]. Also, the production of annual crops can become more environmentally friendly, for example, when tillage in crop rotation is carried out in a minimized mode and the soil can function as a carbon sink [36]. However, the advantage of annual energy crops is the well-known and routine production technology, the flexibility to change the type of crop and acreage and the possibility of applying part of the production at market food, feed, or energy prices.

## Alternative Crops Growing for Energy and Forage in Relation to Climate Change Mitigation

Agricultural activity contributes significantly to environmental damage, mainly due to land use, fertilizer use and energy consumption. The main potential for improvement often includes increased biomass yield and potential energy gain, the choice of gentle agricultural practices and the exclusive cultivation of perennial crops [20]. On the other hand, one of the disadvantages of the crops intended for eco-energy is that they compete on arable land with food crops [33]. This is not the same in the case of forage crops because they serve as a primary source of biomass for animal feeding. Therefore, the cultivation of energy crops is recommended, especially in marginal areas [27] or on low-production or otherwise degraded soils [38]. In general, there are main criteria for rating the sustainability of energy: use and changing the use of lands, the water footprint of energy crops, the impact of energy crops on biodiversity [8], climatic change, C sequestration, mitigation of GHG (balance and life cycle), and maintenance of soil fertility [28].

To apply the principles of sustainability, it is necessary to identify cost-effective ways to avoid, at least in part, GHG in the agricultural sector as well. If we are to think about mitigating greenhouse gas production within the selected cultivation processes, it is necessary to focus primarily on their strongest sources. These are the production and use of nitrogenous fertilizers and field emissions related to their production and application. Reducing the dose of fertilizers or the overall change in the agricultural system can be the solution [36, 14]. After all, reducing the dose of fertilizers used in the agricultural sector has long been considered a key activity in reducing $N_2O$ and NO emissions. The amount of GHG from agriculture is largely also affected by the management system. Conventional agricultural systems are based on higher inputs of fertilizers (organic and mineral), which are key factors for the mitigation of $N_2O$ and NO emissions from soil. $N_2O$ can be considered the main greenhouse gas and ecological management systems usually produce less (also $CO_2$) due to generally lower inputs [7]. The majority of emission flow can be considered the one that is connected to the production and use of mineral fertilizers and the consequences of their application. In the agricultural sector and especially in the crop production sector, nitrogen fertilizers represent a relatively complex problem. For example, Boehmel et al. [6] state that N fertilizer tends to have a 41-64% share of energy consumption in annual crops and a 17-45% share in permanent crops. At higher doses of N, there is no longer a significant increase in biomass [25]. The efficiency of the fertilizer used decreases with increasing fertilization doses because the plant does not take up a large part of the fertilizer and instead enters the water or air [32] in the form of so-called field emissions. One of the general advantages of perennial grasses is fewer nutrient requirements and inputs in the form of chemical protection products than annual crops [29].

Another way to reduce GHG is to replace traditional crops with another crop that is also suitable for the chosen purpose, i.e., forage or energy purposes. Respectively, the possibilities of GHG mitigation can be achieved through the cultivation of less intensive perennial crops [2, 26]. These can be, for example, perennial grasses, which are also suitable due to their properties [3], highly productive species of annual and perennial crops or their mixtures that have already been selected and particularly implemented [37]. However, for example, maize cannot yet be fully replaced by them from the perspective of biomass production [16, 3]. But from the point of view of GHG mitigation in the cultivation of maize, crop rotation and intercrops incorporation, no-till tillage systems [36, 1], or effective N fertilization management can bring the solution [30]. Nevertheless, due to the nature of perennial crops and generally lower fertilization requirements, alternative crops for biomass production are expected to have lower environmental impacts during their life cycle than traditional annual crops grown so far [17].

## Yield Improvement Potential

The possibility of improving the yield potential is in the selection of appropriate crop species and genotypes for the given locations to suit the specific soil types and climate. If alternative energy or forage crops are to be produced sustainably, cultivation practices for energy crops should be optimized rather than maximized, as generally low-input systems requiring reduced inputs of nutrients and agrochemicals are needed. The traditional plant breeding, selection and hybridization techniques are mostly slow. For example, much of the miscanthus currently grown in Europe is derived from sterile triploids that are propagated through expensive cuttings that can be susceptible to late frosts. Therefore, future research can be targeted to increase productivity by reducing sensitivity to cold temperatures.

Given the limited breeding experience to date, it is likely that major advances in bioenergy crop yields, for example, through genetically and non-genetically modified crops, can be expected in the next few decades. Both quantity (the amount of biomass yield) and quality (for example, plant structure or the chemical nature of the input raw material) are identified as the goals of future breeding, while the main task will be to support the resistance of plants to climate fluctuations, the support of a climate resilient cropping system, respectively. Although genetically modified energy crop species may be more acceptable to the public than genetically modified food or feed crops, there are still concerns about the potential environmental impacts of such plants, including gene flow from non-native plants to native plant relatives. As a result, non-genetically modified biotechnologies (i.e., selection of drought-tolerant or frost-resistant plant species) may remain particularly attractive [35].

## Perspective

In general, agronomic research, development and management of alternative energy crops lag far behind established annual food crops. The reason is mainly that in the past, the role of agriculture in energy production was not considered a strategic issue. This situation has recently changed due to increased environmental concerns and the increased cost of fossil fuels. The production of energy crops is expected to benefit the development of new markets, support regional economic structures, provide alternative sources of employment in rural areas, promote the use of marginal lands, bring a reduction of $CO_2$ levels and reduce dependence on centralized resources. Therefore, in the long term, successful implementation of energy crop systems should strive to ensure income generation, environmental sustainability, energy security, flexibility and replicability [41].

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# INTERCROPPING AND AGROFORESTRY

Intercropping and agroforestry, as innovative and sustainable agricultural practices, are essential components of climate-resilient farming. These approaches harness diversity and complementarity to mitigate the impact of climate change on agriculture.

Intercropping, involving the simultaneous cultivation of multiple crop species nearby, maximizes land use efficiency and minimizes vulnerability to erratic weather patterns. This is similar to agroforestry, which integrates trees and shrubs within agricultural systems to provide vital services like shading crops during heat waves and acting as windbreaks during storms. Both practices contribute to improved soil quality through nutrient cycling and are crucial in carbon sequestration to mitigate greenhouse gas emissions.

## Intercropping

Intercropping is a well-established agricultural technique characterized by the simultaneous cultivation of two or more crops within the same field [16]. This practice aims to enhance overall crop productivity by capitalizing on available resources and ecological processes that remain underutilized in the case of single-crop cultivation. By growing multiple crops nearby, intercropping maximizes the efficient use of land and resources, ultimately resulting in higher yields [21].

Intercropping can be an interesting way to strengthen the climate resilience of cultivated crops in European conditions. There are many reasons for that.

Important is diverse crop mix because intercropping allows for cultivating a mixture of crops with different growth patterns, root structures and environmental requirements. This diversity can help mitigate the risks associated with extreme weather events, such as droughts and heavy rainfall. For example, a drought-resistant crop can be intercropped with a crop that thrives in wet conditions, ensuring some level of productivity even when weather conditions are less favorable for one of the crops [13].

Intercropping can improve resource efficiency because it enables more efficient water, nutrients and sunlight use. This is especially important in regions were climate change leads to increased resource availability variability. By complementing the resource needs of different crops, intercropping can ensure that these resources are used more effectively [15].

During the climatic changes, pest and disease management is more difficult. Different crops can disrupt pests' life cycles and reduce disease prevalence. This reduces the reliance on chemical pesticides and helps maintain crop health. In the face of changing pest and disease patterns due to climate change, intercropping can provide a natural defense mechanism [20].

For the long term, plant food production sustainability is important to maintain soil health and increase the potential for carbon sequestration. When intercropping is applied, this technique can improve soil structure and fertility, making it more resilient to extreme weather events. Some intercrops, like legumes, also fix nitrogen, enhancing soil health. Healthy soils are better equipped to withstand the stresses of climate change. Moreover, the enhanced organic matter in soils due to intercropping can contribute to carbon sequestration, which is essential for mitigating climate change [10].

For long-term food security, it is important to maintain crop stability because climate change can increase temperature fluctuations and unpredictable weather patterns. Intercropping can help stabilize crop yields, as the performance of one crop may compensate for the underperformance of another under changing conditions [5].

Economic benefits are also important due to the diversification of farmers' income sources, as they can harvest multiple crops from the same piece of land [14]. This diversity can provide a financial buffer against crop failures or price fluctuations caused by climate-related events.

There are different methods of intercropping, including row intercropping, strip intercropping, mixed intercropping, relay intercropping and push-pull intercropping, each with its unique approach and benefits.



Row intercropping: The cultivation of two or more crops at the same time with at least one crop planted in rows.



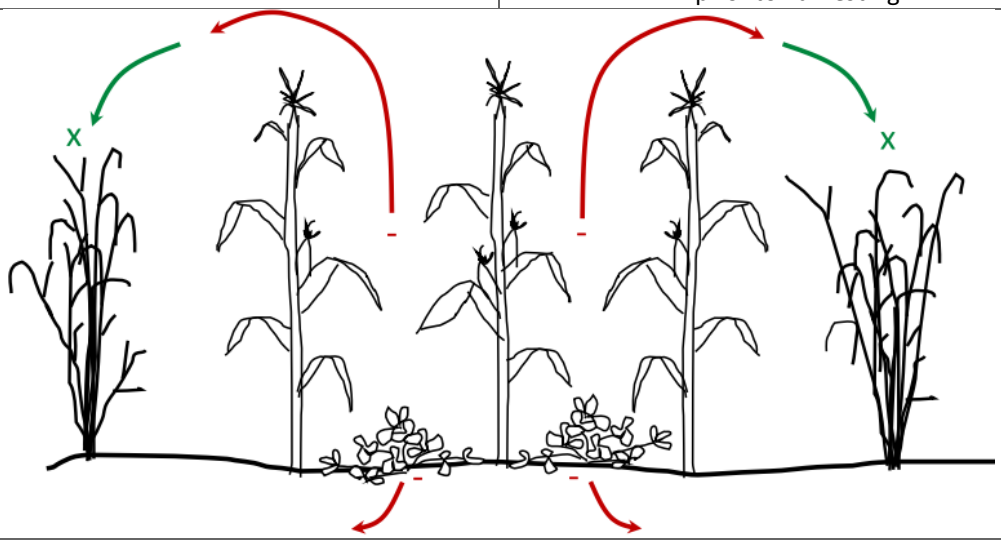
Strip intercropping: The cultivation of two or more crops together, wide enough such that they permit access to separate machinery but close enough for the crops to interact.



Mixed intercropping: The cultivation of two or more crops together in no distinct row arrangement.



Relay intercropping: Planting a second crop into a standing crop part way through its development but prior to harvesting.




Push-pull intercropping: A specific system adopted for pest management whereby a 'trap/pull' crop attracts pests away from the main crop and a 'push' crop aids to repel pests.

*Figure 1. Intercropping methods (from 3)*

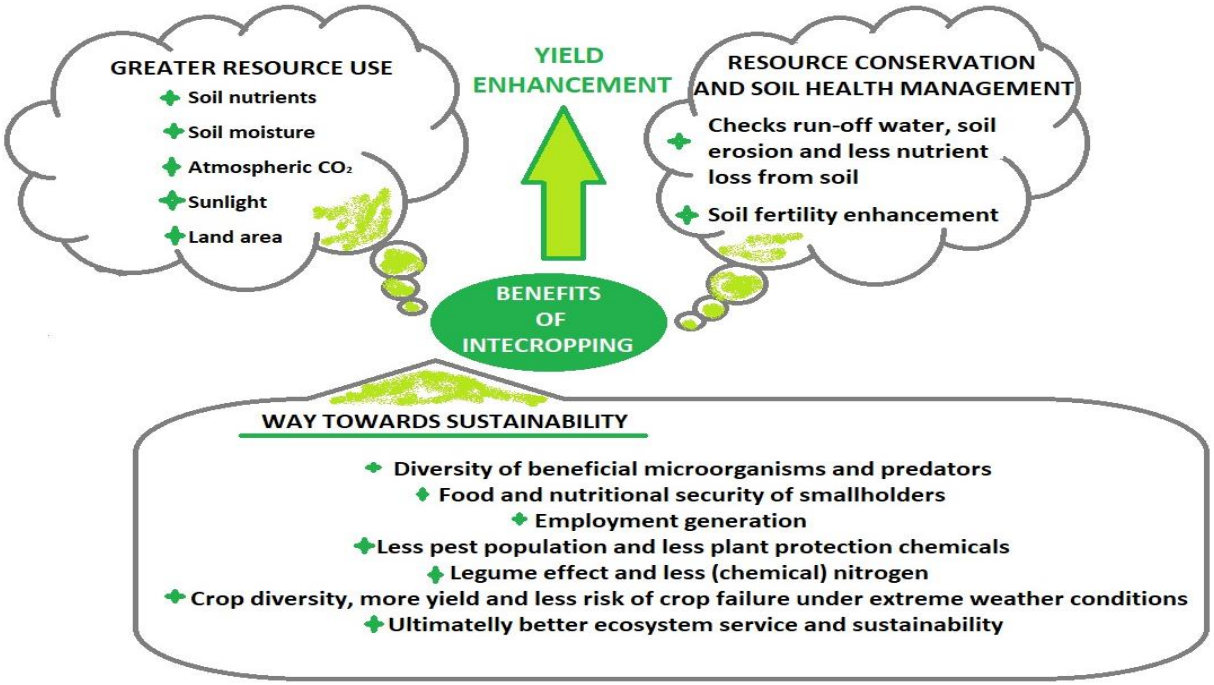



*Figure 2. Benefits of intercropping (from 14)*

Intercropping, the practice of growing two or more crop species together in a single field, holds increasing significance in European agriculture. It offers multiple benefits, including enhanced biodiversity, improved soil health, reduced pest pressure and increased resource use efficiency. This method aligns with sustainable and environmentally friendly agricultural practices, a priority in European policy.

The importance of intercropping in European agriculture is underscored by its potential to contribute to food security, climate resilience and reducing chemical inputs, aligning with EU sustainability goals. Several European countries have promoted intercropping through various support mechanisms, including research funding, training and agri-environmental schemes.

Shortly, European policy is expected to evolve to support intercropping development further. This could involve more explicit incentives, subsidies and knowledge-sharing programs to encourage widespread adoption. Additionally, policy changes may focus on streamlining administrative processes and creating a regulatory environment that facilitates intercropping practices. Ultimately, these policy adjustments aim to maximize the benefits of intercropping while contributing to a more sustainable and resilient European agricultural sector.

## Agroforestry

It is a sustainable land management practice that combines agricultural and forestry techniques to create integrated and diversified land-use systems. Agroforestry is a sustainable land use system with a promising potential to sequester atmospheric carbon into soil [1]. It has the potential to enhance the resilience of European agriculture to climate change and improve overall sustainability.

Diversifying Crops and Income Sources for Resilience in agroforestry systems offers a dynamic blend of tree and crop species, resulting in farmers' various products and income streams [19]. This diversity is critical in helping farmers adapt to changing climate conditions by distributing risks.

In agroforestry systems, trees play a pivotal role in enhancing water retention and preventing soil erosion, which is of paramount importance when addressing the impacts of droughts and intense rainfall events associated with climate change [7].

Furthermore, agroforestry actively contributes to carbon sequestration by storing carbon in tree biomass and improving soil organic matter, mitigating climate change and reducing greenhouse gas emissions [8].

These systems are also champions of biodiversity, reinforcing the resilience of ecosystems in the face of climate change. Various plant and tree species create habitats for wildlife and beneficial insects, ultimately aiding in pest control [11].

In addition, agroforestry, by offering shade and shelter for crops and livestock, facilitates their adaptation to changing temperature and precipitation patterns [1]. This adaptation proves particularly vital in regions susceptible to extreme weather events.

Integrating trees into agroforestry systems significantly enhances soil fertility and structure, making it more resilient to climate-related challenges such as water stress and nutrient imbalances [6].

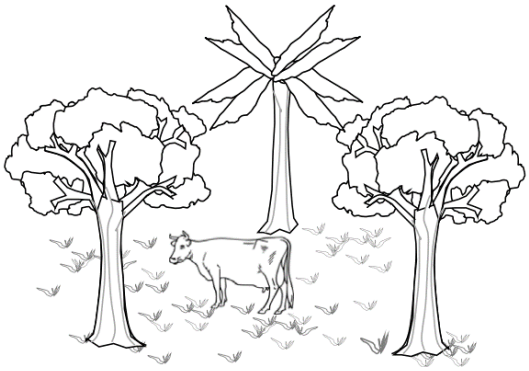
Lastly, trees within agroforestry systems effectively regulate local microclimates, moderating temperature extremes and reducing wind damage to crops. This microclimate control is precious in a changing climate [12].

Agroforestry, the practice of integrating trees with crops or livestock, has gained recognition worldwide for its myriad benefits. It is widely utilized in various forms to address sustainable land management and environmental challenges, enhance food security and mitigate climate change. Agroforestry is practiced extensively in Asia, Africa, Latin America and North America, primarily in developing countries [9]. The most developed regions include sub-Saharan Africa and Southeast Asia, where it is deeply ingrained in traditional farming systems.

In Europe, agroforestry has been increasingly acknowledged for its potential to enhance agricultural sustainability, conserve biodiversity and provide ecosystem services [4]. Various European Union (EU) programs and national policies support agroforestry initiatives. Countries like France, Spain and Portugal have been pioneers in promoting agroforestry, often providing financial incentives and technical assistance to encourage its adoption.

Europe's most promising agroforestry systems are likely silvoarable and silvopastoral systems, which integrate trees with arable crops or livestock [18]. These systems align with EU objectives for enhanced biodiversity, climate change adaptation and improved agricultural resilience.

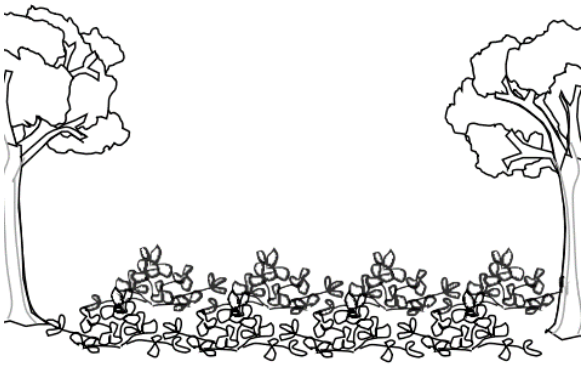
However, several challenges, including land tenure issues and limited awareness, still need to be addressed to unlock the full potential of agroforestry in Europe. The EU's Common Agricultural Policy (CAP) post-2020 aims to increase support for agroforestry practices, paving the way for further regional development [4].



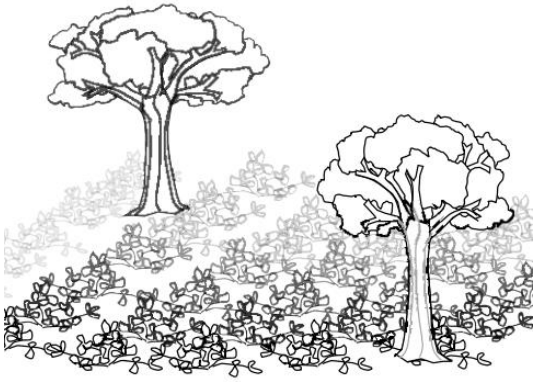
**Silvopastoral:** Combining forestry and grazing of domesticated animals on pastures, rangelands or on farm.



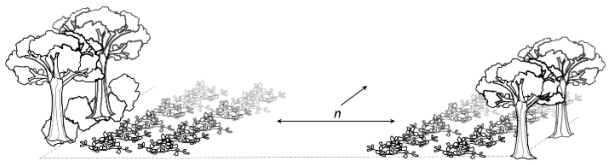
**Agrosilvopastoral:** Combining trees, crops and animals in the same area.



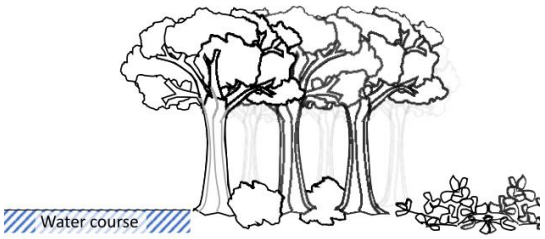
**Agrisilvicultural:** Combining crops and trees in the same area: this can come under different spatial arrangements detailed below.



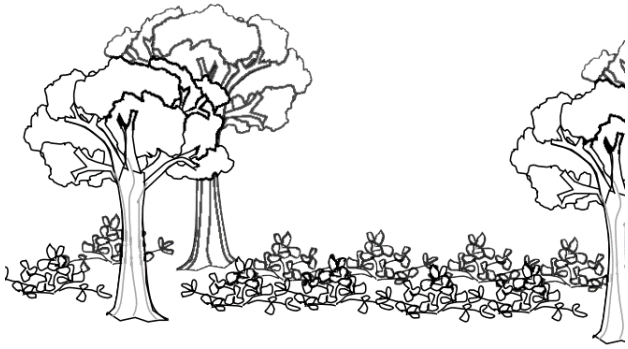
**Random planting:** Trees are randomly distributed throughout the field.



**Boundary planting:** Trees are planted around the edge of the field to form a boundary.




**Riparian buffer:** Linear bands of permanent vegetation, such as trees, shrubs, etc., are grown adjacent to an aquatic ecosystem to maintain or improve water quality



**Alley planting:** Trees are grown in rows with wide alleys in between for crop cultivation.



**Polyculture:** Combining multiple trees and crops in the same space, usually with no distinct arrangement.

*Figure 3. Agroforestry methods (source 3)*

Agroforestry systems can have many benefits from the point of view of ecosystem services. Details are presented in Figure 4. Generally, the portfolio of ecosystem services is extensive, whether it is about biodiversity conservation, climate change mitigation, food or fuel supply, or recreation.




*Figure 4. Three ecosystem services from agroforestry systems, adapted from Palacios and Bokelmann 17*

In conclusion, intercropping and agroforestry offer practical and comprehensive solutions for enhancing the climate resilience of European cropping systems. By diversifying crops, conserving biodiversity and aiding in carbon sequestration, these sustainable practices align perfectly with the goals of climate-resilient agriculture. However, to fully realize these benefits, a concerted effort is required, encompassing policy support, technical assistance and tailored approaches to adapt intercropping and agroforestry to the unique conditions of European agriculture.

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# ECOSYSTEM SERVICES WITHIN CLIMATE RESILIENT CROPPING SYSTEM

Ecosystem services and climate resilient cropping systems are closely linked. Ecosystem services play a crucial role in ensuring the resilience of crop systems to climate change. Ecosystem services are benefits that humans derive from ecosystems, including the provision of services such as food and water, regulatory services such as climate control and disease control and cultural services such as recreation and aesthetic values [10]. Climate resilient cropping systems are those designed to be more resilient to the impacts of climate change, such as drought, floods and extreme weather events. These systems include practices that, among other benefits, increase soil health, reduce soil erosion, save water and improve nutrient cycles in general. Ecosystem services provide the basis for climate-resilient crop systems by providing the necessary resources and functions to support overall crop production. For example, healthy soil provides the basis for crop growth and clean water is essential for irrigation. Biodiversity also plays a key role in pollination and pest control, among others. Therefore, the promotion and maintenance of ecosystem services are essential for the development of climate resilient cropping system. This can be achieved through practices such as conservation agriculture, agroforestry, or integrated pest management, which are designed to improve ecosystem services while increasing crop productivity and reducing agriculture's environmental impacts.

## The Categories of Ecosystem Services

Ecosystems around the world provide key services that essentially enable human society to function. The term ecosystem services have come to be used for these services. These can be divided into several categories. They are commonly divided into four basic ones: [1] Provisioning services, [2] Regulating services and [3] Cultural and social services. These services are directly used by humans. But all sorts of natural processes are necessary for them to exist, which are classified into the so-called [4] Supporting services [3].

Provisioning (production) services cover all the goods and services produced by ecosystems that can be used for the material consumption of a global society. These include the production of plants that provide food, fiber, fuel and other goods, the production of drinking water, etc. Regulating services regulate key natural processes, such as the water cycle, or provide for the regulation of greenhouse gases and related climate change. Regulating services thus largely creates a framework of environmental conditions in which our society operates, the importance of which is usually only realized when there is a deviation in their smooth functioning. Such a deviation can be a flood, drought, dust storm, or climate change. It also follows that these services are not usually subject to the market but become subject to regulations arising from laws and other regulations. Cultural and social services are the sum of what nature means for our psyche, culture, artistic and spiritual inspiration, etc. Although these services make a large contribution to the economy of many sectors of human activity, such as the tourism and entertainment industries, literature and the arts, they are not generally subject to the market per se. However, for example, attractive tourist places, or places with generally rich biodiversity, can be subject to the market and generate profits. Supporting services, such as primary production, pollination, nutrient cycling, etc., are, with the exception of some services, not directly subject to the market. This makes their evaluation very difficult. The use of nature and natural resources often leads to a reduction in the capacity of ecosystems to provide ecosystem services. As human populations grow and opportunities increase, so does the production volume or frequency of transport. In general, human influence on the functioning of ecosystems and geochemical processes is increasing. Mediterranean and temperate biomes are most affected, i.e., in areas that were the cradle of advanced civilizations. Since ecosystem production services are most closely linked to the well-being of society-i.e., subject to the market-the ecosystems concerned are often changed to increase their production capacity. This often happens at the expense of other natural processes and ecosystem services [3].

## Agriculture and Basic Ecosystem Services

Most of the landscape has been altered by agricultural activity and most natural ecosystems lie in the matrix of agricultural soils. The conversion of natural ecosystems into agricultural systems, i.e., agroecosystems, can have a strong impact on the system's ability to provide important ecosystem services. However, agroecosystems can also be important sources of ecosystem services. Traditionally, agroecosystems have been considered primarily as sources of provisioning services and the approach to agriculture has depended on this. However, other types of ecosystem services have been considered in recent decades. Indeed, agroecosystems also provide supporting services such as pollination, pest control, support for genetic diversity for future agricultural use, retention of water in the landscape, protection against soil erosion and support nutrient cycles. However, whether a particular agricultural system provides and supports such services depends on the management. In addition to supplying and regulating services, agroecosystems can provide various regulating and cultural services to humans, too. Regulating services from agriculture can include flood threat control, water quality control, carbon sequestration and climate control through mitigation of greenhouse gas emissions, disease control and the provision of decomposition processes. Cultural services related to agroecosystems can include landscape appearance, education, recreation, tourism, or religious aspects [12]. The preservation of biodiversity can also be considered as a cultural ecosystem service influenced by agriculture, as most cultures recognize the appreciation of nature as an explicit human value. On the other hand, biodiversity can contribute a range of supporting services to agroecosystems and surrounding ecosystems [10].

Biological pest control, which is a supporting service [19], is one of the essential benefits of ecosystems for agriculture. Within agroecosystems, this is an important ecosystem service. Natural ecosystems often support it. Unmanaged habitats provide spaces and diverse food resources for natural enemies of agricultural pests (so-called antagonists), which in turn provide biological regulating services in agroecosystems [2]. Such biological controls can reduce the pressure on populations of harmful insects, ultimately reducing the need for pesticides and their production and distribution. For example, ecosystem services provided by pest antagonists can directly replace insecticides. The value of such an ecosystem service can thus be quantified and expressed economically [5].

One of the most important ecosystem services for agriculture is pollination. This ecosystem service is initiated by natural habitats in agricultural landscapes, i.e., places where pollinators can reside. It is estimated that around 65% of the world's plant species require pollination by fauna (mainly insects), and about 75% of all cultivated crop species of global importance for food production depend on pollination [8]. Pollination services are quantifiable and thus can also be expressed economically, which is not the case for most other ecosystem services. The value of the pollination service can be expressed, for example, by the total value of insect-pollinated crops. However, most crops are only partially dependent on pollination by animals. Therefore, the dependency ratio or the rate of proportional reduction in production in the absence of pollinators should also be considered. Such an approach can provide a more accurate statement [9]. However, such quantifications are rather imprecise and are intended to provide only a general assessment of potential economic benefits, which serves, among other things, to support the very importance of an ecosystem service. Moreover, most estimates do not consider the potential changes in the value of each commodity as demand increases due to reduced crop production [12]. Agriculture is highly vulnerable to the potential loss or degradation of the ecosystem service of pollination. One factor that may amplify this loss or degradation is climate change and its consequences [10]. The vulnerability itself lies primarily in the potential loss of pollination services based on the ratio of the economic value of insect pollination to the economic value of the crop. For example, West African countries produce 56% of the world's stimulant crops (i.e., coffee, cocoa, tea), while the vulnerability to the loss of pollinators is as high as 90%. Thus, the loss of pollination services for these crops could have devastating effects on the regional economies of West African countries in the short term and lead to a significant restructuring of world prices in the long term [12].

Agriculture is the largest global water consumer (about 70%). Providing sufficient amounts of clean water is a basic ecosystem service provided to agroecosystems [10]. The value of ecosystem services associated with the availability and quality of water for agriculture is only partially reflected in most estimates. The vegetation of natural ecosystems, such as forests, can significantly influence the accumulation, infiltration and retention of water in the landscape. Plant communities generally play a dominant role in regulating water swelling and protecting soils from erosion. Forest soils tend to have higher infiltration rates than other soils and tend to reduce culmination flows and flooding while maintaining basic flows [11]. In addition, deep-rooted vegetation, including trees, can improve the availability of both water and nutrients for other species in the ecosystem. This principle is used, for example, in agroforestry, which is one of the tools for climate resilient cropping systems. The availability of water in agroecosystems also depends on ecosystem service, which consists of the ability to retain soil moisture. Surface and groundwater (commonly referred to as blue water) often enter agroecosystems through the sorting of irrigation systems and in some parts of the world, this route is indispensable. However, about 80% of water consumption in agriculture comes from rainfall, which is stored in soil moisture and vegetation. Such water is referred to as green water [13]. In addition to vegetation cover, organic matter (its quantity and quality) and soil biotic communities (edaphon) significantly influence the quantity and quality of water in the soil and thus provide other basic ecosystem services to agriculture. In this relation, predictions of water availability for agriculture are based mainly on assumptions of blue water availability (i.e., surface and groundwater) but often neglect the contribution of green water (i.e., rainwater in soil and vegetation). Thus, final predictions of water availability, e.g., in 2050, might not be so pessimistic. However, climate change brings increased variability of precipitation. This is predicted to lead to a greater risk of drought or flooding. And the associated increased temperature will also increase overall water demand [6]. Currently, water management practices (related to green water) are already known on farms, which can significantly change these predictions of water scarcity. For example, by switching to conservation technologies for soil treatment (i.e., no-till treatment) or mulching, water evaporation from the soil can be reduced by 35-50%. Also, rainwater retention on farms in surface reservoirs and ponds, or subsurface reservoirs, is a very effective way that can allow farmers to recover up to 50% of the water that is normally lost in the system [12].

The basic ecosystem services that are also available to agroecosystems are the structure of the soil and its fertility. Well-aerated soils with sufficient organic matter are the basis for the distribution of nutrients to crops and water retention in the soil. Soil pore structure (soil porosity), soil aggregation and organic matter decomposition are influenced by the activity of bacteria, fungi and macrofauna (invertebrates such as earthworms). Microorganisms mediate the availability of nutrients through the decomposition of detritus (that is, material from the natural decomposition of rocks), plant residues (that is, primarily organic matter), and, where appropriate, the fixation of air nitrogen [14]and [15]. Agricultural practices that degrade soil structure and soil microbial communities include traditional ploughing but also frequent harrow by disc or harvesting processes that are associated with strong soil compaction (pedocompetition). But farming practices can be applied to protect the soil and reduce the risk of erosion and water run-off. Reduced soil processing/cultivation (e.g., no-till technologies) and other soil protection measures such as the implementation of green manure or intercropping (as cover crops), the application of composts and appropriate crop rotation under the cropping process can preserve soil fertility by contributing to good soil structure, minimizing nutrient losses and keeping them available for crops. For example, cover crops facilitate the retention of soil and nutrients between individual crops within the crop rotation [1]. The crop rotation also affects the diversity of agricultural landscapes within space and time. Furthermore, the landscape and its structure, respectively the spatial and temporal structure of the landscape, have a huge impact on the level of provision of ecosystem services and their volume for the agroecosystem [4]. Also, the incorporation of post-harvest residues can contribute to an increase in the organic matter content of the soil. This ultimately helps in water retention and the provision of nutrients to crops. All these processes then protect many ecosystem services related to the structure of the soil and especially its fertility [14].

## Agriculture and Negative Impacts on Ecosystem Services

Agricultural ecosystems provide people with the basic raw materials necessary for human well-being. The value of ecosystem services linked to agriculture is enormous and often underestimated. It is also agriculture that can provide so-called negative services, such as habitat loss, nutrient leaching associated with erosion, greenhouse gas emissions and pesticide pollutant loads, etc. Agriculture itself represents a significant pressure on ecosystem services [19]. In many anthropogenic ecosystems, typically those on arable land, a large amount of nutrients is supplied each year by humans (which can be seen as compensation for the harvested biomass). These nutrients are then taken away by harvesting, with a large part also leaving as a loss through leaching, run-off and other processes. If we carry out a similar type of farming on more than one surface, then its impacts are felt at the level of the entire landscape. In the case of nutrients in agriculture, this leads to an increase in the amount of nutrients in water resources. This can lead, for example, to eutrophication or ecotoxicity. For example, from a global perspective, the application of mineral fertilizers has doubled the nitrogen input from the atmosphere into ecosystems [10]. Thus, increasing production (i.e., intensification of agriculture) due to nutrient inputs can lead, for example, to a reduction in ecosystem services such as the provision of drinking water. The intensification of agriculture increases the total consumption of agrochemicals. All of this has implications for the global flows of energy and substances in nature. The intensification of agriculture can threaten or degrade many ecosystem services provided by the surrounding landscape and its biodiversity. In many regions of the world, the intensification of agriculture has led to a simplification of the landscape structure through the expansion of farmland, increasing the size of fields, reducing vegetation at the edges of fields and eliminating the natural environment [15]. The simplification of the landscape structure contributes to increasing pest pressure through the possibilities offered by monocultures and their area. Conversely, it leads to a reduction in the populations of their natural enemies.

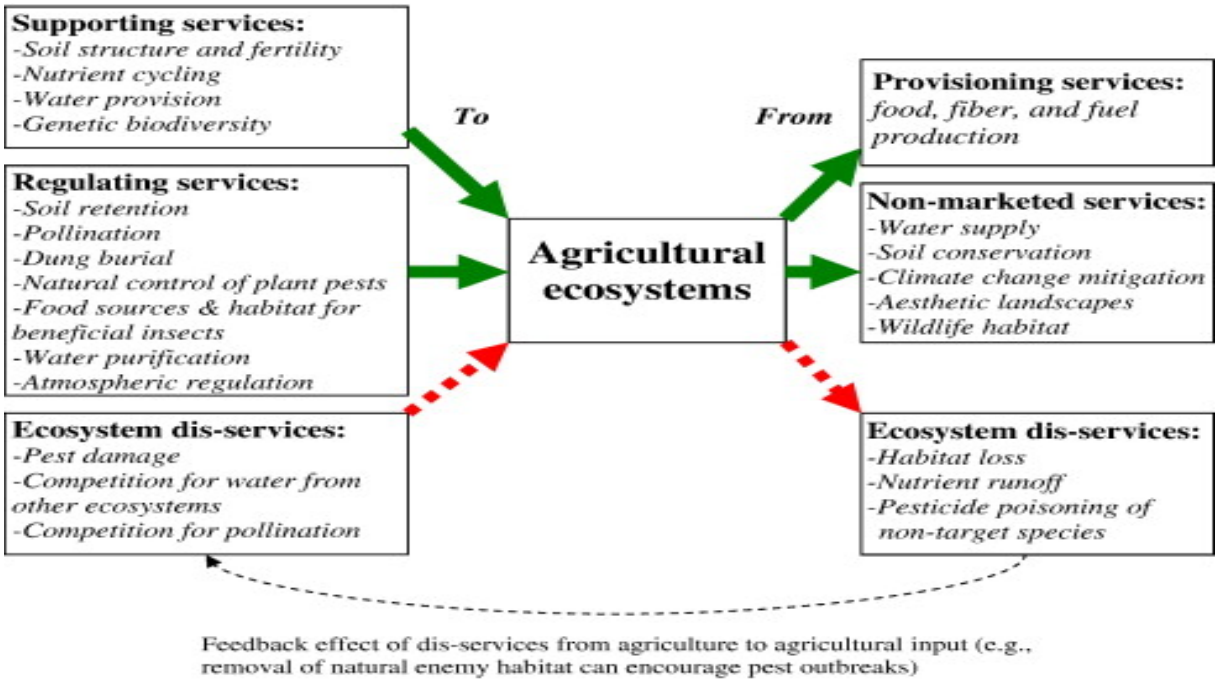



*Figure 1. Ecosystem services and dis-services to and from agriculture. Solid arrows indicate services, whereas dashed arrows indicate dis-services (from 19).*

## Support for Farm Ecosystem Services and Appropriate Management

Around the world, agroecosystems show huge differences in structure and function. Indeed, they have been designed by different cultures under different socio-economic conditions in different climate

regions. Functional agroecosystems include, for example, annual monocultures, permanent orchards, grazing systems, pastoral systems on dry soils, tropical rotation systems, small-scale mixed cultivation systems, rice paddies, tropical plantations (e.g., oil palm, coffee, cocoa), agroforestry systems or species-rich home gardens. This diversity of farming systems results in a highly variable range and carries many ecosystem services. Just as supply services and products derived from these agroecosystems vary, so do supporting services, regulating services and cultural services, resulting in extreme differences in the value these services provide inside and outside the agroecosystem [12]. While maximizing the value of provisioning services, agriculture often reduces the ecological services provided by terrestrial ecosystems. Still, appropriate management of key processes can improve the ability of agroecosystems to provide a wide range of ecosystem services [4].

Appropriate management on farms can significantly improve the overall volume and quality of ecosystem services provided by agriculture [16]. Farmers routinely support provisioning services through inputs and practices to increase yields. But proper management can also improve ecosystem services such as pollination, biological pest control, soil fertility and structure, water regulation, biodiversity promotion, etc. [12]. For example, management of marginal habitats (i.e., hillsides, scattered greenery in the landscape, or land margins) within an agroecosystem can provide the resources necessary for pollinators or natural enemies of crop pests. It is advisable to include perennial plants in cropping practices to promote biodiversity in general and, in particular, to promote pollinators and antagonists. Support for crop diversity can be achieved through polycultures, cover crops, or agroforestry [7]. Similar practices can benefit wild pollinators and reduce agrochemical inputs (i.e., pesticides) or reduce the need for ploughing. At the same time, these practices contribute to promoting carbon sequestration - a major ecosystem service in relation to the increasing amount of $CO_2$ in the atmosphere. Soil carbon sequestration also provides additional ecosystem services by maintaining soil structure and fertility, improving soil quality, increasing efficiency in agronomic inputs and improving water quality by filtering and denaturing pollutants. In particular, soil protection measures such as soil conservation (including minimalization practices) and no-soil treatment can save soil carbon in general. This is also helped by the mentioned crop rotation and sorting of cover crops, which reduce the risk of erosion and contribute to the maintenance of organic carbon in the soil. Effective manure management can also significantly reduce associated animal waste emissions. Replacing synthetic nitrogen fertilizers with leguminous plants, which use biological nitrogen fixation, contributes to reducing greenhouse gas emissions, which in turn contributes to the promotion of the greenhouse effect [12].

Resilient farming systems will be needed in view of climate change [17]. Sustainable management of agroecosystems or sustainable intensification through ecosystem process management has the potential to increase food production while minimizing some of the negative impacts of intensification on biodiversity and related ecosystem services. Appropriate farming management practices, i.e., pathways such as climate resilient crop systems, are key to realizing the benefits of ecosystem services and key to reducing the negative impacts of agriculture [4].

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MODULE 2

# Greenhouse Gas Emissions from Land and Fertilizer Use and Protection Measures Against Climate Change

**Erdinç UYSAL**

## Outline

- Effects of Climate Change on Soil Properties
- Carbon Budget of the Agricultural Soils
- Effects of Land-Use Changes on Carbon Stocks in Soil
- Effect of Soil Properties on Greenhouse Gas Emissions
- Greenhouse Gas Emissions from Fertilizer Use
- Effects of Lime Applications on Greenhouse Gas Emissions
- Making Fertilization More Sustainable in Terms of Climate Change
- Fighting Against Deforestation, Desertification and Erosion

## Introduction

A significant part of the greenhouse gases that cause global warming are released into the atmosphere as a result of agricultural activities. Greenhouse gas emissions from agriculture largely consist of nitrous oxide ($N_2O$) and methane ($CH_4$) gas. Although these gases are less abundant in the atmosphere than $CO_2$, they have a higher global warming potential. Emissions resulting from the use of fertilizers have a significant share in emissions from agriculture. Fertilizer-related emissions are mostly manifested by $N_2O$ emissions resulting from the application of nitrogenous fertilizers. Over the past years, the increase in the amount of emission caused by synthetic fertilizers has increased at much higher rates compared to other agricultural emission factors. In addition to synthetic fertilizers, animal manure also has a significant share in agricultural greenhouse gas emissions. Land use type is of great importance in soil carbon retention. Meadows and forests generally retain higher amounts of carbon than arable agricultural lands. Depending on changes in land use, large differences may occur in the carbon balance of the soil. When forest areas, meadow pastures or other natural ecosystems are converted into arable agricultural areas, decreases in soil organic carbon are observed. Soil is formed in nature after a very long process. The pressure on soil, which is the basis of life on earth, is increasing day by day. Soil is the largest carbon sink after the oceans and is an important balance element against climate change. Carbon is stored in larger amounts in soil than in plants on land. Therefore, even small changes in the mass of soil organic carbon can have profound effects on atmospheric $CO_2$ concentration and thus climate change. There is a constant and reciprocal interaction between climate change and soil. If soil is not managed well, there will be more greenhouse gas emission and carbon storage abilities cannot work adequately. It is of great importance to protect existing agricultural areas and preventing the change of natural areas to agriculture areas while meeting the ever-increasing and diversified food demand on a global scale. In addition to increasing productivity in agricultural areas, taking measures to minimize losses in soil organic carbon is an important responsibility to minimize the effects of climate change.

# EFFECTS OF CLIMATE CHANGE ON SOIL PROPERTIES

Soil is formed after a very long process under the interaction of a number of factors such as climate, main material, topography and organisms. The pressure on the soil, which is the basis of life on earth, is increasing day by day. Proper soil management is of great importance for sustainable agriculture.

Soil is the largest carbon sink after the oceans and is an important balancing factor against climate change. The impact of climate change on soils is a slow and complex process. If soils are not well managed, they are not only affected by climate change, but can also contribute to climate change as a source of greenhouse gases. As the effects of climate change increase, it is inevitable that soils will be affected by this situation. The possible effects of global warming on some basic properties of the soil have been examined.

## Effects of Climate Change on Soil Moisture

Having sufficient moisture in the soil during the plant development period is of great importance for plant production. As a result of the climate changes, some changes in soil moisture are expected.

Conditions caused by climate change, such as heavy rainfall in a short time and more evaporation and transpiration due to temperature increase, can cause a series of fluctuations in soil water [1]. The integrative effect of climate-hydrology vegetation-land use changes is reflected by the field water balance and soil moisture regime. The potential effects of four possible climate change scenarios on soil moisture components are summarized Figure 1.

| Factors | Cold, Wet | Cold, Dry | Hot, Wet | Hot, Dry |
|---|---|---|---|---|
| P | I | D | I | D |
| R | I | d, D | I | D |
| G | i | d | i | D |
| I | I | d | I | D |
| i | i | D | i | D |
| S | I | d | I | D |
| E | D | E | E | I |
| T | D | E | i | I |
| F | - | - | - | - |
| $G_r$ | i | - | I | - |
| $G_s$ | - | I | - | I |

P: Precipitation
R: Surface runoff
F: Filtration in the unsaturated zone
G: Groundwater flow
Gr: Rise of water table
Gs: Lowering of the water table
I: Infiltration into the soils
I: Infiltration into the groundwater
S: Storage within the soil
T: Transpiration
E: Evaporation

*Figure 1. Components of field water balance and soil moisture regime and the impact of four potential climate scenarios on these factors: i and I: slight to large increase, d and D: slight to strong decrease, E: No change*

For example, if the vegetation does not suffer from limited water supply due to climate or soil-induced drought, an increase in temperature increases the potential for E and T. Reduces R, I, S and G if high temperature is accompanied by low precipitation, it softens the adverse hydrological consequences of frost and rapid snowmelt (danger of flooding) and provides more opportunities for water penetration. Since the reduction in atmospheric precipitation will result in a reduction in water infiltration (I) and water storage (S) in soil and plants, surface runoff (R) on sloping lands will therefore increase the danger of water erosion, filtration losses and groundwater recharge (G) and evaporation losses [2].

The change in soil water is closely related to the change in precipitation. In current studies, it is predicted that there may be decreases or increases in the amount of precipitation falling in different parts of the world due to climate change (Figure 2). Precipitation is projected to increase by 10% to 40% by mid-century in some high latitudes and some densely populated tropics and decrease by 10% to 30% in some mid-latitudes arid regions. There is also a highly confident prediction that many semi-arid regions (for example, the Mediterranean Basin, the Western United States, South Africa and Northeastern Brazil) will experience a reduction in water resources due to climate change. Increasing

temperatures will also affect the characteristics of lakes and rivers and will have predominantly negative effects on water quality [3].

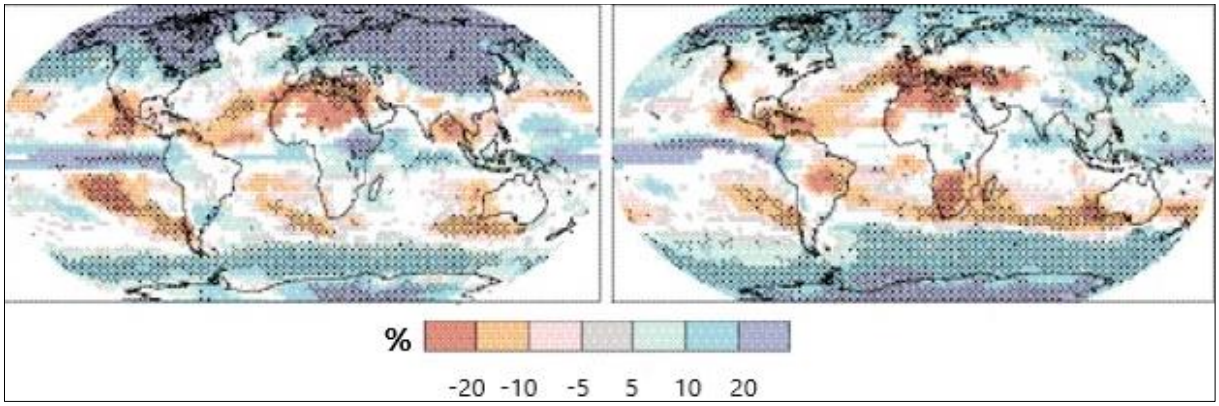



*Figure 2. Proportional changes in precipitation (for the period 2090-2099 compared to 1980 1999). Values are multi-model averages based on the SRES A1B scenario for December-February (left) and June-August (right) [3]*

## Climate Change and the Effects of Changing Precision Regimes on Soil Acidization

Soil pH indicates the alkalinity or acidity of the soil and is closely related to the fertility of the soil. The pH value of the soil solution is the pH value most closely related to the soil and plant biochemical processes. It is expected that there will be changes in soil mineral decomposition and, accordingly, in soil reaction, along with changes in increasing temperature and precipitation intensity due to climate change.

Increase in soil acidification can occur as a result of the production of more biomass due to increased temperatures and the increase in the partial pressure of $CO_2$ in the air. If such plant material decomposes in situ, the alkalinity accumulated in this material returns to the soil, neutralizing the acidity. However, in cases where the produced biomass is harvested and removed from the field, the acidity cannot be neutralized and remains in the soil. On the other hand, increased $CO_2$ partial pressure in soil air alone is unlikely to affect soil pH, since $H_2CO_3$ is a weak acid [4].

Evans et al. [5] used a dynamic model (the Basin Groundwater Acidification Model) and climate scenarios of increasing temperature and decreasing precipitation in their study in the UK to predict the effects of climate change on soil and water. They reported that high dissolved organic carbon and high organic acidity due to high temperature are expected to lower soil pH and increase leaching of basic cations into surface waters. Emphasizing the importance of using lime to control acidity in this type of agricultural soils, the researchers stated that soils with high clay and organic matter content are more resistant to pH increases and decreases, whereas sandy soils are more vulnerable to acidification. While it is not possible to change the clay content in the soil, it would be appropriate to take measures to increase the organic matter content.

## Effects of Climate Change on Soil Salinity and Alkaline

Salinity is a condition that limits the water uptake of plants by reducing the osmotic potential. In addition, due to its special ion toxicity, it may cause the nutrient balance in plants to deteriorate. It is a very important feature in terms of soil health.

Some basic prerequisites are necessary for salt accumulation in soils. First of all, it needs to be a source of salt. Salts can come from different sources. They can be formed as a result of local weathering by dissolution of soluble compounds of certain rocks, minerals and other geological sediments. Surface and groundwater may contain salt. In addition, salt resources are added to the soil through some human activities such as irrigation, fertilization and the use of various wastes. It is possible to transport

these salts to different areas by means of transport agents such as water and wind and the movement of the solution in the presence of a driving force is also effective in salt transport. If there is a negative water balance in the soil, that is, evapotranspiration is higher than precipitation plus irrigation water, salinization may occur. Limited drainage conditions are also a factor that facilitates the formation of salinity [2].

The salt composition of soil water can be an important factor affecting soil permeability. In sodic soils, the soil structure deteriorates and permeability is greatly reduced. Also, salinization of the soil is considered to be the driving force of desertification [6].

Depending on climate change, possible higher temperatures and periodic rainy and dry periods will accelerate the decomposition of geological sediments, which are the main material of salts and their dissolution and transport will increase. Thus, there will be the formation of soluble salts in the soil solution and their accumulation over time. In addition, the increased drought due to increasing temperatures and the excess food demand that will occur over time will cause an increase in the number of irrigated lands. This situation will cause soils to be affected by salts due to incorrect irrigation and fertilization practices as it is today [2].

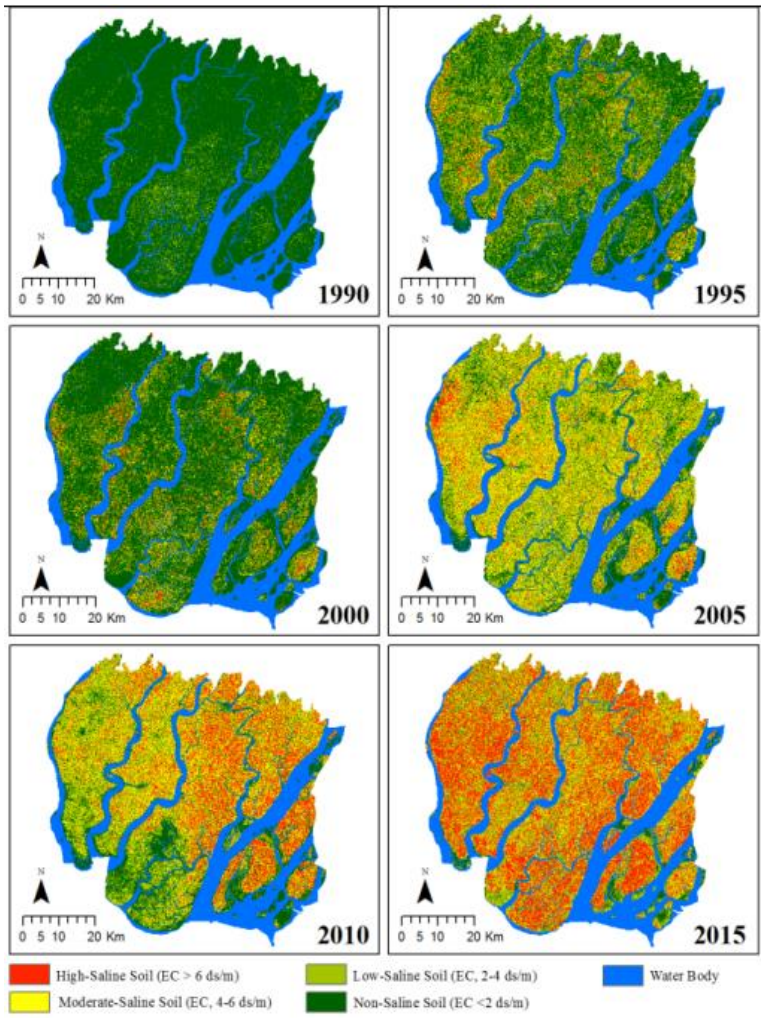



*Figure 3. Soil salinity map obtained in different years by remote sensing [8]*

Too much or too little precipitation can have significant effects on soil salinity in the root zone. Groundwater rises due to excessive precipitation. If the ground water falls below two meters, the movement of water towards the surface will occur with capillarity. If there is not enough rainfall for these salts to leach from the root zone, salt deposits are seen on the soil surface during dry times. Similarly, in areas with drought, salt accumulation is possible with the movement of water with

capillarity. Another example of drought that causes salinity accumulation in the root zone is the intrusion of water from an aquifer with saline water in the nearby region due to excessive water withdrawal from some wells. The decrease in water resources and the use of more wastewater in the future will cause an increase in the amount of salt in the root zone of the plant. Rising ocean levels due to melting glaciers due to global warming may result in more seawater intrusion [7]. Especially in case of direct salt water intrusion, great changes can be seen in soil salinity values in a very short time. Figure 3, the differences in the salt changes of the soils on the Bangladesh coast over a 25-year time period due to sea level rise are shown on the map [8].

## Climate Change and Soil Structure

The particles in the soil coming together and clustered in groups form the soil structure. Structure is considered one of the important physical properties of soil due to its effects on water and gas movement. Soil structure, which is not static but dynamic, may change depending on soil properties.

Soil texture is a soil property that plays an important role in agricultural production. At the same time, the degree of erosion of the soil is closely related to the soil structure. It seems inevitable that there will be an interaction depending on climate change on the soil structure, which can be affected by environmental factors. However, the extent of these changes may vary depending on the magnitude of climate changes and soil structural fragility. As a result, the actual impact will be site and soil specific.

Figure 4, it is possible that with possible changes in climatic events, the soils will sometimes be exposed to drought and sometimes be faced with more intense precipitation and raids. Under these conditions, the soil becomes more prone to structural deterioration. As a result of climate change, it is expected that the soil structure will deteriorate as a result of cultivating the soil when it is too moist or too dry [9].

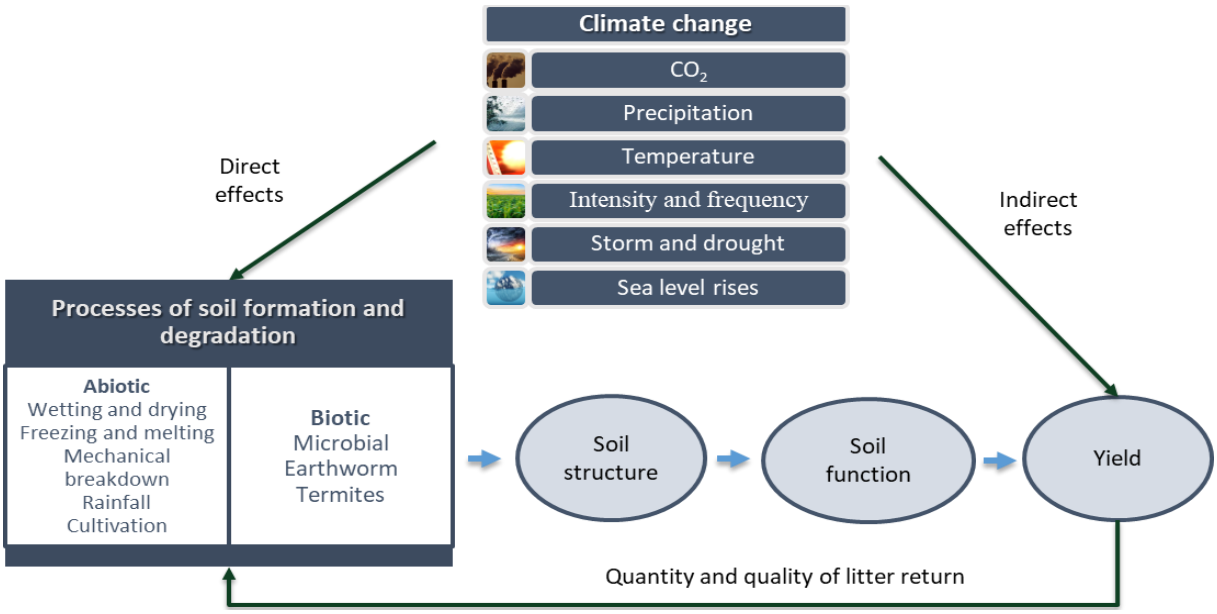



*Figure 4. Basic relationships between soil structure and crop yield in climate change scenarios.*

Climate change will trigger more fires and floods. Fire often reduces soil aggregate stability and can induce, increase or destroy the permeability of water depending on the temperature reached and its duration [10].

The effects of climate change on the soil fauna may indirectly affect the soil structure. Soil organisms, especially earthworms and termites, have important effects on the physical properties of the soil. In the absence of these organisms, strong profile differentiations may occur due to insufficient mixing of the soil [11].

## Effects of Climate Change on Soil Fauna and Soil Flora

Soil fauna and flora, which are represented in very large numbers even in a very small area, are one of the most basic components of the soil, which is of vital importance for many activities in the soil. The soil is home to a wide variety of bacteria, fungi and animal species, as well as many plants. Since the main function of these organisms is to recycle soil organic matter, they are absolutely essential for the functioning of terrestrial ecosystems.

It is expected that the changes that will occur in the soil habitat due to climate change will also affect the soil biota. In drought conditions, less microbial biomass is formed and less microbial activity occurs. In addition, extreme drought can also result in the death of some larger soil organisms. In cases where climate change increases the soil's susceptibility to erosion, soil biota may be affected due to erosion [12].

As a result of a study conducted to determine the effects of climate change on soil biota, it was reported that microbial biomass increased significantly due to the increased amount of $CO_2$, but the number of bacteria was negatively affected by warming [13]. In the same study, it was stated that the mushroom biomass increased with increasing precipitation.

In the presence of high $CO_2$, more plant growth occurs due to increased photosynthesis, which leads to increased carbon input into the soil, strongly changing the activity and density of soil biota [14].

$CO_2$ concentrations increase in the atmosphere, although the rate of use of carbon by plants increases, this situation will be limited to the water and nutrients they can get from the soil [15]. In this case, plants that can coexist with mycorrhizae to obtain more water and nutrients may have an adaptive advantage in conditions were insufficient water and nutrients are available.

## The Effects of Climate Change on Nitrogen Mineralization, Nitrification and Denitrification Events

There are various factors that limit nitrogen mineralization, which is the conversion of organic nitrogen into inorganic N forms in soils. In addition to the amount of organic matter in the soil, environmental factors related to climate have an important effect on nitrogen mineralization.

The mineralization rate, which remains very low in winter, when the temperature drops below 4°C, occurs in large amounts in late spring and summer [15]. Since increased summer droughts due to climate change will reduce the microorganism activities of the soil, nitrogen mineralization is expected to decrease in these conditions [16]. Since only anaerobic microorganisms can be active in soils with heavy precipitation conditions, oxygen deficiency in such soils limits N mineralization [17].

Nitrification and denitrification processes in soils are the most important processes in determining the inorganic nitrogen concentration. The conversion of ammonium to nitrate ions by some microorganisms in the soil is defined as nitrification. Nitrification is a reaction that requires oxygen.

Reduction of nitrate to free nitrogen gas ($N_2$) after various processes. At the end of this process, there may be significant nitrogen losses from the soils to the atmosphere. Denitrification is a process that takes place in the presence of anaerobic organisms and poor aeration in soils leads to favorable conditions.

Higher mineralization and denitrification due to increased temperature under climate change may result in greater $N_2O$ emissions from soils to the atmosphere [18]. Due to climate change in the future, higher amount and frequency of precipitation, which is likely to occur in some regions, will increase denitrification and, accordingly, $N_2O$ flow from the soil [19].

## Climate Change and Soil Organic Matter

Soil organic matter, which regulates the physical, chemical and biological properties of the soil, is the main energy source of the soil and is one of the most important elements required for the preservation of soil fertility. Soil organic carbon refers to the carbon formed in organic matter and is the main component of organic matter.

Carbon dioxide levels in the atmosphere have increased by nearly 50% since the industrial revolution. It is reported that at high $CO_2$ levels and especially in the presence of water and nitrogen in the soil, C3 plants perform photosynthesis at increasing rates and produce more biomass [20]. However, C4 plants rarely respond to high $CO_2$ concentrations, even in the presence of high N [21].

It has been suggested that additional nitrogen provided through atmospheric nitrogen accumulation may promote plant growth. Additional nitrogen supply may not only increase the effect of high $CO_2$ concentration on soil organic carbon, but also slow down the rate of organic matter decomposition in some ecosystems [20].

In general, the presence of water in soils together with increased precipitation, especially in areas where water is limited, contributes more significantly to the accumulation of soil organic carbon than temperature. [21]. In a climate change study conducted on this subject in which carbon dioxide, soil moisture and temperature were used as factors, it was reported that soil moisture had a more significant effect on soil organic carbon stock than high $CO_2$ and temperature [22].

There are not many studies examining the changes in soil organic carbon stocks of climate change. In a 25-year study conducted in England and Wales, they reported that the annual loss of soil organic carbon was 0.6% and this was related to climate change [23]. In addition, in another study conducted in the United Kingdom, measurements were made over a period of more than 100 years and it was stated that there was no significant change in carbon stocks [24].

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# CARBON BUDGET IN AGRICULTURAL SOILS

After the use of fossil fuels all over the world, we encountered a problem that has become increasingly influential. Especially with the century we left behind, global warming has entered our lives as an important problem due to the increase in greenhouse gases in the atmosphere.

In fact, the world's climate has changed many times throughout history. Most of these climate changes have resulted from changes in the amount of solar energy the planet receives due to small changes in the earth's orbit.

The rate of greenhouse gases in the atmosphere started to increase with the industrial revolution that started in the middle of the 18$^{th}$ century and reached values approaching 400 ppm today (Figure 1). The increase in the carbon dioxide ratio is largely due to the use of fossil fuels. Another important factor in this increase is the change in land use, especially deforestation.

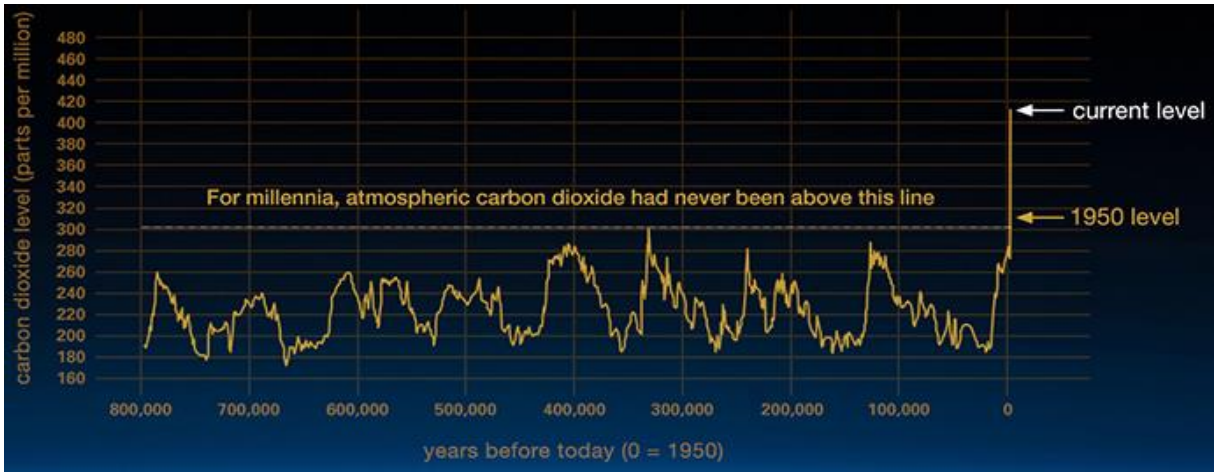



*Figure 1. Changes in atmospheric $CO_2$ over the years (climate.nasa.gov)*

## Global Carbon Cycle

Carbon is an essential element for life. The movement of carbon in inorganic and organic forms between the atmosphere, biosphere, hydrosphere and pedosphere is called the carbon cycle [1]. The carbon cycle is a system that supports all life. Carbon in the atmosphere is bound by photosynthesizing organisms and then passed to animals through the food chain. These creatures give off $CO_2$ to the atmosphere by respiration, or when they die, the carbon in their bodies accumulates in the soil or water.

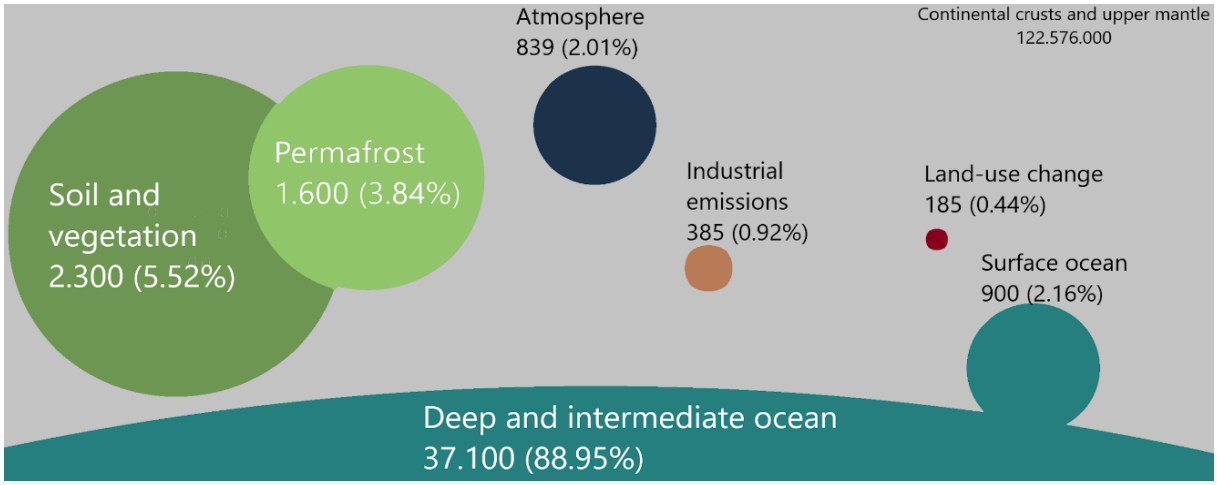



*Figure 2. World carbon stocks in gigatons (adapted from Janowiak et al. [2])*

Throughout the world, carbon is stored in different forms and areas (Figure 2). The largest stock of carbon on earth is in the continental plates and upper mantle of the world. Afterwards, the largest stock is found in the oceans, the vast majority of which is in the form of inorganic dissolved carbon and is not subject to change. There is only 900 Gt of carbon in the oceans for exchange. Carbon in the atmosphere is in the form of $CO_2$ and contains about 839 Gt of carbon. It is estimated that the soils, together with the frozen soils, store around 3,500 Gt of carbon in total [2].

## Soil Organic Carbon

Soil organic carbon is the part that remains in the soil after the wastes of living organisms have been partially decomposed. Soil organic carbon is the main component of soil organic matter and is the energy source of the soil. Organic carbon, which plays a major role in the regulation of basic soil properties, plays an important role in maintaining soil fertility. The loss of organic carbon in soils is an important indicator of soil degradation.

After the oceans, terrestrial ecosystems are the largest carbon storage areas. Carbon is not only stored in plants on land, it is stored in the soil in greater amounts. Therefore, even small changes in soil organic carbon mass can have profound effects on atmospheric $CO_2$ concentration and therefore on climate change. The estimated carbon stock in terrestrial ecosystems on Earth is shown in Table 1.

*Table 1. Estimated carbon stock in terrestrial ecosystems on Earth [3]*

| Ecosystem | Global Carbon Stocks (Pg C) | | |
|---|---|---|---|
| | Herb | Soil | Total |
| Tropical Forests | 212 | 216 | 428 |
| Temperate Climate Forests | 59 | one hundred | 159 |
| Arctic Forests | 88 | 471 | 559 |
| Tropical Meadows and Grasslands | 66 | 264 | 330 |
| Temperate Grasslands and Shrublands | 9 | 295 | 304 |
| Deserts and Semi-Deserts | 8 | 191 | 199 |
| Tundras | 6 | 121 | 127 |
| Farming Areas | 3 | 128 | 131 |
| Wetlands | 15 | 225 | 240 |
| **Total** | **466** | **2011** | **2477** |

There can be significant differences in the distribution of stored carbon depending on factors such as climatic conditions, land structure and use and environmental factors. For example, the amount of carbon stored above ground is higher in the wet and warm parts of the tropics than underground. In contrast, forests at northern latitudes have enormous underground carbon reserves. The situation is more complex in temperate climatic regions [2].

The amount of carbon in different depths of the soil also differs. Since the main source of soil organic matter is living beings that have died, mostly the upper depths of the soil are rich in organic carbon and decrease towards the depths of the soil. Carre et al. [3] produced estimates of soil organic carbon stocks using IPCC methodology and HWSD (Harmonized World Soil Database) modelling. The results produced are summarized in Table 2 according to the soil depths and the climate regimes of the IPCC.

Soil organic carbon is estimated to be deposited with the largest amount of 190 Pg in areas of mostly peat soils located in northern latitudes. The carbon stored in these areas is largely found in the first 30 cm of soil. Low biological activity and slow decomposition of organic matter have resulted in the accumulation of large amounts of carbon in the soils of this region. This type of soil is often called Histosol and contains about 12-18% organic carbon [4]. On the other hand, in dry and hot regions such as the Sahara Desert, the vegetation cover is low and the carbon entry into the soil is very limited. Arenosols, the typical soils of these areas, often contain less than 0.6% soil organic carbon [5].

*Table 2. Distribution of soil organic carbon stocks according to climate regimes*

| IPCC Climate Regime | IPCC | HWSda | | |
|---|---|---|---|---|
| | 0-30 cm | 0-30 cm | 30-100 cm | 0-100 cm |
| | Pg C | | | |
| Tropical Wet | 52.4 | 62.6 | 65.4 | 128.0 |
| Tropical Humid | 94.5 | 78.6 | 72.3 | 150.9 |
| Tropical Dry | 99.9 | 67.3 | 69.0 | 136.2 |
| Tropic Highland | 49.8 | 29.6 | 26.5 | 56.1 |
| Temperate Climate Humid | 41.7 | 33.3 | 29.7 | 63.0 |
| Dry Temperate Climate | 42.9 | 38.9 | 39.6 | 78.5 |
| Cold Climate Humid | 110.6 | 104.1 | 106.2 | 210.3 |
| Cold Climate Dry | 56.9 | 52.2 | 50.0 | 102.2 |
| Boreal Moist | 137.3 | 162.0 | 194.7 | 356.7 |
| Boreal Dry | 30.3 | 32.0 | 37.0 | 68.1 |
| Polar Moist | 26.8 | 30.6 | 21.7 | 52.4 |
| Polar Dry | 7.2 | 8.0 | 4.3 | 12.3 |
| **Total** | **750.3** | **699.3** | **716.4** | **1415.7** |

Global soil organic carbon (SOC) mass is related to the carbon cycle. A modeling based on current estimates (HWSD: Harmonized World Soil Database) gives a total mass of 2476 Pg globally [6]. The value obtained by correcting for the bulk density of HWSD of organic soils and especially Histosols equals a mass of 1062 Pg (Figure 3).

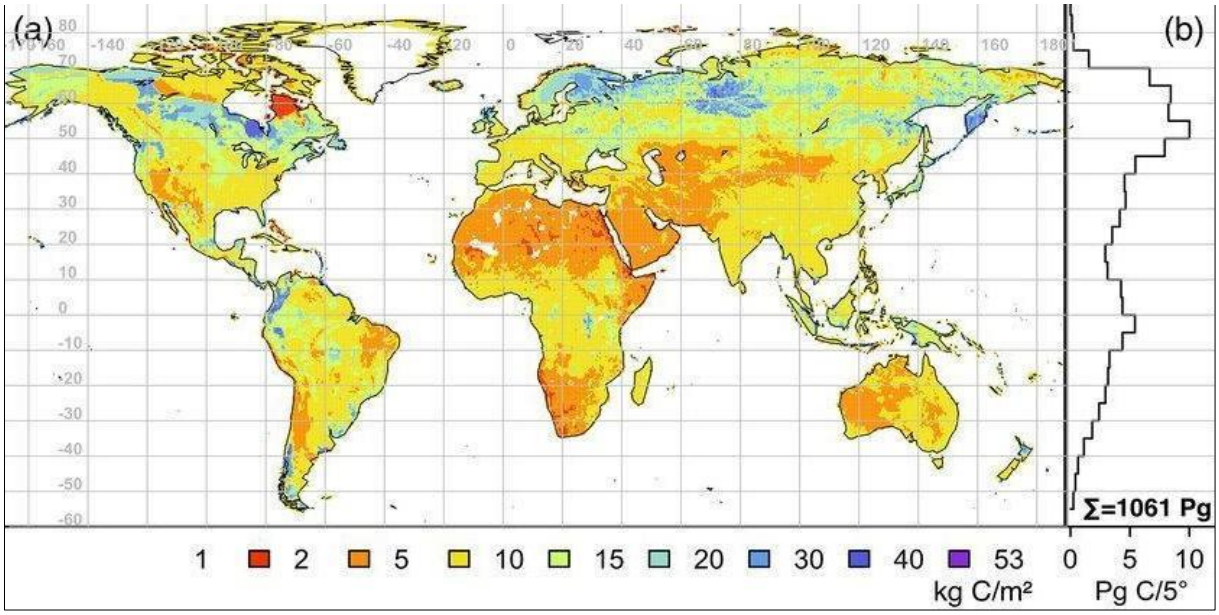



*Figure 3. (a) Global organic carbon stock calculated by HWSD v.1.1 in 1 meter topsoil slice (b) Mass per 5° latitude of organic carbon in the same section [6].*

## Changes in Carbon Stock

The amount of carbon stored in the Earth's atmosphere is very small compared to the carbon stored in the oceans and land (Figure 2). Both the amount and direction of carbon moving between different carbon pools can have a major impact on climate change. According to the measurements taken from the ice cores, the $CO_2$ concentration, which was known to be around 280 ppm in the pre-industrial period, has increased over 380 ppm today and the most important share in this increase was due to the use of fossil fuels. In the 1960s, it was already found that only some of the $CO_2$ emitted accumulates in the atmosphere, while the remainder is retained on Earth. However, after 1980, it became clear that the terrestrial biosphere is also an important actor in the global atmospheric carbon balance, like the

oceans [7]. It has been understood that land use transformations, especially deforestation, cause significant terrestrial carbon losses to the atmosphere.

The global atmospheric $CO_2$ budget is shown in Table 3 for the period 1980-2005 [8]. As seen in Table 3, the net release by the terrestrial biosphere is approximately 50% smaller than the net ocean release. $CO_2$ emissions due to land use change are more difficult to predict.

*Table 3. Carbon budget for different time periods Gt C year$^{-1}$ (numbers in brackets reflect estimated ranges)*

| | 1980s | 1990s | 2000-2005 | 1980-2005 |
|---|---|---|---|---|
| Atmospheric Increase | 3.3±0.1 | 3.2±0.1 | 4.1±0.1 | 3.5±0.1 |
| Industrial Emissions | 5.4±0.3 | 6.3±0.3 | 7.2±0.3 | 6.2±0.3 |
| Net Flow from Ocean to Atmosphere | -1.8±0.8 | -2.2±0.4 | -2.2±0.5 | -2.0±0.5 |
| Net Land to Atmosphere Flow | -0.3±0.9 | -0.1±0.6 | -0.9±0.6 | -0.7±0.6 |
| Flow Due to Land Use Change | 1.4 (0.4-2.3) | 1.6 (0.5-2.7) | 1.5 | 1.5 (0.5-2.5) |
| Amount Remaining in Terrestrial Pools | -1.7 (-3.4-0.2) | -2.6 (-4.3-0.9) | -2.4 | -2.2 (-3.8-0.6) |

Fossil fuel consumption is accepted as the driving force of climate change [9]. Human-induced (anthropogenic) carbon emissions have affected not only the atmosphere but also ocean and land stocks. In fact, the carbon storage of the oceans and terrestrial vegetation has increased over the past two centuries. The oceans take in 2.3 Gt of C carbon each year [10]. Similarly, the net rate of atmospheric $CO_2$ uptake by terrestrial biomes has nearly doubled compared to the 18$^{th}$ century, exceeding 2.6 Gt C per year. Currently, there is a net accumulation of 4 Gt C per year in the atmosphere, despite the annual removal of about 5 Gt C from the atmosphere via the ocean and land [2]. This increase in atmospheric $CO_2$ will continue to cause increases in $CO_2$ levels, resulting in reduced oxygen availability and increased acidity in the oceans and thus harmful climate feedbacks [11]. On the other hand, it is expected that there will be an increase in $CO_2$ and $CH_4$ emissions stored in frozen soils due to melting. There is a potential for an increase in terrestrial climate-carbon feedbacks as a result of increasing frequency and intensity of extreme climate events [12].

There is a decrease in soil organic carbon in areas that have been converted from forest areas to agricultural lands. Under these conditions, the cover layer consisting of vegetal residues at the top of the soil disappears and the source of organic matter disappears. With the cultivation of the soil, the decomposition of organic matter is accelerated and it becomes open to transport due to erosion. The disappearance of forest areas means that these areas, which act as a carbon sink, become carbon sources. It is claimed that 2.1 billion tons of $CO_2$ emissions occur annually due to the degradation of tropical forests, of which 53% is due to timber production, 30% to firewood and 17% to forest fire [13].

Soil degradation, which is both the cause and the result of climate change, is defined as the long-term decrease and loss of soil value and biological productivity and according to estimates, the earth's soil surface has been degraded by 7-40% due to human causes [14].

Mangroves, which consist of trees and shrubs in coastal areas and are important carbon sinks for the world, are constantly decreasing. 40% of mangrove areas, which have suffered significant loss in recent years, are under threat of extinction [15]. Mangroves can store up to 25.5 million tons of carbon per year [16] and provide the global oceans with more than 10% of the required organic carbon [17]. It is estimated that between 0.15 and 1.02 billion tons of carbon is released annually due to degradation of mangroves, swamps and seagrass meadows [18].

In regions close to the poles, more soil is exposed with the melting of glaciers and snow and this causes more heat to be absorbed by the soil instead of reflecting and returning the rays, thus causing a more warming effect. According to a scenario created by modeling, during the 21$^{st}$ century, an increase of 1.4-1.8 Wm$^{-2}$ in the amount of absorbed shortwave radiation on a global scale was determined due to the reduction of the North Sea ice cover and the Antarctic Ocean ice cover [19].

Due to increasing urbanization, changes are seen in land cover, while biodiversity decreases, soil degradation increases. As a result, loss of biomass and carbon storage occurs. If current trends in

population density continue, the urban area is expected to increase by 1.2 million km² by 2030. This increase will lead to significant habitat losses, especially in areas that were relatively less affected by urban expansion. Within the pan-tropics, the loss of vegetation biomass from areas with a high probability of urban expansion is estimated to be 1.38 PgC (0.05 PgC $year^{-1}$), which is close to 5% of emissions from tropical deforestation and land use change [20].

## The Importance of Carbon Retention in the Soil

Carbon sequestration is the transfer of $CO_2$ in the atmosphere in such a way that it cannot be re-released into the atmosphere in a short time and can be stored in soil organic carbon pools for a long time. It is a phenomenon that has attracted a lot of attention recently in order to be less affected by the negative effects of climate change by reducing the $CO_2$ emission towards the atmosphere. There is general agreement that carbon sequestration in soils is technically feasible and has significant potential. It is estimated that 0.90 to 1.85 Pg of carbon per year can be captured in cultivated areas worldwide [21].

## Carbon capture mechanism

Carbon stored by the plants forms a cover on the soil with the dead plant parts that return to the soil. The organic materials in this cover layer can decompose and return to the atmosphere in the form of $CO_2$ and mix with the soil to a significant extent. In this way, organic carbon is stored in the soil.

The main source of soil organic carbon is organic matter that has been mixed into the soil by the decomposition of dead vegetation. The decomposition of dead vegetation occurs with two events called oxidation and humusification [22]. Organic materials in the litter become mineralized by oxidation if the conditions are suitable. As a result of oxidation, carbon turns into $CO_2$, hydrogen into $H_2O$, nitrogen into $NO_2^-$ and to $NO_3^-$, sulfur to $SO_3^{-2}$ and $SO_4^{-2}$, and phosphorus to $PO_4^{-3}$ [23]. Meanwhile, the plant nutrients contained in the organic matter are also released [24]. In the absence of the necessary conditions for decomposition, oxidative decomposition is limited. In this case, the humification event, which progresses more slowly and ensures the decomposition of organic matter, comes into play [23]. These events take place in three stages. First, high polymer compounds are broken down into building blocks. In the second stage, the plant tissues are partially consumed by the animals in the soil and decomposed. In the final stage, the decomposed and shrinking organic residues are changed by microorganisms. While the most easily degraded parts are water-soluble substances such as carbohydrates and pectin, the cellulose and lignin-rich parts take more time to decompose [24]. The part that emerges as a result of decomposition loses its textural structure and turns into amorphous and colloidal humus, which part of the plant is unknown [23]. As a result of advanced decomposition, humic substances appear in the soil. Humic substances with a large surface width are found either adhered to each other or bound to clay minerals and oxides [24]. Some compounds in the structure of organic matter, such as amino acids, carbohydrates and some organic acids, are called non-humic substances. The classification of the organic matter in the soil as humic and non-humic is related to whether the carbon, which forms the basis of soil organic matter, is stable or unstable [22]. Unstable soil organic carbon is the part of organic matter that decomposes in a short period of time, while stable soil carbon can take thousands of years to decompose. $CO_2$ flow between soil and atmosphere is directed by oxidation of unstable soil organic carbon [25].

## Effect of Land use change in carbon capture

Land use pattern is of great importance in soil carbon sequestration. Grasslands and forests generally sequester carbon at a higher rate than arable land. Among these categories, it is expected that the carbon balance of the soil will be affected depending on the changes in land use (Table 4). Soil organic carbon tends to decrease when woodlands, grasslands or other local ecosystems are converted into

arable farmland. On the other hand, when the opposite is the case, there is an upward trend in soil organic carbon [26].

*Table 4. The effect of land use change on soil carbon*

| Available New | Meadow | Forest | Agricultural Field |
|---|---|---|---|
| Meadow | | no effect | C loss |
| Forest | no effect | | C loss |
| Agricultural field | C gain | C gain | |

There are many studies that follow the status of soil organic carbon content in land use changes.

The effects of land use changes on soil carbon stocks were tried to be revealed by Guo and Gifford [27] with a meta-analysis by reviewing a large number of literatures. According to the results, soil carbon stocks decreased in conversion from rangeland to plantation (-10%), from natural forest to plantation (-13%), from natural forest to field (-42%) and from pasture to field (-59%). In addition, an increase in soil organic carbon content was observed in areas converted from natural forest to pasture (+8%), from field to pasture (+19%), from field to plantation (+18%), and from field to forest (+53%).

In a study in which different study results were compiled in order to reveal possible soil carbon changes when forest areas were converted into agricultural areas, it was revealed that the soil carbon content was lost on average by 30% with the conversion from forest to agricultural lands [28].

In a study examining the effects of afforestation, especially on carbon storage in the soil, *Pinus radiata* fields were created where grain and vine were grown in the past. The results, in which soil carbon storage was determined by modeling, were shared by establishing radiata pine plantations [29]. After the afforestation of the old vineyards, carbon increases were observed in the top 5 cm of the soil, while the nitrogen contents remained the same or decreased. While most of the organic matter accumulation during afforestation took place in the upper soil layers, annual carbon accumulation per square meter was found to be 19 g in vine-grown areas and 41 g in grain-grown areas. In the study, a carbon sequestration potential of 950 and 700 g.C.m² in 20 years was estimated for vine and grain, respectively, using RothC and Century models.

## Increasing carbon capture in agricultural fields

While meeting the increasing and diversifying food demand in the world, it is of great importance to protect the existing agricultural lands and to provide this demand without encouraging the opening of natural areas to agriculture. In addition, increasing the productivity in existing agricultural areas and taking measures to minimize the losses in soil organic carbon while increasing agricultural productivity imposes responsibility on people in order to minimize the effects of climate change.

The term "carbon sequestration in soil" refers to the removal of atmospheric $CO_2$ by plants and the storage of fixed carbon as soil organic matter. The main strategy in combating climate change is to increase the organic carbon density in the soil, improve the depth distribution of carbon and stabilize the carbon. In this context, managing agroecosystems correctly is an important strategy to increase soil organic carbon sequestration.

In particular, the wrong use of the land and the wrong soil management practices cause the depletion of organic carbon with the release of $CO_2$ and other greenhouse gases into the atmosphere, while strengthening the organic carbon pool is a powerful tool to balance greenhouse gas emissions.

When degraded soils and ecosystems are restored, marginal agricultural lands are rehabilitated, plantations are established with perennial plants and agricultural practices are adopted in line with the recommendations (Table 5), the sequestration capacity of soil organic matter for atmospheric $CO_2$ can be significantly increased. Although the suggested agricultural practices are generally similar (mulch applied agriculture, reduced tillage, integrated plant nutrition practices, integrated agricultural

control practices, precision farming techniques), specific practices for each area are extremely important in practice.

*Table 5. Comparison of traditional practices and recommended agricultural practices regarding soil organic carbon sequestration*

| Traditional practices | Recommended agricultural practices |
|---|---|
| Biomass burning and waste disposal | Waste recycling with mulch applications |
| Conventional tillage | Conserved tillage or no-till farming |
| fallow practices | Application with cover crops out of season |
| Monoculture applications | High variety of crop rotations |
| Intensive use of chemical fertilizers | Integrated nutrient management with compost, organic fertilizers and nutrient cycling, precision farming practices |
| Intensive cultivation | Integration of plant and animal production |
| Surface irrigation | Use of pressurized modern irrigation systems |
| Intensive pesticide use | Integrated combat |
| Cultivation of marginal lands | Conservation reserve program, restoration of degraded lands through land use change |

In line with the practices summarized in Table 5, if soil disturbances caused by tillage are eliminated, erosion losses are minimized and large amounts of root and above-ground biomass are returned to the soil, more carbon will enter the soil. These practices conserve soil water, improve soil quality, increase productivity and improve soil organic carbon pooling. With the transport of organic carbon to the subsoils, the retention time of carbon in the soils is extended.

Soil biodiversity has a positive effect on soil organic carbon. Ecosystems with high biodiversity hold more carbon than ecosystems with less biodiversity. Grassland, pasture and forest ecosystems have more carbon biomass than farmland [30].

Some of the soil and crop management practices that improve the soil organic carbon pool are briefly discussed below.

## Conservation tillage

Conventional tillage and erosion result in the depletion of organic carbon pools found in agricultural soils. Therefore, the carbon storage capabilities of the soils will be increased if the soil is switched to non-tillage agriculture or if protective tillage methods are applied to minimize soil degradation.

## Use of cover crops

It is important to include cover crops in crop rotation in order to increase soil organic carbon sequestration. The use of cover crops is a sustainable method to reduce the effects of climate change. With the use of cover crops, nitrogen and carbon can be added to the soil, nitrate leaks are reduced and the soil is protected from erosion [5]. In plant rotations, the use of cover crops, especially during fallow periods, is an important way to increase carbon input into the soil with the help of biomass production. If the plants to be used are selected among leguminous plants, they will add a significant amount of nitrogen to the soil.

With cover crops, nitrate leaching can be reduced in two ways. On the one hand, plants absorb the nitrate in the soil, on the other hand, they reduce the effect of infiltration by using soil water that will cause infiltration. It has been found that non-legume cover crops reduce the amount of $NO_3$ leaking into groundwater resources by an average of 56% [31].

## Plant nutrition and irrigation applications

A correct plant nutrition management in agricultural areas is very important for soil organic carbon sequestration. In general, the use of organic fertilizers and compost will improve the soil organic

carbon pool more than the use of inorganic fertilizers. When the amount of organic carbon in the soil falls below 1%, soil health is adversely affected and productivity decreases. On the other hand, increasing the amount of organic carbon in the soil is also a way of increasing carbon sequestration, as it increases the capacity of agroecosystems to absorb atmospheric $CO_2$ and store it in the soil [32]. A 41-yearlong study was conducted in a paddy field in India and the effects of organic fertilizer applications on soil organic carbon content were tried to be determined [33]. As a result of the study, while 36 mg C was found in 1 hectare area in the control plots where organic fertilizer was not applied, the amount of organic carbon was found to be 46.3 mg with an increase of 29% in the application where chemical fertilization was combined with animal manure.

On the other hand, if irrigation is done by considering the plant requirement, as in fertilizer application to the soil, an increase in plant biomass will occur and the amount of organic carbon entering the soil will increase in this way.

## Meadow pasture management and forest lands

Globally, restoring degraded grazing lands is important for soil carbon sequestration. Increasing the carbon sequestration in the soil can be achieved by some measures such as transforming the marginal areas used in agriculture into pastures, using fertilizers in the pastures, controlled grazing and choosing legumes suitable for the region in the pastures. It has been reported that 0.11-3.04 mg C can be retained annually in one hectare area by improving the pastures and the average amount of carbon captured will be 0.54 mg [34].

Similarly, converting some of the marginal areas used in agricultural production but degraded to forests or perennial plant plantations can be a useful way to improve the soil organic carbon pool. Correct planning is of great importance here. In some studies, it has been reported that decreases in organic carbon content may occur in such applications. Afforestation of a cemetery with radiata pine (*Pinus radiata*) in New Zealand has been reported to decrease the organic carbon content of the soil by 15% [29].

## Potential of earth's soils for carbon sequestration

130 Pg of carbon is stored in the upper 30 cm of soils in farmlands (Table 6).

*Table 6. Current regional soil organic carbon totals and totals in medium and high sequestration scenarios 20 years later (adapted from Zomer et al. [21])*

| **Arable Land (0-30 cm depth)** | **Arable Land** | **Soil Organic Carbon** | | | | |
|---|---|---|---|---|---|---|
| | | **Available** | **20 Years Later** | | **Annual Increase Amount** | |
| **Scenario** | | | **Middle** | **High** | **Middle** | **High** |
| **REGION** | **km²** | **Pg C** | | | **Pg C year⁻¹** | |
| Australia | 659.834 | 3.75 | 4.50 | 5.29 | 0.04 | 0.08 |
| Central America | 139.742 | 1.22 | 1.37 | 1.52 | 0.01 | 0.02 |
| Middle Asia | 369.061 | 5.01 | 5.40 | 5.81 | 0.02 | 0.04 |
| East Asia | 1.262.134 | 9.14 | 10.52 | 11.97 | 0.07 | 0.14 |
| East and South Africa | 1.055.461 | 5.64 | 6.80 | 8.02 | 0.06 | 0.12 |
| Europe | 1.995.564 | 21.05 | 23.26 | 25.60 | 0.11 | 0.23 |
| North Africa | 258.602 | 1.51 | 1.83 | 2.17 | 0.02 | 0.03 |
| North America | 1.260.786 | 28.07 | 31.52 | 35.16 | 0.17 | 0.35 |
| Russia | 1.235.827 | 21.94 | 23.19 | 24.52 | 0.06 | 0.13 |
| South America | 1.753.039 | 9.42 | 10.72 | 12.09 | 0.06 | 0.13 |
| South Asia | 852.619 | 7.68 | 9.87 | 12.18 | 0.11 | 0.22 |
| Southeast Asia | 1.307.174 | 8.15 | 9.06 | 10.03 | 0.05 | 0.09 |
| West and Central Africa | 891.532 | 4.83 | 6.35 | 7.95 | 0.08 | 0.16 |
| West Asia | 2.893.928 | 4.38 | 5.44 | 6.57 | 0.05 | 0.11 |
| SPHERICAL | 15.935.304 | 131.81 | 149.84 | 168.87 | 0.90 | 1.85 |

North America, Eurasia (Russia) and Europe regions account for more than 50% of all organic carbon stocks in cultivated land around the world. In contrast, the region of Central America, North Africa and Australia has slightly more soil organic carbon than 4.6% of the global total. South America has 9.42 Pg C despite having a sizable amount of farmland. Russia is the country with the highest carbon stock in the world, with 21.9 Pg C in cultivated areas, with 17% as a country. This is followed by the United States (18.9 Pg C), China (8.4 Pg C), India (6.4 Pg C) [21].

In Table 6, the retention potential of soil organic carbon stocks in agricultural soils according to two different scenarios is given together with the carbon stocks available globally and the forecasts for the next 20 years are shown regionally and globally. Accordingly, as a result of the analysis, it is seen that there is a global storage potential of 0.90 and 1.85 Pg C per year. North America showed the highest overall carbon storage potential globally, with Pg C values of 0.17 to 0.35 per year. North Africa has very little arable land and thus has the lowest potential for total carbon sequestration.

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# EFFECTS OF LAND-USE CHANGES ON CARBON STOCKS IN SOIL

The biggest reason for the global climate change, the effects of which we have felt much more clearly in recent years, is the increase in the rates of greenhouse gases in the atmosphere. Carbon dioxide is the gas with the highest percentage of these greenhouse gases. The rise of atmospheric carbon ($CO_2$) concentrations at increasing rates after the industrial revolution is due to anthropogenic (human activities).

After the oceans, terrestrial ecosystems are the largest carbon storage areas. Soil is the largest carbon reserve in the terrestrial biosphere and stores three times as much carbon as atmospheric carbon. Even the slightest change in soil carbon affects atmospheric carbon because there is a constant flow between atmosphere and soil carbon. Depending on the differences in land use, the carbon in the soil stocks also changes. When the direction of this change is from the soil to the atmosphere, the amount of atmospheric greenhouse gas increases.

Changes in land use and land surface cover can contribute to climate change by affecting the world's energy balance, as well as being affected by climate change. While more than half of the land changes occur directly with human activities, the remaining part is associated with indirect factors such as climate change [1]. Human-induced changes in land surface cover are of great importance for the structure and function of ecosystems, but equally important for providing food and shelter for humans. In this module, the interaction between land use changes and climate change is examined.

## Effects of Different Uses of Terrestrial Lands on Carbon Capture

There is uncertainty about exactly how the land on earth is used. On the other hand, it is a known fact that these lands are constantly being transformed. There are 13 billion hectares of non-glacial land worldwide, of which one-third (4.3 billion hectares) consists of permanent grassland and agricultural land [2]. In general, the proportional distribution of non-glacial terrestrial areas in the world has been tried to be summarized in Figure 1.

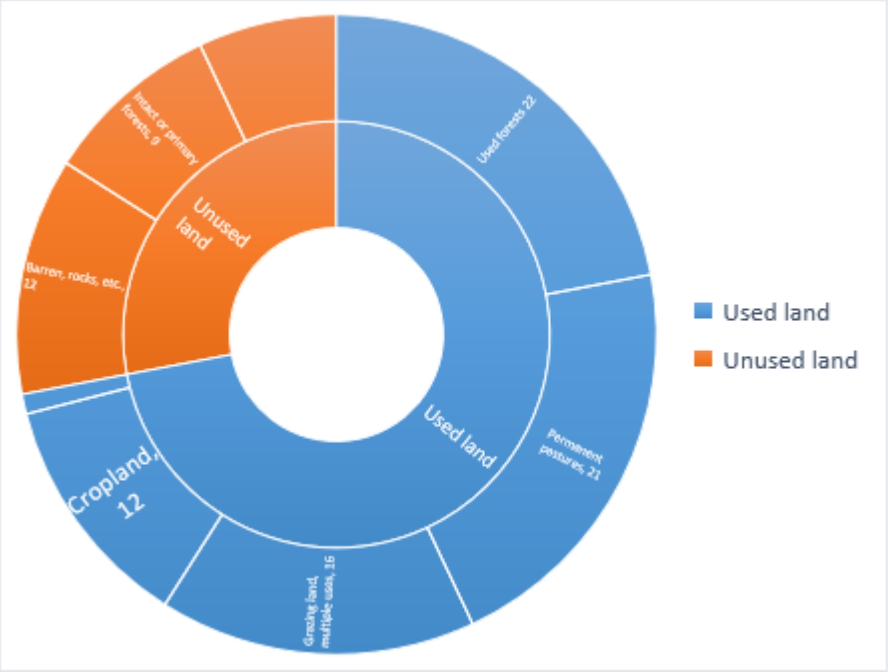



*Figure 1. Estimation of global uses of non-glacial land (adapted from Brewood and Garnett 2020 [2])*

It has long been known that changes in land surface cover can change the amount of carbon stored in the soil and as a result, atmospheric carbon may be affected. However, a large number of studies examining changes in land use change and soil C stocks have shown that there can be significant

disagreements about the direction and magnitude of the change that occurs as a result of some use differences.

The transition from one ecosystem to another can occur spontaneously in nature, but mostly as a result of human activities. Each soil has a carbon carrying capacity and an equilibrium carbon content depending on the type of plants on it and the climatic characteristics of the region [3]. In land use changes, there are differences in carbon input and output to the soil and this balance is disturbed. At the end of the process, soil C stocks will have changed either as a carbon source or as a carbon sink. There are many studies on this subject.

In a literature reviewing study done by Deng et al. [4], based on the synthesis of 103 new publications from 29 countries, they tried to reveal the effects of land use changes on soil carbon stocks. In their results they stated that as a general average, land use transformations significantly reduced soil carbon stocks (0.39 $mg.ha^{-1}.year^{-1}$). Other results found by the researchers are summarized in Table 1. While the soil carbon stocks increased in the transition from agricultural land and forest areas to meadow pasture in soil carbon stocks, the change in carbon stocks appeared as a decrease in areas converted from meadows and forests to agricultural land. It is also stated that carbon stocks decrease in places where there is a transformation from forest to forest. However, researchers reported that there was no change in soil carbon stocks in areas converted from agricultural land and grasslands to forest. In addition, it was also stated in the results of the same study that the changes in carbon stocks fluctuated over time due to changes in land uses.

*Table 1. Effects of land use changes on soil C uptake*

| Land use Changes | Soil Carbon Sequestration ($mg.C.ha^{-1}.year^{-1}$) |
|---|---|
| From farmland to grassland | +0.30 |
| From forest to grassland | +0.68 |
| From grassland to farmland | -0.89 |
| From forest to farmland | -1.74 |
| From forest to forest | -0.63 |
| From farmland to forest | No difference |
| From grassland to forest | No difference |
| Overall | -0.39 |

In a similar study, Dawson and Smith [5] made a comparison of the results of many researches and emphasized in their findings that the carbon content of the soil decreased with the conversion of forest and pasture lands into agricultural land, whereas carbon increases were observed in the opposite case. The results compiled by the researchers from the data they obtained are given in Table 2.

*Table 2. Potential changes in soil carbon stocks due to land use change (adapted from Dawson and Smith (2007) [5]. Positive values show gains negative values show losses)*

| Land use Changes | Net Carbon Amount ($ton.C.ha^{-1}.year^{-1}$) |
|---|---|
| From arable land to temporary pasture (rotation) | 1.6 |
| From arable land to pasture (35 years) | 0.63 |
| From arable land to permanent pasture | 0.27 |
| From arable land to forest | 0.6-2.8 |
| From arable land to forest (25 years) | 0.3-0.6 |
| From permanent crop to arable land | 0.27 |
| From pasture to arable land | -1.0 to -1.7 |
| From pasture to arable (20 years) | -0.95±0.3 |
| From pasture to afforested (90 years) | 0.1±0.02 |
| From steppe to pasture | -0.9 to -1.1 |
| From forest to arable land | -0.6 |
| from forest to pasture | -0.1±0.1 |
| From natural vegetation to pasture | 0.35 |
| From peat to arable land | -2.2 to -5.4 |
| From wetland to arable land | -1.0 to -19 |

As can be seen from the charts, forests and meadows have a vital importance in the storage of carbon. Considering the area they cover on the world; they play an important role in reducing emissions by ensuring carbon sequestration in the global carbon cycle.

## Effects of Land Use Changes in Meadow Pasture Areas

Pasture is of vital importance for the world in terms of their biodiversity and ability to prevent erosion. In addition, they are among the most important terrestrial carbon sinks. Grassland-pasture areas are one of the main elements of the global carbon cycle and it can be said that they hold approximately 0.5 Pg $CO_2$ annually, although there is uncertainty in their efficiency and cycle times [6]. It is reported that the carbon stock in the soil is 634 Pg, together with the vegetation on the meadows and grasslands located in the tropical and temperate climate regions globally [7]. Grasslands, which are an important carbon sink, have a vital role in reducing the effects of climate change.

Conversion of grassland pastureland to farmland is one of the biggest changes in land use, accelerating both soil erosion and the loss of soil organic carbon. Since soil carbon can be released more easily in pasture areas that have been transformed into arable areas, it causes an increase in atmospheric carbon. However, there are too many variables that affect organic carbon loss in such transformations. In a study that tried to reveal the effects of land use changes on soil carbon stocks with a meta-analysis, Soil carbon stocks decreased by 10% when converted from pasture to plantation, while this loss was 59% in conversion from pasture to field. In addition, soil organic carbon increased by 8% in areas converted from natural forest to pasture and by 19% in areas converted from field to pasture [8].

In another meta-analysis study conducted by examining 81 samples, it was stated that soil organic carbon decreased after the transformation of meadow pasture areas and this decrease occurred at a soil depth of 0-60 cm and remained the same at deeper depths [9]. The same researchers emphasized that the decrease in organic carbon in the soil continues over time and reaches equilibrium at the end of 20 years. As a result of the study, it was stated that the organic carbon loss mainly occurs as a result of precipitation, physical and chemical properties of the soil and changes in soil microorganisms.

Apart from the direct loss of pasture lands, it is a very common situation in the world that they lose their productivity, especially due to wrong practices. Soil carbon stocks naturally decrease in areas damaged in this way. The most damaging practice in this regard is improper grazing. Satellite observations made in Mongolia, one of the countries with the largest grasslands in the world, have shown that significant biomass losses have occurred over time. The decrease in biomass of approximately 60% as a result of observations made over a period of 21 years in almost the entire steppe region of the country is associated with decreased precipitation and increased temperature, as well as increased goat production due to the demand for cashmere products in the country and the resulting overgrazing [10].

It will be possible to increase productivity in these areas with the right rangeland management to protect and improve the rangelands. This will cause an increase in the carbon stocks of meadow pastures, which are important carbon sinks. As a result of an examination made on the data obtained as a result of many researches, it has been stated that an increase in C levels ranging from 0.105 to 1 mg per hectare is achieved annually with improved grazing management, fertilization in meadow pasture areas, enrichment of grazing lands with leguminous species and irrigation [11].

Intensive grazing increases soil organic carbon content by 6-7% in $C_4$-$C_3$ mixed pastures dominated by $C_4$ plants, while soil organic carbon content in grasslands dominated by $C_3$-plants showed an average decrease of 18% [12]. Researchers emphasized that the $C_3$ and $C_4$ dominant grasslands show such strong differences in soil organic carbon content related to grazing that the focus should be placed on this.

To assess the carbon storage potential of soils, the global effects of improved grassland management practices and conversion to pastures were evaluated by analyzing the results of 115 studies [13].

According to the results, methods such as fertilization, improved grazing management, conversion of arable land to pasture, use of natural vegetation, sowing of legumes, irrigation and earthworm incorporation were evaluated among the improved rangeland management practices and it was revealed that soil C content increased with improved management in 74% of the studies. While the increase in carbon sequestration rates continued for 40 years, it was generally highest at 10 cm soil depth. C retention rates by type of remediation range from 0.11 to 3.04 mg $C.ha^{-1}.year^{-1}$ with an average of 0.54 mg $C.ha^{-1}.year^{-1}$.

## Effect of Land Use Differences on Carbon Stocks in Forested Areas

Forests are one of the most important carbon sinks in terrestrial ecosystems in terms of both soil and biomass. Globally, about half of the carbon held on land is located in forests ($1146\times10^{15}$ g), while 2/3 of this amount is retained in soil pools [14]. Soils contribute to net carbon sequestration on a global scale, as the amount of carbon entering the soil by decomposition ($61.4\times10^{15}$ g) on an annual basis slightly exceeds the amount released by respiration ($60\times10^{15}$ g) [15].

Although soil carbon sequestration is an important phenomenon in terms of the global carbon cycle, the use of some products obtained from forests is also needed. Forestry is an important industry sector today and it is expected that changes will occur in the carbon pools of the forests depending on the different forestry practices. Cutting and spacing of trees are among them.

In a meta-analysis in which 432 data were analyzed and evaluated on a global scale, it was stated that there may be an 8±3% decrease in soil carbon after cutting and this decrease is expected to be 30±6% in litter [16]. In the study, it was stated that the decrease in the amount of carbon could be different according to tree species and the decrease in coniferous and coniferous species was around 20%, while it was around 36% in leafy species. Researchers also stated that the reduction in soil carbon may vary according to soil class. While no significant change was observed in soils with low organic matter content, it was stated that the decrease was more significant in soils with higher organic matter content. For example, while the change in alfisols and spodosols was not significant, the decrease in soil carbon content in inseptisols and ultisols was 13% and 7%, respectively.

The disappearance of forest areas causes these areas, which act as a carbon sink, to turn into carbon sources. It is claimed that 2.1 billion tons of $CO_2$ emissions occur annually due to the degradation of tropical forests, of which 53% is due to timber production, 30% to firewood and 17% to forest fire [17].

In a study conducted to measure the net annual changes in the aboveground carbon density of living vegetation on the tropical forests of the world, 12-year data between 2003 and 2014 were evaluated using MODIS satellite data and it was stated that the tropical forests of the world were carbon sources with annual net carbon emissions of 425.2±92.0 Tg [18]. In the study, the net carbon emission was found to be 861.7±80.2 Tg $C.year^{-1}$, while the gain was calculated as 436.5±31.0 Tg $C.year^{-1}$ It was stated that the carbon gains obtained were due to forest growth, while the losses were due to deforestation and the subsequent decrease in carbon density in the remaining forests. The data obtained in the study are given in Table 3 on the basis of continents.

*Table 3. Changes in aboveground carbon storage (Tg $C.year^{-1}$) in tropical forests of the world*

| Regions | Loss | Increase | Net |
|---|---|---|---|
| America | 516.0±69.5 | 191.2±18.2 | 324.8±73.5 |
| Africa | 205.0±24.7 | 132.9±19.3 | 72.1±32.9 |
| Asia | 140.7±17.9 | 112.4±10.3 | 28.2±21.5 |
| Total | 861.7±80.2 | 436.5±31.0 | 425.2±92.0 |

In forest areas, the change in soil organic carbon depending on the changes in land use is an inevitable result. However, there are many factors that affect the change in soil organic carbon stocks. For example, in a study examining the effects of conversion from forestry to plantation, it was reported that there was a very small change in soil carbon stocks in a forest with broad-leaved species, while

the reduction in carbon stocks reached 15% in an area transformed from conifers [8]. The change in soil carbon has been affected by the precipitation intensity and losses reaching 56% have been experienced in areas with precipitation over 1500 mm. Soil carbon loss in areas transformed from forest to plantation continued throughout the process and was found to be 20% and stabilized after the 40$^{th}$ year. In the results of the same study, it was stated that the loss of soil organic carbon in the lands converted from forest to agricultural land was 42% and this occurred in the first 60 cm of the soil.

In another study examining the effect of the conversion of agricultural areas to forest areas, Pinus on the formerly grain and vine cultivated areas. The results in which soil carbon storage was determined by modeling were shared by establishing radiate plantations [19]. While it was reported that organic matter accumulation occurred, mostly in the topsoil layers, during afforestation, annual carbon accumulation per square meter was given as 19 g in vine-grown areas and 41 g in grain-grown areas.

Mangrove areas, which consist of trees and shrubs in coastal areas and are important carbon sinks for the world with their carbon storage potential of up to 25.5 million tons per year [20], are also constantly decreasing. It is estimated that between 0.15 and 1.02 billion tons of carbon is emitted annually due to degradation of mangroves, swamps and seagrass meadows [21].

## Changes in Carbon Stocks Due to Urbanization

Due to increasing urbanization, changes are seen in the land cover and as a result, there are significant losses in terrestrial carbon stores. Especially in areas less affected by urban expansion, habitat losses reach higher levels. It is clear that there has been rapid urbanization on a global scale in recent years.

A study evaluating the effects of urbanized land on carbon dynamics in South America over a 63-year period between 1945 and 2007, using a process-based dynamic model was done. In this study it was calculated that the carbon emission to the atmosphere was 0.21 Pg due to urbanization during this period [22]. According to the researchers, the type of land vegetation that existed before urbanization and the time elapsed over land transformation determine the extent of the effects of urbanization on carbon dynamics. After the rapid decline in carbon storage during land conversion, an urban ecosystem gradually accumulates carbon and can compensate for the initial carbon loss in 70-100 years. According to the researchers, the carbon sequestration rate of the urban ecosystem decreases over time and almost disappears after two centuries.

In another study that tried to determine the effect of rapid urbanization on terrestrial carbon resources, the effect of land use changes on carbon sinks and emissions from 2000 to 2012 in Guangzhou, China was analyzed [23]. Urbanization in the city of Guangzhou increased by 119% during the study period and carbon emissions significantly exceeded their carbon sink capacity. While the decrease in the total carbon sink was 30%, the total carbon emissions increased from $13.73\times10^6$ tons to $39.67\times10^6$ tons. Researchers warned that "urban growth limit" and "ecological red lines" should be determined for land use in state policies in order to ensure the economic use of land.

The emission of carbon to the atmosphere by keeping it in the oceans and terrestrial ecosystems has become very important today. Land use is of great importance in terms of carbon sequestration in soils. Grasslands and forests generally have higher carbon sequestration potential than arable land. Avoiding land use changes that will increase net carbon emissions in terrestrial areas will become increasingly vital for the control of global warming.

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# EFFECTS OF SOIL PROPERTIES ON GREENHOUSE GAS EMISSIONS

The increasing population and the related increase in people's demand for food and energy have brought along important environmental problems. Global warming, which occurs with the increase of greenhouse gases in the atmosphere, is one of these problems. Although the increase in greenhouse gas rates in the world's atmosphere is largely due to activities in the energy sector, there are also significant emissions into the atmosphere related to agriculture, forestry and land use. Emissions as a result of agricultural activities $CO_2$, $CH_4^-$ and in the form of $N_2O$ gases.

After the settled life and agriculture started, soils became one of the main sources of atmospheric $CO_2$ and other greenhouse gases. It is estimated that the greenhouse gas emission from the soil to the atmosphere since the industrial revolution is 78±12 Pg $CO_2^-C$ [1].

However, terrestrial ecosystems are in the position of a pool in terms of carbon, since carbon can be held both in biomass and directly in the soil. Emissions from soils to the atmosphere and retention of carbon in soil and biomass can be affected by some soil properties.

## Greenhouse Gas Emissions Due to Soil Organic Carbon Content

One of the most important problems encountered in many areas of agriculture is the low levels of soil organic matter, which is one of the main components of the sustainability of agriculture. In areas with intensive agriculture, there is a decrease in soil organic matter content over time due to reasons such as monoculture cultivation, excessive tillage, burning of remaining plant residues. Increasing carbon content in agricultural areas can increase soil fertility and biodiversity and thus contribute to climate change mitigation by sequestering carbon from the atmosphere [2].

Adding various organic materials to the soil and regaining the lost carbon is one of the recommended practices to improve soil properties and even combat climate change. However, adding these materials to the soil can facilitate the release of $CO_2$. For this reason, it is important to know what the expected effect is from the organic material added to the soil, to know the carbon holding capacity of the soil and to know the soil carbon balance status for the short and long term after the application. Therefore, the goal should be to increase the biologically stabilized soil organic matter in the long term in accordance with environmental conditions [3].

Soil organic carbon is an important component of the global carbon cycle (Figure 1), and its presence in soils will have a significant impact on the global climate with which it interacts in the future [4]. This effect is complex and may differ according to soil properties. For example, since the microbial activity will be higher in soils with high temperatures, the decomposition of organic matter accelerates and this causes an increase in the release of $CO_2$ and $CH_4$ into the atmosphere. On the other hand, increased carbon sequestration can encourage more plant vegetation.

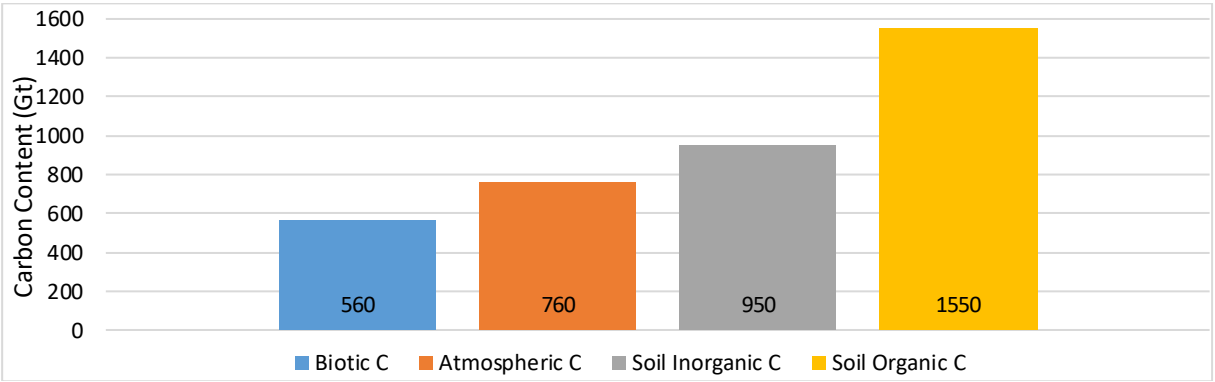



*Figure 1. Carbon content of soil, atmosphere and biota (adapted from Lal, 2004 [34])*

There are two basic approaches that are commonly used to reduce the amount of $CO_2$ in the atmosphere. The first of these is the reduction of emissions and the other is carbon sequestration. Soil plays an important role in both cases. Carbon sequestration means that $CO_2$ in the atmosphere is taken by plants through photosynthesis and transferred to the soil [5]. Soil organic matter content can be increased by mixing plant residues into the soil. Increasing carbon stocks in the soil means supporting the processes that form stabilized organic compounds. If the impact of global warming is to be reduced, supporting carbon sequestration by soils, which is the largest terrestrial carbon pool, will undoubtedly be an important strategy [3].

## Carbon Storage and Soil Conditions

Increasing the organic matter content by adding organic material to the soil may vary depending on the soil properties and the type of material, apart from the amount of added material. Organic matter added to soils does not always mean that carbon is stored in the soil. For example, grassland and forest soils with good drainage conditions can store significant amounts of carbon, while arable land can be a source of carbon [32, 33].

The carbon storage capacities of soils are not unlimited and may differ depending on the soil type. In mineral soils, the presence of clay and silt particles increases the stability of soil organic carbon through adsorption, but its amount is limited [6].

## Soil Aggregate Size on Greenhouse Gas Emissions

Depending on the aggregate size in soils, there may be differences in gas transport and emissions. In a study conducted for this purpose, the effect of soil aggregate size on greenhouse gas emissions was compared in two soils with sandy loam and clayey loam texture [7]. Soils with aggregate sizes of less than 0.5 mm, 0.5-1 mm, 1-2 mm and 2-4 mm were used in the study. According to the results obtained, pore sizes significantly affected the release of $CO_2$ and $CH_4$ from the soil, but did not show any effect on the release of $N_2O$. The highest $CO_2$ emission occurred in clayey loam textured soil with the smallest aggregate size. On the other hand, in soils with sandy loam texture, the highest $CO_2$ release occurred in soils with the largest aggregate size. In the study, it has been reported that there are increased $CH_4$ flows in soils with small aggregates. As a result of their study, the researchers stated that tillage practices, which greatly affect the pore properties of soils, may have a direct effect on greenhouse gas emissions. It has been reported that $CO_2$ emission decreases with increasing aggregate size in a clay loam soil [8], whereas $CH_4$ release is higher in soils with small aggregate size [9].

## Soil pH on Greenhouse Gas Emissions

Soil pH is an expression that represents the amount of $H^+$ ions in the soil solution that is in dynamic equilibrium with a negatively charged solid phase. $H^+$ ions, which are strongly attracted to negatively charge solid surfaces, can replace other cations present there. pH, which is closely related to soil and plant biochemical processes, is the pH of the soil solution [10].

There are different ideas related to the soil pH on greenhouse gas emissions. pH, which has an important effect on the physical, chemical and biological properties of the soil, inevitably also affects the carbon flow in the soil [11]. Alkaline soils have a significantly higher $CO_2$ content and the organic carbon in these soils is not very chemically stable for mineralization. Addition of calcium agents to the soil can alter soluble organic carbon concentrations and stimulate a limited soil organic carbon mineralization [12].

In a study with acidic tropical forest soils, the pH of the soil was increased from 3.9 to 5.7 by adding $Ca(OH)_2$ and $CaSO_4$ and as a result, it was understood that the mineralization of carbon in organic fertilizer was supported [13]. Contrary to what has been reported, in a different study, it was found that soil respiration decreased and organic carbon accumulation in the soil was promoted due to the

increase in pH as a result of calcium addition in organic tundra soils [14]. Researchers stated that more studies should be done in natural ecosystems to elucidate the effect of calcium-induced pH changes on soil organic carbon.

In a study examining the effects of soil pH on long-term $CO_2$ emissions, emission measurements were made in soils with pH values of 3.65, 5.00, 6.90 and 8.55 [15]. In the study, the subjects in which nitrogen fertilizer was not applied and the subjects that the fertilization was made in the form of nitrate and ammonium were combined with plots at different pH values. According to the results obtained, the $CO_2$ emissions were not affected by ammonium and nitrate fertilization at different soil pH values. With the nitrogen fertilizer applications, the amount of dissolved organic carbon decreased at all pH values. Researchers reported pH increase and nitrogen fertilization increases $CO_2$ emission and heterotrophic microbial respiration in soil plays a dominant role in $CO_2$ emissions.

## Soil Moisture and Greenhouse Gas Release from Soil

While plant growth in non-irrigated areas is limited by the available soil moisture, an increase in above-ground parts and root development occurs with irrigation. This situation also increases the carbon entry into the soil. By fertilizing and irrigating arable lands and pasture lands, carbon entry into the soil is increased. With the increase in soil moisture, the microbial activity also increases. As a result of both the increase in biomass and the increase in carbon input and the increase in microbial activity, the acceleration of the decomposition process of organic carbon also increases the $CO_2$ release from the soil [16].

In a study examining the effect of restricted irrigation on greenhouse gas emissions by years where a drip irrigation system is used, the highest $CO_2$ emission values were obtained in the area with the most irrigation and the emission values measured after irrigation were higher than the values measured before irrigation [31]. Similar results were obtained in terms of $N_2O$ emission values measured in the study and the highest emission values were achieved in the subject with the most irrigation. $N_2O$ values after irrigation were higher than before irrigation, as were $CO_2$ values. As a result of the study, the researchers stated that irrigation practices significantly increased greenhouse gas emissions. However, in limited irrigation applications, lower $CO_2$ emission has been seen due to the slowdown of microorganism activities [17].

While gas emissions from the soil are affected with the amount of irrigation water applied, there may be changes in the amount of emissions related to the quality characteristics of the water used in irrigation too. Salinity value of irrigation water is another parameter that effects the emission rates. In a study conducted with irrigation waters with different salinity rates, the effect of salts on soil organic carbon mineralization was investigated by monitoring the amount of $CO_2$ emission from the soil [18]. According to the results obtained, it was observed that the rate of formation of $CO_2^-C$ decreased with the increase in the salinity of the irrigation water. In addition, according to the researchers, when the salt source is NaCl, the decrease in carbon mineralization is higher than when it is of $CaCl_2$ and $MgCl_2$.

## Soil Temperature and Greenhouse Gas Emission from Soil

Soil temperature can be effective in the emission of greenhouse gases due to its effects on microbial activity along with moisture. Under favorable soil temperature conditions, $CO_2$ release increases due to the oxidation of organic matter [19]. An increase in soil temperature accelerates organic matter decomposition, increases microbial activity and root growth and as a result accelerates the carbon mineralization process and $CO_2$ emissions increase [20].

In a study the effect of soil temperature and moisture on the concentration of $N_2O$ and $CO_2$ in an organic soil from two different depths were investigated [21]. According to the results obtained in the study, $N_2O$ concentration increased in parallel with the increase in soil moisture at a depth of 10-30

cm. $CO_2$ concentration in soil increased with the increase in soil temperature. This increase occurred both at a depth of 10-30 cm and at a depth of 50-100 cm.

Similarly, in another study, it was noted that $CO_2$ emission increased with the increase in soil temperature and the rate of increase reached 59% [20].

However, since the microbial activity in the soil can be active between certain temperature values, it has been reported that a linear relationship cannot always be obtained between $CO_2$ emissions and the soil temperature [22].

## Changes in Greenhouse Gas Emissions Related to the Tillage

As a result of tillage practices, there can be significant changes in greenhouse gas transfers between the atmosphere and the soil. Greenhouse gas emissions arising from tillage can be caused by the use of fossil fuels consumed by the vehicles used directly, as well as the effects it has on soil properties.

Although the effects of no-till agriculture, especially on erosion control are now considered fundamental, scientists continue to discuss the effectiveness of no-till practices in reducing $CO_2$ emissions today. It is noteworthy that in many studies, different results have been obtained depending on soil, environmental characteristics and time.

Tillage can affect the distribution and conversion of soil carbon content by opening or closing new transfer channels between the soil surface and the atmosphere. In addition, changes in some soil properties such as aggregate stability, water holding capacity and temperature as a result of tillage can change the decomposition dynamics of organic matter [23].

Four different applications were compared in a study aiming to determine the possible effects of reduced tillage practices on $CO_2$ emissions from soils [24]. These applications are 12 cm deep tillage with chisel plow, 5 cm deep tillage with chisel plow, mulching of straw on the surface and fallow land. Tillage with chisel plow at a depth of 10-12 cm in the summer period has increased $CO_2$ emission about 2 times compared to other applications. This application was followed by shallow (5 cm deep) tillage, mulching and fallow land respectively.

In a study comparing the effects of direct sowing with traditional tillage on $CO_2$ emissions, soybeans were grown by direct sowing vs cultivating the soil with chisel, disc harrow and cultivator and $CO_2$ emissions from the soil have been measured for 55 days. As a result of the study, it was determined that the lowest emission occurred in direct sowing application [25].

With a meta-analysis evaluating 56 studies targeting $CO_2$ emissions directly from the soil, it was aimed to reveal the status of emissions from no-till and conventional tillage practices [26]. The researchers summarized their findings as follows:

Soil $CO_2$ emissions were found to be almost twice as high in the first hours after tillage compared to uncultivated soils. The variability of the $CO_2$ emissions from soil was associated with soil texture, crop rotation, time and soil organic carbon content rather than tillage practices. Emission reduction in no-till applications has been realized especially in clay textured soils where crop rotation is performed, soil carbon content is low and in arid climate conditions. According to the results obtained by the researchers, the effect of no-till applications on $CO_2$ emissions is open to debate and that the reduction of emissions mostly occurs under certain soil and environmental conditions.

In order to measure and evaluate the effect on soil $CO_2$ emissions, the results of 46 studies conducted in different climate and soil conditions were evaluated with a meta-analysis and it was noted that the effect of tillage on soil $CO_2$ emissions was inconsistent [27]. According to the findings obtained, the researchers stated that, on average cultivated soils emit 21% more $CO_2$ than uncultivated soils. It has been stated that this difference increases to 29% in sandy soils where soil moisture and carbon content are low in arid climate conditions. However, it has also been reported that there is no difference in emission related to the tillage type in clay soils with high soil organic carbon content. According to the

researchers, it has been noted that no-till farming can be an effective measure in reducing $CO_2$ emissions from soils in arid conditions.

Mulching is one of the effective applications on carbon sequestration and this effect may vary depending on the soil properties and the application time of the mulch material. Mulching helps reduce the negative effects of climate change by offsetting greenhouse gas emissions and increasing organic carbon sequestration in soil [1]. However, continued residue addition can bring soils to carbon saturation level, resulting in a situation where greenhouse gas emissions from soils exceed the amount of carbon sequestration [28].

In a study in which mixing plant residues to the soil was compared with the mulch application, two different soil types were used and carbon in the upper soil layer was monitored [30]. According to the results of the study carried out for two years, the mixing of corn residues to the soil in clay soils caused $CO_2$ flow to increase 38% compared to mulching, this increase was 16% in sandy soils. Soil moisture content was maintained and the decomposition of organic carbon on the soil surface increased when mulching is used in sandy soils. Therefore, researchers pointed out that mulching may deplete soil carbon stocks in sandy areas in the long run.

In another study, wheat straw used as mulch material was applied as 0, 8 and 16 mg per hectare every year [29]. In this study, 244 kg N application per hectare and no nitrogen application was combined with mulch applications. At the end of the 15-year trial, important findings were obtained, some of which are as follows:

With long-term mulch applications, there was an increase in the macro aggregates, especially those larger than 250 µm, in the soil. This increase was largely due to mulch applications. This caused the accumulation of high carbon and nitrogen concentrations in macro aggregates. In the study, it was stated that the carbon in the micro aggregates was relatively preserved, whereas the carbon in the macro aggregates and between the micro aggregates was not stabilized and was prone to microbial decomposition. Increasing carbon and nitrogen concentrations of macro aggregates significantly affected $CO_2$, $CH_4$ and $N_2O$ flows and higher emission values were measured in mulch applications. Compared to the control, soil organic carbon concentration in the first 10 cm depth in soil increased by 32% and 90% with 8 and 16 mg mulch applications, respectively and approached soil organic carbon capacity with 15 years of mulch applications. Finally, the global warming potential was calculated in the study and the results are given in Table 2 as $CO_2$ equivalent. Accordingly, with the annual 16 mg mulch application, higher greenhouse gas flow was realized and the highest net global warming potential value was calculated.

*Table 2. Global warming potential calculated on a yearly basis (adapted from Lenka & Lal, 2013 [29])*

| **Amount of Mulch ($mg.ha^{-1}.year^{-1}$)** | **Global Warming Potential ($mg.ha^{-1}$ $CO_2^-C$ equivalent)** | **Net Global Warming Potential ($mg.ha^{-1}$ $CO_2^-C$ equivalent)** |
|---|---|---|
| no nitrogen applied | | |
| 0 | 5.85 | - |
| 8 | 6.56 | 0.46 |
| 16 | 8.43 | 1.98 |
| with an application of 244 $kg.ha^{-1}$ N | | |
| 0 | 6.31 | - |
| 8 | 7.18 | 0.57 |
| 16 | 10.09 | 3.05 |

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# GREENHOUSE GAS EMISSIONS FROM FERTILIZER USE

A significant portion of greenhouse gases that cause global warming are released into the atmosphere as a result of agricultural activities. The amount of greenhouse gas emissions due to agricultural activities and land use on a global scale has reached 9.3 Gt $CO_2$ equivalent as of 2018 [1]. While the amount of emissions based on plant and animal production was 5.3 Gt $CO_2$ equivalent in 2018, this amount increased by approximately 14% when compared to 2000.

Greenhouse gas emissions originating from agriculture mostly consist of methane ($CH_4$) and nitrous oxide ($N_2O$) gas. The highest greenhouse gas emission among agricultural activities is enteric It occurs as a result of fermentation and its ratio in all agricultural activities is close to 48%. One of the most important agricultural inputs in plant production is fertilizers and due to fertilizers, there is a significant greenhouse gas emission to the atmosphere. 10% of the gases emitted to the atmosphere due to agricultural activities were realized through synthetic fertilizers in 2020 [2]. Apart from chemical fertilizers used in agriculture, animal manures also have an important share as an emission source. In Table 1, the amount of greenhouse gas emissions originating from agriculture worldwide in 2020 is given.

*Table 1. Distribution of Agricultural Greenhouse Gas Emissions in 2020 on a Global Scale*

| Emission Source | Amount of Emission (kiloton of $CO_2$ equivalent) | % |
|---|---|---|
| Enteric fermentation | 2.849.716 | 47.60 |
| Animal manure left in the pastures | 772.541 | 12.91 |
| Rice cultivation | 686.111 | 11.46 |
| Synthetic fertilizers | 625.107 | 10.44 |
| Animal manure use and management | 399.815 | 6.68 |
| Burning of savannas | 211.921 | 3.54 |
| Agricultural product residues | 191.540 | 3.20 |
| Animal manure applied to the soil | 165.093 | 2.76 |
| Cultivated organic soils | 46.996 | 0.79 |
| Burnt agricultural product residues | 37.387 | 0.62 |
| TOTAL | 5.986.227 | 100.00 |

There is a general increase in greenhouse gas emissions to the atmosphere over the past years. This situation is also valid for greenhouse gas emissions originating from agricultural production and emission rates have increased over the years depending on the activities carried out. However, the increase in emissions from agriculture due to the use of chemical fertilizers has reached much higher rates. Table 2 shows the greenhouse gas emissions of some agricultural activities over the years. In the 60-year period, the rate of increase, which was around 40-50% according to the activity, was realized at a rate approaching 10 times in the same period for synthetic fertilizers. In addition, as it can be understood from the Table 2, a significant amount of greenhouse gas emissions occurs during the production of these fertilizers, apart from the use of fertilizers.

*Table 2. Changes in Agricultural Greenhouse Gas Emissions over the Years*

| Emission Source | Emission Amount (kiloton of $CO_2$ equivalent) | | | | | | | Rate of Change (%)* |
|---|---|---|---|---|---|---|---|---|
| | 1961 | 1970 | 1980 | 1990 | 2000 | 2010 | 2020 | |
| Enteric Fermentation | 1829661 | 2069925 | 2320767 | 2493671 | 2473802 | 2654500 | 2849716 | 56 |
| Rice Cultivation | 487941 | 560752 | 609831 | 620854 | 653281 | 682752 | 686111 | 41 |
| Fertilizer Applied to Soil | 109013 | 122615 | 144580 | 156499 | 145270 | 156386 | 165093 | 51 |
| Synthetic Fertilizers | 63209 | 174069 | 334374 | 425288 | 446178 | 559822 | 625107 | 889 |
| Fertilizer Production | | | | 152687 | 225708 | 361709 | 389142 | 155 |

**Change rates are based on the amounts realized in 2020 compared to 1961 (as there is no data for 1961 in fertilizer production values, 1990 is based on)*

## Mechanism of Greenhouse Gas Release to the Atmosphere by Fertilizers

Agricultural greenhouse gas emissions mainly consist of nitrous oxide ($N_2O$) from fertilization and methane ($CH_4$) gas from cattle breeding. As shown in Figure 1, although $N_2O$ and $CH_4$ gases are less common in the atmosphere compared to $CO_2$ gas, they have higher global warming potentials. In the Global Climate Change Panel, it has been stated that the unit masses of $CH_4$ and $N_2O$ gases have a global warming potential of 25 and 298 times more respectively, compared to $CO_2$ gas for a period of 100 years [3]. It is predicted that the emission of greenhouse gases originating from agriculture to the atmosphere has increased significantly in recent years and if no measures are taken, the amount of $N_2O$ in the atmosphere will increase by 35-60% and the amount of $CH_4$ by 60% by 2030 [4].

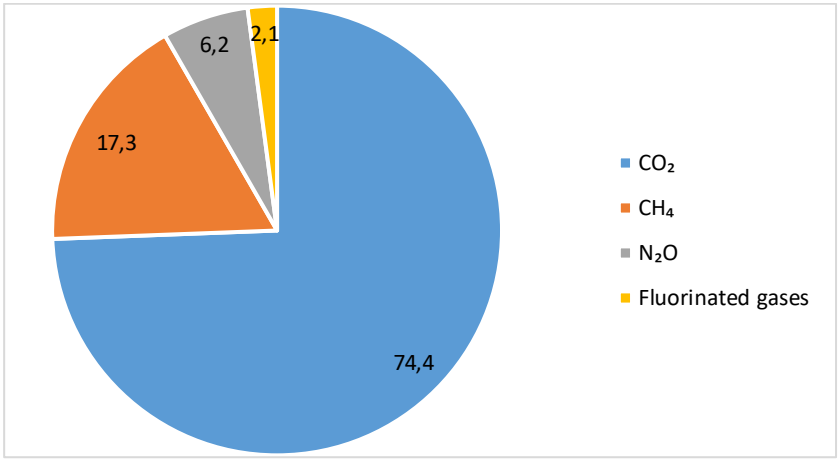



*Figure 1. Global greenhouse gas emission rates (adapted from Ritchie et al. 2020 [5]).*

Nitrous oxide molecules can stay in the atmosphere for an average of 114 years [3]. Globally, the majority of $N_2O$ emissions enter the atmosphere naturally, but about 40% are caused by human activities [6]. Human-induced $N_2O$ emissions are largely released into the atmosphere by agricultural activities (Figure 2). Nitrogen fertilizer use in agricultural activities has a great effect on $N_2O$ emission.

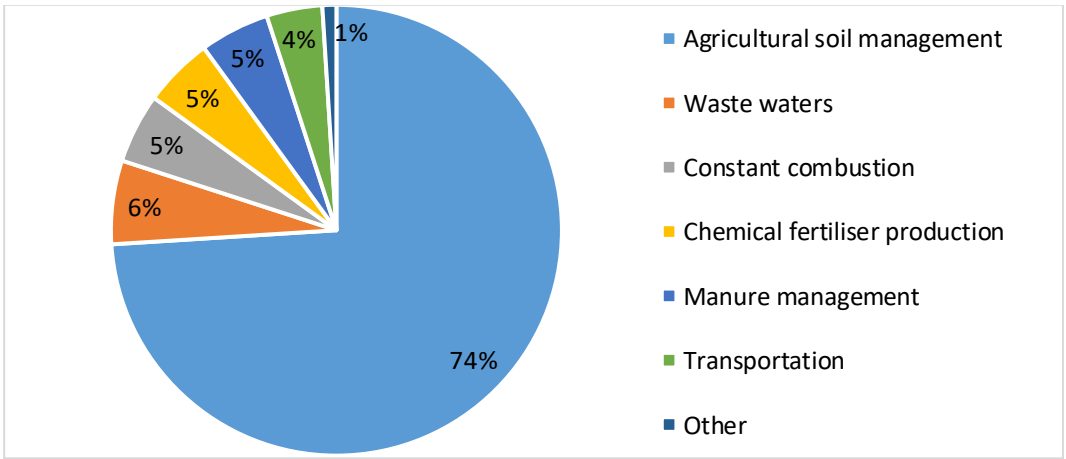



*Figure 2. $N_2O$ emission sources in 2020 [7]*

The two main ways $N_2O$ is produced in agricultural soils are nitrification and denitrification. The conversion of ammonium to nitrate ions by some microorganisms in the soil is defined as nitrification. Nitrification takes place in the presence of oxygen. Denitrification is the reduction of nitrate to free nitrogen gas ($N_2$) after various processes. In this process, although the conversion of nitrate to $N_2$ gas is usually complete, a small and variable amount of nitrogen is released into the atmosphere in the form of $N_2O$ gas [8]. Nitrification and denitrification events are tried to be summarized in Figure 3.

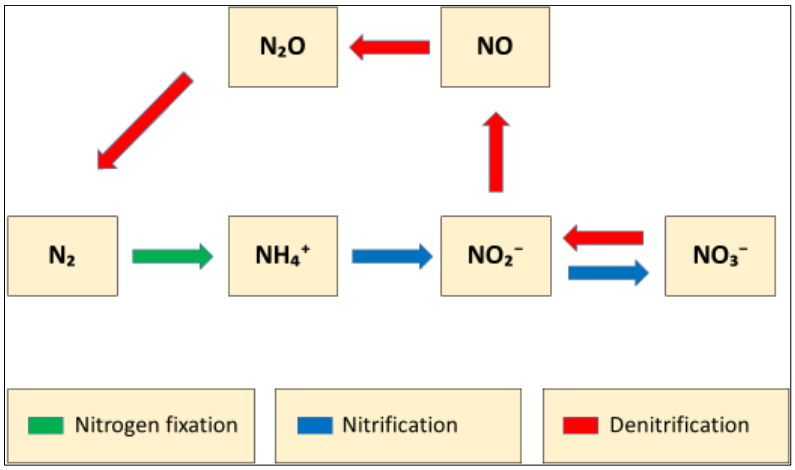



*Figure 3. Schematic representation of the nitrogen cycle (adapted from Tilstra, et al. 2019 [9]).*

Nitrogen gas emission from the soil to the atmosphere can occur directly in the form of $N_2O$ emission and have a radiative effect, as well as through nitrogen emissions such as $NO_2$ and NO (together called NOx) and other greenhouse gases such as ozone ($O_3$) and methane ($CH_4$). It has an indirect effect by affecting the atmospheric concentrations of the gases [10]. Ozone gas, which is a strong oxidant, can cause some problems in plant growth. In plants exposed to ozone gas for a long time, carbohydrate production decreases [11], and sensitivity to diseases and pests increases [7].

Unlike other nitrogen fertilizers, when urea fertilizer is applied to the soil, the $CO_2$ added in the industrial production process is released. Urea ($CH_4N_2O$) turns into ammonium ($NH_4^+$), hydroxyl ($OH^-$) and bicarbonate ($HCO_3^-$) ions in the presence of water and urease enzymes. The $HCO_3^-$ formed as a result of the reaction is separated into $CO_2$ and $H_2O$, which form itself after lime is added [12]. In this way, the $CO_2$ release from the soil is at lower levels compared to the $N_2O$ release from nitrogen fertilizer applications [8].

## Greenhouse Gas Emissions from Synthetic Nitrogen Fertilizers

Fertilization is the first method used to increase productivity in crop production. Nitrogen, the nutrient element that limits plant growth the most, is an indispensable element of continuity and productivity in plant production. Nitrogen fertilizers are among the most used fertilizers globally. Annual nitrogen fertilizer production is estimated to be around 100 Tg N on a global scale [13].

However, nitrogen fertilizers can cause some serious environmental problems if they are not used carefully. Nitrate pollution in groundwater is one of these problems. Another important problem is the emission of nitrogenous fertilizers into the atmosphere by turning into $N_2O$ gas, which plays an active role in global warming, as a result of denitrification after the application. A very small portion (0.5-3.0%) of the nitrogen applied to agricultural fields is actually released into the atmosphere as $N_2O$ [14, 15], but its effect is very strong due to its high global warming potential and its ability to stay in the atmosphere for a long time. When evaluated in terms of global warming potential, each 1 kg of N input applied to the soil corresponds to 1.4-14.0 kg of $CO_2$ and is accepted as an average of 4.65 kg of $CO_2$ [12].

$N_2O$ released into the atmosphere due to the use of nitrogen fertilizers is the largest human source of $N_2O$ [16]. Greenhouse gas emissions have increased approximately 10 times due to the use of synthetic fertilizers since 1961 (that is the start of when we can access data on a global scale related to this). Greenhouse gas emissions from synthetic fertilizers account for about 11% of total emissions from agriculture [2]. A significant amount of these emissions come from the Asian continent (Figure 4).

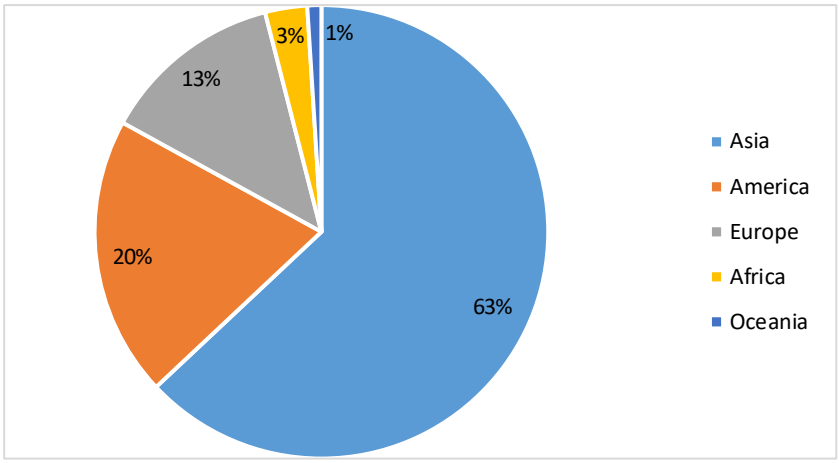



*Figure 4. $N_2O$ emission ratios from synthetic fertilizers in 2001-2011 by continents [17].*

China is the largest producer and consumer of nitrogen fertilizers in the world. About 7% of all greenhouse gas emissions in China come from the production and use of nitrogen fertilizers [18]. Greenhouse gas emissions from the use of synthetic nitrogen fertilizers account for approximately 55% of agricultural emissions in China and synthetic nitrogen fertilizer applications are considered to be the most important factor contributing to $N_2O$ emissions from agricultural soils [19]. For this purpose, researchers tried to determine the amount of greenhouse gas emissions caused by the production and application of synthetic nitrogen fertilizers for wheat and corn, which are important agricultural products of China, with a modeling method. Accordingly, annual synthetic nitrogen fertilizer consumption for wheat and corn is reported as 12.63 Mt. The greenhouse gas emissions associated with the production of synthetic nitrogen fertilizers across the country are given as 41.44 Mt $CO_2$ equivalents for wheat and 59.71 Mt for corn. As a result of the application of nitrogen fertilizers, $N_2O$ release into the atmosphere was estimated at 35.82 and 69.44 Gg $N_2O$ $year^{-1}$ for wheat and corn, respectively.

One of the most important problems encountered worldwide in the management of synthetic nitrogen fertilizers is the application time of the fertilizer. The main thing in fertilization is to prepare nitrogen in the soil when the plant needs it. Otherwise, nitrogen in excess of the plant need will be lost in the form of $N_2O$ emission or washed down in to soil. Adjusting this, is a complicated issue especially in plants such as corn, where the nitrogen requirement is very low in the first period of vegetation, but this need increases greatly in the later stages [10]. Giving nitrogen fertilizers during periods when plants are not planted yet or when their requirements for vegetation are very low can lead to loss of a large amount of nitrogen.

## Some Environmental Factors Affecting Greenhouse Gas Release from Fertilizers

Nitrous oxide in soils is affected by various environmental factors. The amount of $N_2O$ formed depends on the amount of oxygen in the soil voids and the reaction direction depends on the temperature. In low temperature conditions, the conversion of nitrogen compounds slows down, while the rate of conversion increases with increasing temperature. As the water saturation ratio increases in soils, $O_2$ concentration decreases. Another factor affecting $N_2O$ release from agricultural soils is the amount of ammonium ($NH_4^+$) that can be used for nitrification and the concentration of nitrite ($NO_2^-$) to be used in denitrification. In addition, in light textured, neutral or slightly acidic soils, $N_2O$ release increases with the presence of $NO_3$ nitrogen in the environment [8].

In a study, it was tried to determine the effects of synthetic and organic fertilizers on greenhouse gas emissions in soils with different soil structures [20]. For this purpose, greenhouse gas flows were measured for 8 weeks by applying urea ammonium nitrate (UAN) fertilizer and liquid pig manure in

two different soils with sandy loam and clayey texture. It has been revealed that $N_2O$ and $CH_4$ gas emissions in urea ammonium nitrate and pig manure applications are higher in sandy loam soil than in clay soil. It is thought that the amount of emission is less since, high cation exchange capacity and increased adsorption of $NH_4^+$, reduces the presence of nitrogen. In addition, it was stated that the higher water-filled pore volume in sandy loam soil may have supported denitrification and methane production compared to clay soil.

Emissions due to the application of nitrogen fertilizers can vary depending on the soil and the properties of the fertilizers used, as well as the composition and amount of soil microorganisms. In a study on this subject, it was desired to determine the possible effects of different nitrogen fertilizers on greenhouse gas emissions in different soil, plant and microorganism interactions [21]. In the study, three different fertilizer types were tested on two different soils with different properties in barley cultivation. Overall, the results showed that fertilization strongly increased plant respiration, resulting in higher $CO_2$ emission levels and as a result of increased root secretion, higher microbial activities were detected. At the end of the study, it was emphasized that the evaluation of soil microorganism structure is of primary importance while examining the effect of nitrogen fertilization on soil-induced global warming potential. Particular emphasis was placed on the contribution of bacterial and archaeal ammonia oxidizers to $N_2O$ emissions. Since $N_2O$ emissions may increase as a result of nitrification, it has been pointed out that it is important to determine the optimum ratios of $NH_4^+$ ions to $NO_3^-$ ions and to use nitrification inhibitors while fertilizing.

## Effects of Fertilizers with Increased Efficiency on Emission Reduction

Increasing the effectiveness of fertilizers, both minimizing possible losses in the soil and enabling plants to benefit from the nutrients they contain at a higher rate has been a method that has been started to be preferred in recent years. These fertilizers, which are generally called as productivity-enhanced fertilizers, are defined by the Association of American Plant Food Control Officials (AAPFCO) as "fertilizer products with properties that increase plant uptake and reduce nutrient loss" [22]. Different methods such as coating, encapsulation and inhibitor addition are used in such products, which aim to increase the efficiency of nitrogen fertilizers. In this way, it is possible to spread the nitrogen release over a wide period and the losses are minimized.

Slow and controlled release fertilizers and inhibitor added fertilizers have higher nitrogen utilization efficiency and have the potential to reduce $N_2O$ emissions from fertilization. Some of the results presented by Halvorson et al. [23], who compiled their studies on this subject at different times, are given below. Studies are done in irrigated farming conditions and on corn plant cultivation:

A controlled release polymer-coated urea reduces $N_2O$ emissions by 42% compared to urea and 14% compared to urea ammonium nitrate fertilizer (UAN) in no-tillage and minimum tillage environments, there was no difference in emission values under conventional tillage conditions. The application of inhibitory urea fertilizer decreased the $N_2O$ emission value by 46% compared to normal urea and by 21% compared to urea ammonium nitrate.

In the application of inhibitory urea ammonium nitrate (UAN) fertilizer, the emission value decreased by 61% compared to normal urea and by 41% compared to urea ammonium nitrate fertilizer.

In a study using a slow-release UAN source, the decrease in $N_2O$ emissions was found to be 57% for urea and 28% for UAN.

In a study conducted in the central regions of China, the effects of nitrogen fertilizer sources on greenhouse gas emissions in rice fields were tried to be determined [24]. For this purpose, a control plot without fertilizer (N0), only inorganic fertilizer application (IF), only organic fertilizer application (OF), mixed application of inorganic fertilizer and slow-release fertilizer (SRIF) and mixed application of inorganic and organic fertilizer (OFIF) topics are compared. According to the results obtained in the study, nitrogen fertilizer sources significantly affected $CH_4$ and $N_2O$ emissions. Compared with the

control (N0) implementation, the IF, SRIF, OF and OFIF increased $CH_4$ emissions by 55%, 42%, 51% and 66% and $N_2O$ emissions by 165%, 93%, 130% and 251% respectively. As a result of the study, the researchers suggested that the application of chemical fertilizers together with slow-release fertilizer is a sustainable strategy to increase rice production and reduce greenhouse gas emissions, but the high fertilizer costs that arise should be subsidized by public institutions.

## Greenhouse Gas Emissions During Fertilizer Production

Haber-Bosch's technique for the production of ammonia ($NH_3$) using nitrogen (N) and hydrogen (H) is the primary method of nitrogen fertilizer production in the world and this method requires high temperature and high energy [25]. It is estimated that approximately 1.2% of the energy used in the world is consumed during fertilizer production also same rate (1.2%) of the total greenhouse gas emissions are produced [26]. During the production of ammonia, approximately 1250 $m^3$ of natural gas is required for 1 metric ton of anhydrous ammonia [27]. Production of ammonia and urea, are among the major sources of $CO_2$ emissions from human activities. Therefore, depending on their use, fertilizers not only emit greenhouse gases, but also release a significant amount during their production. The amount of greenhouse gases released into the atmosphere during fertilizer production globally in 2020 has been reported as 389142 Kilotons of $CO_2$ equivalent [2].

Greenhouse gas emissions from fertilizer production varies greatly depending on the type of fertilizer used and the production technology. Considering the complex processes in the production phase, it is clear that the calculation of emission data will be difficult and limited. Life Cycle Assessment (LCA) is a widely used method to reveal emissions. This evaluation is an application that calculates the results of all activities carried out during the production phase that have a direct or indirect effect on living life and is defined as an ecological indicator. In this assessment, the environmental impacts of products and processes are thoroughly analyzed, i.e. emissions from production and application are included. Emission factors provide a convenience that does not require detailed emission calculations in the Life Cycle Assessment [28]. An emission factor is the typical amount of greenhouse gases released into the atmosphere per unit activity. Researchers conducted a study in which they compiled published emission factors related to nitrogen, phosphorus and some compound fertilizer production to be used as inputs in greenhouse gas balance calculations. Some of the results given in this study are tried to be summarized in Table 3. The main greenhouse gases that occur during the production of nitrogen fertilizer are $CO_2$, which is formed as a result of the burning of natural gas used in the synthesis of ammonia and $N_2O$, which is released during the production of nitric acid. $CO_2$ emitted due to the use of fossil fuels during the production of phosphorus fertilizers and $CO_2$ emitted during the transportation of raw materials have been the main greenhouse gases in production.

When Table 3 is examined, it can be seen that there are significant differences between different studies in terms of emission factors for each fertilizer product. It has been reported that these differences are due to plant differences, emission control mechanisms and differences in raw material inputs.

In a study examining greenhouse gas emissions arising from the production and use of inorganic and organic fertilizers, more than 200 articles were selected from among many original studies and the results were shared [33]. In the study, emission factors were evaluated during fertilizer production. In the production of synthetic nitrogen fertilizers, depending on the type of fertilizer and the hydrogen source used during production, the emission factor has been reported to vary between 1 to 10 kg $CO_2$ equivalents per 1 kg N while the emission factor reported for phosphorus fertilizer production varies between 1-1.5 kg $CO_2$-eq.$kg^{-1}$ $P_2O_5$. It is stated that there is insufficient information about emissions from potash fertilizer production. Researchers have generally emphasized that there are variations in emission factors due to differences in raw materials and application differences between countries.

The emissions generated during compost production varied in a wide range. The emission factor for one ton of solid waste has been reported as 1-2300 kg $CO_2$ equivalent. Emissions from transport have generally been found to be very low for all fertilizer types

It has been reported that organic fertilizers have high emissions, especially during long-term storage. It has been stated that while the $CH_4$ emissions decrease during the storage of liquid organic wastes or fertilizers, there is an increase in $N_2O$ emissions. Emissions from the storage of synthetic fertilizers or compost have been reported to be negligible, but it has also been stated that there is little data on the storage of compost.

*Table 3. GHG emission factors of some fertilizers (adapted from Wood & Cowie, 2004 [28])*

| Product | Country | Contents | g $CO_2$ equivalent | | | | | Source |
|---|---|---|---|---|---|---|---|---|
| | | N:P:K | (kg) N | (per kg) $P_2O_5$ | (per kg) $K_2O$ | (kg per) Product | $CO_2$:$N_2O$:$CH_4$ | |
| AN | European average | 35.0:0:0 | 7031 | - | - | 2461 | 39.6:59.5:0.9 | [29] |
| AN | Holland | 33.5:0:0 | 7109 | - | - | 2381 | 38.5:60.9:0.5 | [30] |
| AN | United Kingdom | 33.5:0:0 | 6537 | - | - | 2190 | 29.1:69.7:1.2 | [31] |
| CAN | Sweden: | 27.6:0:0 | 8467 | - | - | 2337 | 38.3:60.9:0.8 | [29] |
| CAN | European avg. | 26.5:0:0 | 7482 | - | - | 1983 | 39.8:60.6:0.9 | [29] |
| Urea | European avg. | 46:0:0 | 4019 | - | - | 1849 | 97.5:0.1:2.3 | [29] |
| Urea | Europe | 46:0:0 | 1707 | - | - | 785 | - | [32] |
| UAN | European avg. | 32:0:0 | 5763 | - | - | 1844 | 59.1:39.5:1.4 | [29] |
| UAN | European avg. | 32:0:0 | 4093 | - | - | 1310 | - | [26] |
| UAN | European modern technology | 32:0:0 | 2000 | - | - | 640 | - | [26] |
| TSP | European avg. | 0:48:0:0 | - | 1084 | - | 520 | 96.7:0.5:2.8 | [29] |
| TSP | European avg. | 0:48:0:0 | - | 354 | - | 170 | - | [26] |
| MAP | European avg. | 11:52:0 | 6393 | 1352 | - | 238 | 97.9:0.3:1.9 | [29] |
| MAP | European avg. | 11:52:0 | 2818 | 596 | - | 310 | - | [26] |
| DAP | European avg. | 18:46:0 | 4812 | 1883 | - | 866 | 97.8:0.2:1.9 | [29] |
| NPK | Sweden | 17:04:13 | 9416 | 40018 | 12313 | 1601 | 40.2:59.0:0.8 | [29] |
| NPK | Sweden | 20:05:04 | 9546 | 38183 | 47729 | 1909 | 37.9:61.4:0.8 | [29] |
| NPK (Acid) | European avg. | 15:15:15 | 7496 | 7496 | 7496 | 1124 | 52.1:46.9:1.0 | [29] |
| NPK (Nitro) | European avg. | 15:15:15 | 7896 | 7896 | 7896 | 1184 | 50.8:48.2:1.1 | [29] |

## Greenhouse Gas Emissions through Animal Manures

Animal manure has a significant share in greenhouse gas emissions originating from agriculture. The management of animal manure, manure left in the pastures and manure applied to the soil cause approximately 22% of the greenhouse gas emissions from agriculture [2]. Emissions from animal manure resulting from livestock activities are methane ($CH_4$) and nitrous oxide ($N_2O$) gases [34]. Greenhouse gases emissions by animal manure vary greatly according to many factors. The IPCC, established by the United Nations Environment Program in a decision-making capacity to assess the risks of climate change caused by human activities, offers methodologies to be used in estimating national inventories for greenhouse gas emissions. For this purpose, $CH_4$ gas emission factors based on the IPCC's "National Greenhouse Gas Emission Inventory Report and based on the average annual temperature of 20°C for different animals are given in Table 4.

In the table, Eastern European values are taken into account for cattle, pigs and buffaloes, while the values of developed countries are used for other animals.

With the increasing human population, the number of animals raised in a closed system in order to meet their food needs is also increasing. Fertilizers from animals are widely used in arable fields. These products, which are of great importance as improving soil health, also contribute directly or indirectly to greenhouse gas emissions. The potential greenhouse gas emission amounts of animal manures obtained from different countries are presented in Table 5.

*Table 4. Methane emission factor in animal manure management (adapted from IPCC 2006 [35])*

| Farm Animal | Emission Factor (kg $CH_4$ per animal$^{-1}$.year$^{-1}$) |
|---|---|
| Dairy cattle | 27 |
| Other cattle | 13 |
| Pig | 5 |
| Breeding pig | 8 |
| Buffalo | 11 |
| Sheep | 0.28 |
| Goat | 0.20 |
| Camel | 2.37 |
| Horse | 2.34 |
| Donkey and mule | 1.10 |
| Chicken | 0.02 |
| Turkey | 0.09 |
| Duck | 0.03 |

*Table 5. Emissions of carbon dioxide ($CO_2$), methane ($CH_4$) and nitrous oxide ($N_2O$) from animal manure produced in some countries (adapted from Thangarajan et al. 2013 [36])*

| Country | Animal type | Amount and Rate of Potential Greenhouse Gas Emissions | | | | | |
|---|---|---|---|---|---|---|---|
| | | $CO_2^-C$ (Gg year$^{-1}$) | % of total emissions | $CH_4CO_2^-C$ eq. (Gg year$^{-1}$) | % of total emissions | $N_2O$ $CO_2^-C$ eq. (Gg year$^{-1}$) | % of total emissions |
| Australia | Chicken | 357 | 0.09 | 56 | 0.05 | 118 | 0.51 |
| | Cattle | 8781 | 2.10 | 1850 | 1.66 | 1947 | 8.36 |
| | Pig | 158 | 0.04 | 41 | 0.04 | 53 | 0.23 |
| | Sheep | 4509 | 1.08 | 907 | 0.81 | 1162 | 4.99 |
| USA | Chicken | 9040 | 0.16 | 1417 | 0.21 | 2983 | 0.97 |
| | Cattle | 30837 | 0.54 | 6497 | 0.97 | 6837 | 2.23 |
| | Pig | 4493 | 0.08 | 1151 | 0.17 | 1506 | 0.49 |
| | Sheep | 372 | 0.01 | 75 | 0.01 | 96 | 0.03 |
| New Zeeland | Chicken | 58 | 0.18 | 9 | 0.03 | 19 | 0.18 |
| | Cattle | 3240 | 9.76 | 683 | 2.54 | 718 | 6.87 |
| | Pig | 23 | 0.07 | 6 | 0.02 | 8 | 0.07 |
| | Sheep | 2156 | 6.50 | 434 | 1.62 | 556 | 5.32 |
| Chinese | Chicken | 20674 | 0.67 | 3242 | 0.45 | 6822 | 2.58 |
| | Cattle | 27525 | 0.90 | 5800 | 0.81 | 6103 | 2.31 |
| | Pig | 32960 | 1.07 | 8444 | 1.17 | 11047 | 4.18 |
| | Sheep | 8875 | 0.29 | 1786 | 0.25 | 2288 | 0.87 |
| Bangladesh | Chicken | 982 | 5.96 | 154 | 0.02 | 324 | 7.26 |
| | Cattle | 7572 | 46 | 1595 | 6.38 | 1679 | 37.65 |
| | Sheep | 121 | 0.73 | 24 | 24 | 31 | 0.70 |
| South Africa | Chicken | 689 | 0.22 | 108 | 0.25 | 227 | 1.10 |
| | Cattle | 4510 | 1.43 | 950 | 2.20 | 1000 | 4.84 |
| | Pig | 110 | 0.03 | 28 | 0.07 | 37 | 0.18 |
| | Sheep | 1623 | 0.51 | 327 | 0.76 | 418 | 2.02 |
| Germany | Chicken | 491 | 0.05 | 77 | 0.16 | 162 | 0.29 |
| | Cattle | 4208 | 0.51 | 887 | 1.86 | 933 | 1.70 |
| | Pig | 1835 | 0.22 | 470 | 0.99 | 615 | 1.12 |
| | Sheep | 138 | 0.02 | 28 | 0.06 | 36 | 0.06 |

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# EFFECTS OF LIME APPLICATIONS ON GREENHOUSE GAS EMISSIONS

Soil-improving materials are widely used in the world to increase the yield in agricultural production in soils with acid reaction. In the use of these materials, it is mainly aimed to reduce the acidity of the soil and increase the availability of plant nutrients. In this way, soil fertility is increased and as a result, product yield and quality are improved. The most preferred method for this purpose worldwide is liming of agricultural soils.

## Effect of Soil Reaction on Plant Growth

There are many factors that affect the uptake of plant nutrients in the soil by plants. Among these factors, soil reaction is one of the most important. Plants generally need to maintain soil pH. If it is close to neutral reaction, they can make optimum use of plant nutrients. However, acid or alkaline pH increases in the soil solution significantly reduce the solubility of some plant nutrients.

Soil acidity is a term used to express the amount of hydrogen (H) and aluminum (Al) ions in soils. The increase in the amount of hydrogen or aluminum ions means the acidification of the soil and the negatively charged cation exchange capacity (CEC) of the soil will be constrained. This is a detrimental situation for the root growth and normal development of plants. Soil pH is an indicator of "soil acidity" (Figure 1). A pH value of 7.0 is defined as neutral, while below this value is defined as acidic and above it as alkaline. Small changes in pH figures for soil indicate large differences in soil acidity. For example, a soil with a pH of 5 is 100 times more acidic than a soil with a pH of 7 [1].

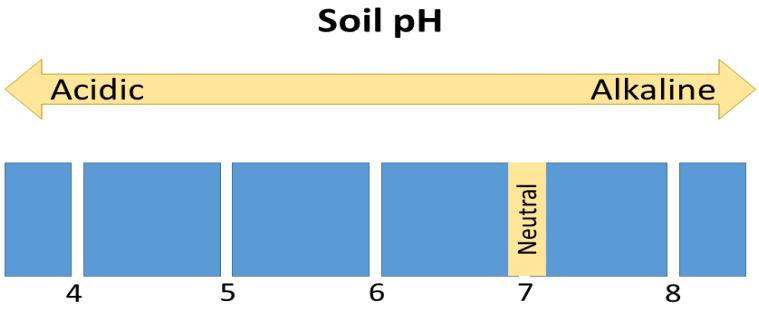



*Figure 1. pH classification of soils in general*

Soils may be acidic during their formation, or they may show acidic properties under the influence of environmental factors. In areas with heavy rainfall, soil acidity increases in cases such as the washing of alkaline ions such as calcium and magnesium in the soil or the continuous use of physiological acidic fertilizers in plant production.

Soil acidity can have negative effects on plant growth in different ways. However, depending on the increase in acidity, the decrease in the intake of some plant nutrients or the effects of toxic ions can be considered as the most important problem. While deficiencies of some nutrients such as phosphorus and molybdenum calcium are observed in acid soils due to the decrease in solubility, ions such as aluminum, manganese and hydrogen can reach levels that can cause toxicity [2].

Acidity is an important factor limiting crop yield in soils and approximately four billion hectares of land in the world is acidic [3]. In an economic analysis, it has been reported that there is a loss of 1.6 Australian dollars per year due to the loss of production in grain cultivation due to acidity [4].

Soils are acidified as a result of the release of protons during nitrification and subsequent leaching of nitrates after nitrogen fertilizer applications or the release of reduced N compounds to natural ecosystems [5]. In the People's Republic of China, it has been reported that as a result of excessive use of nitrogen fertilizers, especially in the form of urea, the pH of the soil decreases in the range of 0.13-0.80 units, depending on the soil properties and accordingly, the cultivated lands are significantly acidified [6]. It is stated that almost half of the arable land in the world is acidic and these areas are increasing gradually [7].

## Liming Applications in Agricultural Soils

In acidic soils, liming is the most commonly used method to neutralize the soil. Liming materials commonly used in deacidification are calcium compounds such as limestone, slaked and quicklime and dolomite [8]. While calcium cannot increase soil pH when used alone, basic cations in liming materials can be neutralized by hydrogen ions in acid soils [9].

Liming is an important cultural practice that increases productivity in agricultural production by removing acidity in the soil. If done correctly, it provides important benefits in plant production, some of these benefits are as follows [1]:

•Show better root development as they will be exposed to less aluminum toxicity.

•Depending on the material used in liming, plant nutrients such as calcium and magnesium are added to the soil.

•As the solubility of nutrients will increase depending on the increase in soil pH with the application, nutrient uptake through plant roots increases.

•With liming, the cation exchange capacity (CEC) of soils increases and this prevents the loss of basic cations, especially potassium, by washing.

•Nodule formation in legumes will be supported, an increase in biological nitrogen fixation is observed.

•As some herbicides will be easier to break down at optimal soil pH risk of damage to plants during crop rotations will be prevented. Some nematicides work more effectively in liming areas.

Depending on the soil properties, the amount of lime to be given varies. The amount of lime that will neutralize the total acidity in order to ensure optimum plant growth in the soil is expressed as the lime requirement of that soil [10]. Although plants generally show good growth at near neutral pH values, it should be noted that the optimum pH requirement is not the same for all plants. For this reason, the optimum pH demand of the plant grown should be known in addition to the soil properties while liming. It is always possible to see different nutritional problems in case of applying more lime than necessary. Optimum pH requirements of some plants are given in Table 1.

*Table 1. Optimum pH demands of some cultivated plants [1]*

| Herb | Target pH for Liming |
|---|---|
| Sweetcorn | 6.0 |
| Soy | 6.0 |
| Cotton | 6.2 |
| Asparagus | 6.5 |
| Bean | 6.0 |
| Tomatoes | 6.5 |
| Clover | 6.5 |
| Apple | 6.5 |
| Strawberry | 6.0 |
| Fir | 5.5 |
| Blueberries | 4.5 |

In general, liming materials are of two different types. The first group, called calcitic limestone, includes calcium carbonate ($CaCO_3$), calcium hydroxide [$Ca(OH)_2$] or calcium oxide (CaO). Dolomitic limestone [$CaMg(CO_3)_2$], which contains a significant amount of magnesium along with calcium, is classified as the second type.

## The Effect of Lime Applications in Soils on Greenhouse Gas Emissions

Neutralization in acid soils also has some environmental effects. These effects may differ depending on many variables. $CO_2$ and $N_2O$ gases, which are greenhouse gases that cause global warming are

more affected by liming applications than $CH_4$. These effects have been tried to be summarized under the following headings.

## The Effects of Liming on Carbon Dioxide Release in Soils

Soil degradation has become a major threat on a global scale in recent years. Soil fertility is tried to be increased by using remedial agents such as lime, sulfur, gypsum and various organic compounds in order to improve the soil as a result of deterioration in the soil. While this situation provides improvements on the one hand, it may cause us to encounter different environmental problems on the other hand. The effect of lime and liming on carbon stock has been an issue that has gained importance in recent years.

In general, the effect of liming on carbon concentration in soils varies with environmental characteristics and soil structure. In a study examining the effects of long-term lime applications on the soil carbon content in grasslands, it was stated that a higher rate of organic carbon accumulation was observed in calcareous soils than in non-calcareous soils [11]. The reason for this is explained by the increase in carbon inputs due to increased biomass and biological activity.

Depending on the application of lime on acid soils, increases in the amount of atmospheric $CO_2$ can be observed [12]. This situation has been tried to be explained by the equation shown below:

$CaCO_3+2H^+ \rightarrow Ca_2^+ + CO_2 + H_2O$

Calcium ($Ca_2^+$) and bicarbonate ($HCO_3^-$) ion concentrations in the exchange complex increase. As a result, $Al_3^+$ ions are replaced by $Ca_2^+$ ions and an increase in soil pH occurs due to the decrease in the acid hydrolysis of aluminum. In the meantime, carbon dioxide ($CO_2$) and water ($H_2O$) are released when the bicarbonate ($HCO_3^-$) ions that are formed react with the $H^+$ ions present in the soil. As a result of these processes, $H^+$ causes acidity in the soil. As the concentration decreases, conditions that hinder plant growth such as toxicity caused by $Al_3^+$ ions and $Ca_2^+$ deficiency are partially eliminated [13].

As a result, with the application of lime to agricultural soils, some of the carbonate in these materials is released into the atmosphere as $CO_2$. Agricultural lime can be applied as calcite ($CaCO_3$) or dolomite ($MgCa(CO_3)_2$). In an analysis to calculate the contribution of agricultural lime to carbon dioxide emissions in the United States, it was stated that net $CO_2$ emissions from agricultural lime applications were 0.059 mg C for 1 mg calcite and 0.064 mg C for 1 mg dolomite [14]. While the researchers reported that these rates did not match the emission factors given by the IPCC as 0.12 for calcite and 0.13 for dolomite, respectively, they reported annual emissions of 4.4-4.6 Tg $CO_2$ for the USA, depending on agricultural lime applications.

It is stated that $CO_2$ released into the atmosphere due to calcite and dolomite applications in the USA constitutes 1.7% of total agricultural greenhouse gas emissions and 0.13% of total greenhouse gas emissions [15].

In a study conducted in Brazil to calculate the $CO_2$ emissions due to liming of agricultural lands, it was reported that the amount of emissions between 1990 and 2000 ranged between 4.9-9.4 Tg per year, with an average of 7.2 Tg [16].

What needs to be done to reduce greenhouse gas emissions from liming is the application of oxides such as quicklime (CaO) or slaked lime ($Ca(OH)_2$) instead of carbonate-containing materials [17].

## Nitrous Oxide Release in Acid Soils

Globally, acid soils make up the majority of arable land and plant growth is limited as acidity increases. The method used in this type of soil is usually liming of the soil. Liming increases the pH and accordingly increases the productivity of the soil. In addition, it also affects greenhouse gas emissions depending on the soil carbon content and the cycle of elements. In a meta-analysis examining the effects of liming

on greenhouse gas flows, over 1500 observations reported in the results of 121 studies were evaluated and their results were shared [18]. According to the data evaluated in the study, the effect of liming on the yield increase in products was 36% and positive. The rate of increase in soil organic carbon stocks was 4.5% annually. There was a 21.3% reduction in $N_2O$ emission from soils due to lime applications. On the other hand, in the paddy fields, there was a 19% decrease in the release of $CH_4$ by liming. According to the data obtained by the researchers, the greenhouse gas budget of soils with acid reaction with regular calcification applications was as follows: Annually, 0.60-0.67 Tg reduction in $N_2O$ emission from soils and 1.75-2.21 Tg reduction in $CH_4$ emissions in rice fields, while the organic carbon stocks was estimated to increase between 66-110 Tg. However, it has been stated that the $CO_2$ emission due to calcification will occur between 624-656 Tg values annually. According to these results, it is stated that the greenhouse gas balance will be neutral and it is emphasized that liming will provide a potential benefit globally depending on the yield increases.

It was stated that nitrogen loss and $N_2O$ emissions to the atmosphere by liming decreased, but direct $CO_2$ emissions due to liming increased [19]. In the study, it was stated that the greenhouse gas emissions from liming are approximately four times higher than the amount saved by reducing $N_2O$ emissions.

Despite the addition of liming materials for the improvement of acidic soils, the effects of changes in soil pH with the addition of these materials on $N_2O$ emission have not been fully demonstrated [20]. For this purpose, the researchers investigated the possible effects of four different liming materials on $N_2O$ release in a soil with a pH of 5.35. In the study, dolomite-$CaMg(CO_3)_2$, calcite-$CaCO_3$, calcium hydroxide-$Ca(OH)_2$ and calcium oxide-CaO were used as liming materials and as a result of all applications, a decrease in $N_2O$ release was observed. Compared to other applications, the highest decrease in $N_2O$ release was obtained in $Ca(OH)_2$ application and this was associated with a higher pH increase. According to the results obtained, it was emphasized that the soil pH was more effective than the C and N dynamics of the soil in the reduction of $N_2O$ release.

In a study conducted to reveal the effects of greenhouse gas emissions in no-till farming and lime applied areas, $N_2O$ and $CH_4$ emissions have been observed from an acidic soil with insufficient drainage. [21]. According to the results of the study while liming, $N_2O$ emissions decreased by 61% in the areas where conventional farming practices were applied, no effect was observed in the areas where no tillage was applied. According to the results of the researchers, no-till agriculture can improve the physical properties of the soil and at the same time, they emphasized that it is an important tool to reduce emissions of $N_2O$ and $CH_4$.

The $N_2O$ emission increases with the application of nitrogen fertilizers during plant development in semi-arid regions following summer rains; a study was conducted to determine the change of these emissions with the application of lime in these regions [22]. For this purpose, one year before the experiment, the pH was increased by applying lime and soil with two different pH (4.21 and 6.34) was formed. In the study, $N_2O$ emissions changed from 0 when the soil was dry to 0.065 μg $N_2ON$ g dry $soil^{-1}$ $hour^{-1}$ after the soil was wet and this situation was associated with denitrification and nitrification. Increasing soil pH reduced $N_2O$ emissions only when losses were associated with nitrification. Researchers have proposed to increase soil pH by liming in order to reduce $N_2O$ emissions in semi-arid soils with acidic properties, where the releases originate from nitrification.

Moreover, the net effect of soil pH on $N_2O$ emissions is often difficult to estimate [23] and may vary depending on the emission source [24]. According to the results obtained in a study examining the possible effects of liming on $N_2O$ emission in a soil with acidic properties, cumulative $N_2O$ emissions during denitrification reached very high values compared to nitrification conditions [25]. According to the results of the study, $N_2O$ emission during denitrification increased significantly with increasing soil pH.

## Biochar Applications on Greenhouse Gas Emissions

Organic compounds that are rich in carbon, resistant to decomposition and have a porous structure obtained by thermo-chemical transformation of biomass under high temperature, oxygen-free or limited oxygen conditions are defined as biochar.

As the produced biochars are mostly alkaline, the studies carried out to date were mostly on acidic soils. It has been the subject of many researches because it causes an increase in the availability of nutrients by increasing the pH of the soil when applied as in liming [26].

Biochar, which has become increasingly popular as a soil conditioner in recent years, will make a significant contribution to the reduction of global warming because it keeps the atmospheric carbon in the soil. However, studies have shown that the effects of biochar applications may vary according to soil, plant and other environmental factors. For example, in a study examining the effects of biochar applications on yield and greenhouse gas emissions in two different areas of paddy and wheat farming, the application of biochar increased the release of $CH_4$ by 37% during the development period in the field of rice production, while the addition of biochar in wheat did not affect the release of $CH_4$ [18]. In addition, depending on the biochar application, $N_2O$ emissions decreased by 54% and 53% for rice and wheat, respectively, while the rates of increase in yield were realized as 12% and 17%.

It is possible to come across many studies examining the effects of biochar applications on soil greenhouse gas emissions. In a meta-analysis conducted for this purpose, the effects of biochar applications on $CO_2$, $CH_4$ and $N_2O$ emissions were tried to be evaluated based on the results of 91 articles made around the world [27]. According to the results of the study, it was reported that while the soil $CO_2$ emissions increased by 22% depending on the biochar applications, there was a 31% decrease in the $N_2O$ emission. However, biochar applications did not show any effect on $CH_4$ emission in soil.

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# MAKING FERTILIZATION MORE SUSTAINABLE IN TERMS OF CLIMATE CHANGE

In parallel with the rapid population growth in the world, people's food consumption has also increased. Increases in agricultural production have increased the use of agricultural inputs to significant levels. The main goal of those who produce agricultural products in the world today is to obtain the highest quantity and quality of products they can afford. In order to achieve this goal, fertilizers are one of the most important inputs used in agriculture. Chemical fertilizers are widely used today. The amounts of nitrogen, phosphorus and potassium fertilizers used in agricultural production worldwide in recent years are shown in Table 1.

*Table 1. Consumption of nitrogenous, phosphorus and potassium fertilizers in the world by years [1]*

| Years | Nitrogen Fertilizer (N) | Phosphorus Fertilizer ($P_2O_5$) | Potassium Fertilizer ($K_2O$) |
|---|---|---|---|
| 2017 | 109,923,828 | 44,807,567 | 38,872,528 |
| 2018 | 108,795,192 | 44,456,769 | 38,961,263 |
| 2019 | 105,111,079 | 44.119.119 | 36,995,315 |
| 2020 | 110,541,659 | 48,364,923 | 39,024,540 |
| 2021 | 108,688,168 | 46,269,708 | 40,128,174 |

In addition to chemical fertilizers, organic fertilizer applications are also important in crop production. According to 2020 data, nearly 28 billion tons of animal manure was used worldwide [1]. Although fertilization is increasing rapidly, there are very important problems regarding the effective use of fertilizers. It is a known fact that the efficiency of fertilizer use remains at very low rates in many studies conducted around the world today. Successful fertilization should be measured by providing the necessary nutritional needs of plants throughout their development periods, as well as being able to do this in a way that causes minimal damage to the environment. As a matter of fact, today we are faced with serious environmental problems in the world, especially due to incorrect and excessive use of fertilizers.

A significant part of the greenhouse gases that cause global warming are released into the atmosphere as a result of agricultural activities. Greenhouse gas emissions from agriculture largely consist of methane ($CH_4$) and nitrous oxide ($N_2O$) gas. Significant greenhouse gas emissions are released into the atmosphere through fertilizers. According to 2020 data, 13% of the gases released into the atmosphere as a result of agricultural activities were due to synthetic fertilizers and animal manures applied to the soil [1].

The increase rate in agricultural emissions due to the use of chemical fertilizers has reached much higher levels over time compared to other emission sources. Table 2 shows the greenhouse gas emissions of some agricultural activities over the years. In the last 60 years, the increase in the amount of emissions caused by chemical fertilizers has approached 10 times.

*Table 2. Changes in greenhouse gas emissions from agriculture over the years [1]*

| Emission Source | Emission Amount (kiloton $CO_2$ equivalent) | | | | | | | Rate of Change (%)* |
|---|---|---|---|---|---|---|---|---|
| | 1961 | 1970 | 1980 | 1990 | 2000 | 2010 | 2020 | |
| Enteric fermentation | 1829661 | 2069925 | 2320767 | 2493671 | 2473802 | 2654500 | 2849716 | 56 |
| Paddy farming | 487941 | 560752 | 609831 | 620854 | 653281 | 682752 | 686111 | 41 |
| Synthetic fertilizers | 63209 | 174069 | 334374 | 425288 | 446178 | 559822 | 625107 | 889 |

**Change rates are based on the amounts realized in 2020 compared to 1961.*

## Environmental Effects of Fertilizer Use

Greenhouse gas emissions from agriculture largely consist of nitrous oxide ($N_2O$) and methane ($CH_4$) gas. Although these gases are less abundant in the atmosphere than $CO_2$, they have a higher global warming potential. It has been stated in the Global Climate Change Panel that, for a period of 100

years, the unit masses of $CH_4$ and $N_2O$ gases have a global warming potential of 25 and 298 times more than $CO_2$ gas, respectively. Nitrous oxide molecules can remain in the atmosphere for an average of 114 years [2]. Globally, although some of the $N_2O$ emissions enter the atmosphere naturally, a significant amount of emission occurs due to human activities [3]. While human-induced $N_2O$ emissions are largely caused by agricultural activities, the use of nitrogenous fertilizers has the largest share in these activities. The two main ways $N_2O$ is produced in agricultural soils are nitrification and denitrification. In addition to synthetic fertilizers, animal fertilizers also have a significant share in agricultural greenhouse gas emissions. Greenhouse gas emissions through animal manures cause approximately 22% of total greenhouse gas emissions from agriculture [1].

The negative effects of fertilizers on the environment are not limited to their contribution to greenhouse gas emissions. They can also cause different environmental problems, especially due to overuse. Some of the important ones are mentioned below.

## Nitrate pollution in groundwater

Groundwater is used as a drinking water source in many parts of the world. The most important factors that threaten human health in drinking water are microbiological pollution and nitrate pollution. Fertilizers are one of the main factors causing nitrate pollution in groundwater today. Although nitrogenous fertilizers directly contain nitrate, they can easily turn into nitrate after application. Nitrogen applied to the soil and not used by plants is not retained by the soil and moves with water, especially after it turns into nitrate. This is the main factor in the contamination of groundwater with nitrate. It is stated that 2-10% of the nitrogen fertilizer applied to the soil mixes with surface water or groundwater [4]. The mixing of nitrate into soils and subsequently into surface and groundwater does not occur solely due to the use of chemical nitrogen fertilizers. A significant amount of nitrogen is added to the soil through the use of organic fertilizer. Nitrate formed as a result of mineralization causes the same environmental damage.

## Nitrate accumulation in plants

Just as nitrate is a problem in surface and ground water, it can sometimes cause problems by rising above a certain level in plants. Nitrogen is one of the elements most removed from the soil by plants and they naturally contain large amounts of nitrogen. Plants use this nitrogen in the synthesis of some compounds, especially protein. However, sometimes due to excessive nitrogen fertilizer consumption, the level of nitrogen absorbed by plants increases and nitrate accumulation may occur in plants. This situation is especially a problem in vegetable species whose leaves are edible.

Nitrate taken through drinking water and food first turns into nitrite in living things and then forms nitrosamine compounds. These compounds are also considered toxic, mutagenic and carcinogenic [5].

## Salinity formation in soils

Soil salinity is the accumulation of water-soluble salts in the soil in various forms. It can occur naturally and artificially. Naturally occurring salinity occurs especially in arid and semi-arid regions. In these areas, soluble salts mixed with groundwater through leaching are carried to the upper layers of the soil by capillarity and then as a result of evaporation, water moves away from the environment and salts remain. Salinity created in soil by artificial means is mostly caused by irrigation and fertilization. Especially in areas where cultivation is intensive, the amount of salinity in the soil increases over many years due to the use of high amounts of fertilizer. This process is further accelerated if fertilization is applied together with drip irrigation. In the drip irrigation method, a smaller area is irrigated rather than the entire soil. Therefore, a more intense fertilizer concentration occurs in this small area (Figure 1).



*Figure 1. Salt accumulation on the soil surface as a result of fertilizer application (Source: West Coast Nut, https://www.wcngg.com)*

Salinity is one of the most important soil properties that limits plant growth in agricultural production. Salinization of soil negatively affects plants' water and nutrient uptake. Due to the increase in salt concentration in the plant root area, osmotic pressure increases and it becomes difficult for the plant to absorb water. Additionally, toxic effects occur due to the increase of some ions and salt stress occurs in plants [6]. Fertilizers create a salinity effect at different rates compared to each other. The salt concentration created by a fertilizer in the soil solution gives its salinity index value. Salinity index values of some nitrogenous fertilizers are given in Table 3. Especially in areas where salinity is a problem, fertilizers with a lower salinity index should be preferred.

*Table 3. Salinity index values of some fertilizers [7].*

| Name | Active Substance Rate (%) | Salinity Index | Salinity Index Value Per Unit Food* |
|---|---|---|---|
| Anhydrous Ammonia | 82 N | 47.1 | 0.57 |
| Ammonium Nitrate | 34 N | 104 | 3.06 |
| Ammonium Sulfate | 21 N, 24 S | 68.3 | 3.25 |
| Urea | 46 N | 74.4 | 1.62 |

**One unit is equivalent to 9 kg.*

## Eutrophication

Eutrophication can be defined as the increase in aquatic life in waters due to the increase in some plant nutritional elements, the resulting decrease in water quality and the deterioration in aquatic habitats. Fertilizers used in agricultural production mix with surface or subsurface waters if they are used excessively. Fertilizers that mix with water, especially those containing nitrogen and phosphorus, are the most important pollutants that cause eutrophication. Although eutrophication is mostly seen in areas such as lakes and ponds, it can sometimes be seen in rivers and seas (Figure 2).

Due to the increase in nutritional elements, the density of phytoplankton, algae and some aquatic plants in the water increases. When they die, they form a sediment on the water bottom and are broken down by microorganisms. Meanwhile, the amount of dissolved oxygen in the environment decreases rapidly due to intense oxygen consumption. This causes the death of other aquatic creatures, especially fish and a decrease in the existing water quality.



*Figure 2. Eutrophication in water (http://mk.uni-pannon.hu/)*

## Increasing Fertilizer Use Efficiency and Preventing Unnecessary Fertilizer Use

Fertilizers, one of the most important inputs of agriculture, have limited effectiveness due to misuse. The most commonly used fertilizer type in plant production is nitrogenous fertilizers. Nitrogenous fertilizers constitute the main source of $N_2O$ emission from agricultural soils to the atmosphere. In addition to causing greenhouse gas emissions, they play an important role in many environmental problems as mentioned above. Therefore, they will continue to pose significant risks to the environment unless their use is taken into consideration.

The most important condition for successful fertilization is to meet the nutritional needs of the plant throughout its development period while doing this with minimal damage to the ecosystem.

Fertilizer use efficiency can be defined as the ability of plants to use the nutritional elements they need for healthy development at the optimum level or the ability to create plant parts at the maximum level [8].

Although nitrogen use efficiency varies depending on the applications and environmental factors, it is approximately 25-40% worldwide [9]. Some factors that reduce fertilizer use efficiency and their reduction rates are shown in Table 4.

*Table 4. Some factors that reduce the efficiency of fertilizer use [10]*

| Factors | Reduction Rate (%) |
|---|---|
| Unsuitable seed bed | 10-20 |
| Inappropriate plant variety | 20-40 |
| Late sowing-planting | 20-40 |
| Insufficient watering | 10-25 |
| Diseases | 15-20 |
| Pests | 5-50 |
| Excessive and unnecessary use of fertilizer | 20-50 |

The way to achieve sustainable production in agriculture is to prevent excessive fertilizer use by increasing fertilizer use efficiency and to focus on practices that will preserve soil fertility in the long term.

## Applying correct fertilization programs

Excessive and unnecessary use of fertilizer in agricultural production globally is one of the most important issues awaiting solution. It is of great importance to know the nutrient requirements of the plant to be grown for correct fertilization. However, soil properties must be known when creating nutrition programs for plants. Otherwise, it is very difficult to determine the correct amount and appropriate type of fertilizer to be applied. Yield losses occur due to fertilizer application below the plant requirement. In addition, excessive application of fertilizer not only deteriorates productivity and quality, but also harms the environment. The only way to accurately determine the amount and type of fertilizer to be used is to use soil and leaf analysis. Soil samples for fertilization should be taken before sowing or planting and at the beginning of the growing season for perennial plants.

Animal manure applications or different organic fertilization applications are frequently used methods. Such practices are very important in terms of meeting the nutrient need of the plants. If fertilization in an area will be combined with a different animal manure, animal manure analysis should also be performed before fertilization. The amount of fertilizer to be given should be adjusted accordingly by calculating the plant nutrient contents in animal manure.

When applying nitrogen fertilization, fertilizer should be divided into doses, taking into account the development periods of the plant and fertilization plans should be supported by appropriate irrigation management. Remaining of applied nitrogen fertilizer on the soil surface or deep infiltration as a result of irrigation reduces the efficiency of the use of fertilizer and causes significant environmental problems.

When using nitrogen, it is important to apply fertilizer at the appropriate time by taking advantage of local weather forecasts to prevent possible nitrogen losses. Nitrogen loss from soil increases proportionally due to the increase in soil temperature and soil water saturation. The relationship between climatic factors and nitrogen loss should be taken into account in the management of agricultural soils. This situation can be seen in Table 5 [11].

*Table 5. Estimated N losses due to denitrification depending on soil temperature and water saturation*

| Soil Temperature (°C) | Number of Days Saturated with Water | Nitrogen Loss (% of nitrogen applied) |
|---|---|---|
| 13-16 | 5 | 10 |
| | 10 | 25 |
| 24-27 | 3 | 60 |
| | 5 | 75 |
| | 7 | 85 |
| | 9 | 95 |

## Using fertilizers that create lower emissions

One of the largest sources of agricultural greenhouse gas emissions is fertilizer applications. Therefore, knowing the effects of different types of fertilizer use on emission rates and choosing suitable fertilizers can help reduce emissions. For this purpose, in a study conducted in China, the greenhouse gas emission amounts of different fertilizer types were compared and the fertilizers with the lowest emissions and lowest costs were tried to be determined [12]. According to the data obtained, when direct $N_2O$ emissions from the field are not taken into account, emissions from fertilizer constituted 48% of the total emissions resulting from production. Researchers stated that reducing emissions from fertilizers is a necessary and priority measure and according to their results, they stated that ammonium bicarbonate, calcium superphosphate and potassium chloride are the fertilizers with the lowest greenhouse gas emissions. It has been pointed out that a 49% decrease in the amount of emissions will be achieved with the use of these fertilizers.

Unlike other nitrogenous fertilizers, when urea fertilizer is applied to the soil, $CO_2$ added during the industrial production process is released. Urea ($CH_4N_2O$) turns into ammonium ($NH_4^+$), hydroxyl ($OH^-$)

and bicarbonate ($HCO_3^-$) ions in the presence of water and urease enzymes. The $HCO_3^-$ formed as a result of the reaction is separated into $CO_2$ and $H_2O$ after the addition of lime and thus $CO_2$ is released from the soil [13].

Studies on determining the contribution of different types of fertilizers to greenhouse gas emissions in soils with different characteristics should be increased and care should be taken to choose fertilizers that cause less emissions in those regions.

## Increasing soil organic matter content

Correct plant nutrition management in agricultural areas should be considered together with soil organic carbon retention. In general, the use of organic fertilizers and compost will improve the soil organic carbon pool more than the use of inorganic fertilizers. When the amount of organic matter in the soil is low, soil health is negatively affected and productivity decreases. On the other hand, increasing the amount of organic carbon in the soil is also a way to increase carbon sequestration, as it increases the capacity of agricultural ecosystems to absorb atmospheric $CO_2$ and store it in the soil [14]. Burning crop residues after harvest and excessive use of chemical fertilizers leads to a decrease in biological resources, which weakens the potential capacity of the agricultural ecosystem as a carbon sink and may also lead to an increase in emissions caused by fertilization.

In a study conducted for this purpose, crop residues were composted with cattle manure and different applications were tried in winter wheat and corn rotation [15]. In the study, four different fertilizer applications were tried: 100% cattle manure, 100% mineral nitrogen, 75% cattle manure + 25% mineral nitrogen and 50% cattle manure + 50% mineral nitrogen. According to the results obtained, it was stated that replacing chemical fertilizer with organic fertilizer significantly reduced greenhouse gas emissions and wheat and corn yield increased with the addition of cattle manure. Researchers have emphasized that if chemical fertilizer is replaced with organic fertilizer, the agricultural ecosystem will turn from a carbon source to a carbon sink and greenhouse gas emissions will decrease.

## Using enhanced-efficiency fertilizers (EEFs)

Increasing the effectiveness of fertilizers, minimizing possible losses in the soil and ensuring that plants benefit more from the nutrients soil contain has become a widely preferred method in recent years. These fertilizers, which are generally named as enhanced-efficiency fertilizers (EEFs) are defined as "fertilizer products that have properties that increase plant uptake and reduce nutrient loss" [16]. Different methods such as coating, encapsulation and inhibitor addition are used in such products that aim to increase the efficiency of nitrogenous fertilizers. Slow and controlled release fertilizers and inhibitor fertilizers not only have higher nitrogen use efficiency but also have the potential to reduce $N_2O$ emissions resulting from fertilization.

Although it is clear that the inclusion of such fertilizers in the nutrition programs of plants is important to increase efficiency in production and reduce greenhouse gas emissions, it seems a necessity to subsidize the resulting cost in some way.

## Microbial fertilizers

The intensive use of chemicals in agriculture to meet the increasing food demand in the world causes increasing environmental problems. It becomes inevitable to turn to alternative inputs for a more sustainable production. One of these is microbial fertilizers.

Microorganisms fixes atmospheric nitrogen to soil when applied to seeds or soil, promotes vegetative growth by increasing the availability of plant nutrients or by producing secondary metabolites. Material consisting of microorganisms living in the rhizosphere that can colonize or enter plant tissues is called biological fertilizer [17]. This group of fertilizers, which mostly consists of bacteria that fix

atmospheric nitrogen, also includes phosphate-dissolving and hormone-producing bacteria. Bacteria used as biological fertilizer are generally called Plant Growth Promoting Rhizobacter (PGPR). In the studies conducted to date, it has been observed that species especially belonging to the genus Azotobacter, *Azospirillum*, *Burkholderia*, *Pseudomonas*, *Bacillus* and *Paenibacillus* stand out as PGPR [18].

Although they are often not sufficient on their own, it may be possible to reduce the use of intensive chemical fertilizer with the use of microbial fertilizers. Generally, active bacteria isolated from soil can be applied successfully, considering their effectiveness and adaptability to the environment in which they are applied.

## Benefiting from precision agriculture technologies in fertilization

One of the applications that have become increasingly prevalent in agriculture in recent years is precision farming techniques. It is an application that emerged as a result of the integration of innovations in technology with agriculture and provides significant advantages, especially in large-scale enterprises. Precision agriculture adopts a method based on variable level applications to areas with different characteristics, instead of applying the same application to the entire area in the cultivation area.

Variable rate fertilizer application is one of the applications in precision agriculture and has become a frequently preferred method, especially in the application of nitrogenous fertilizer, in recent years. There are basically two methods used in the realization of variable rate fertilizer applications [19]:

•One of these is a map-based variable rate application, which uses maps obtained from parameters measured in the field.

•The other method is sensor-based variable rate application. There is no mapping in the sensor-based application, but measurements are taken on the move via real-time sensors based on soil or plant characteristics. The data obtained from these measurements is sent to the variable rate applicator and the application is carried out (Figure 3).

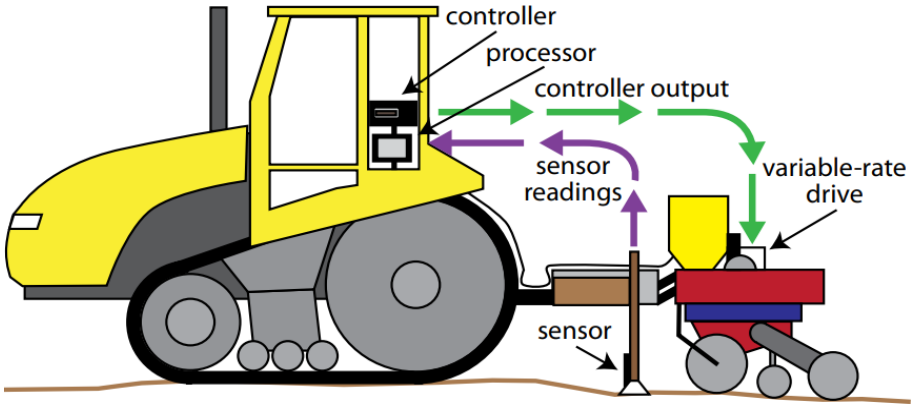



*Figure 3. Sensor- based variable rate application components [19]*

The main purpose of both methods is to adjust the amount of fertilization according to the determined variations in the soil or plants, rather than applying a fixed and equal amount of fertilizer to the entire field.

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# FIGHT AGAINST DEFORESTATION, DESERTIFICATION AND EROSION

Climate change is one of the most important global environmental problems today. Due to the increase in greenhouse gas rates in the Earth's atmosphere, average surface temperatures are increasing and this may cause environmental disasters. However, in parallel with the great increase in human population, it causes forests, pasture areas and agricultural areas to gradually decrease.

Deforestation, desertification and erosion are among the most important environmental problems we face today. These interact with climate change and have triggering effects on each other. Although the size of these problems increases due to the effects of climate change, it is vital to prevent deforestation, desertification and erosion in order to prevent climate change.

## Deforestation

Global Forest Resources Assessment (FRA) report is being prepared every five years by FAO. According to the latest report prepared and published in 2020, the total of forest areas around the world is 4.06 billion hectares [1]. This corresponds to one third of the total land area. 20% of the world's forests are located in the Russian Federation, followed by Brazil, Canada, the United States and China (Figure 1).

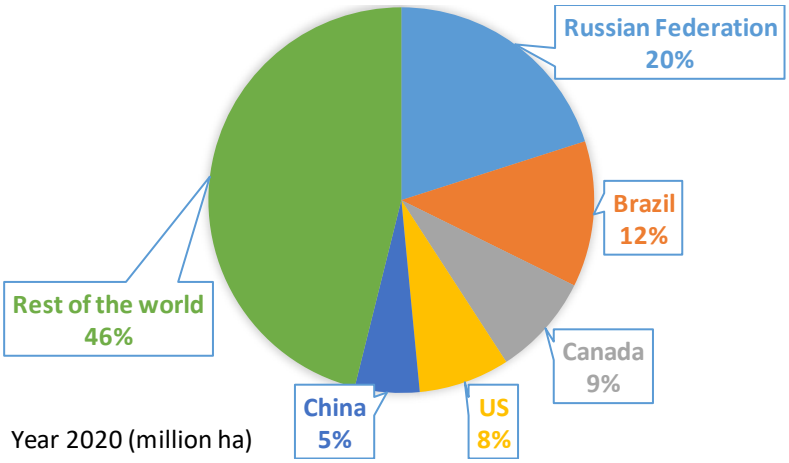



*Figure 1. Forest areas by country [1]*

Although the forest area per capita in the world is 0.52 ha, forests are not evenly distributed around the world. The largest share consists of forests located in tropical regions, with a rate of 45%. This is followed by boreal forests with 27%, forests in temperate regions with 17% and subtropical forests with 11% (Figure 2).

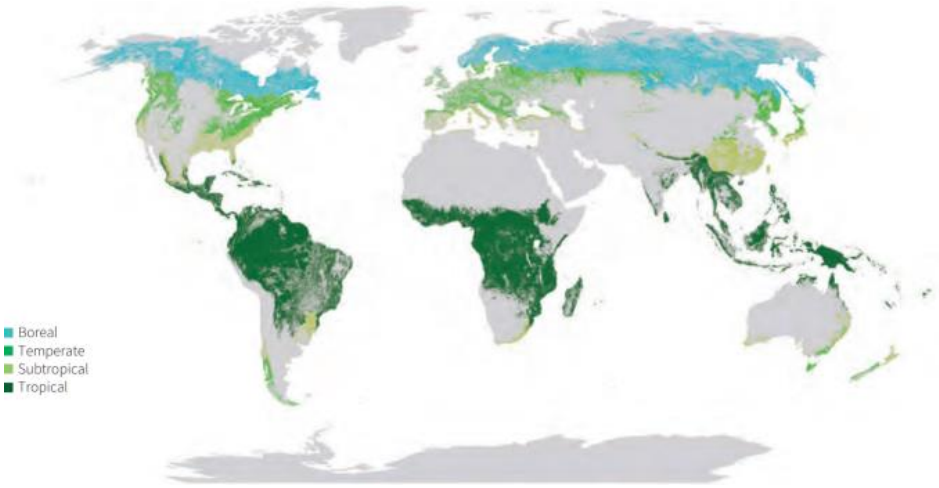



*Figure 2. Distribution of forests according to climate zones (adapted from FAO, 2020)*

After humans settled down, there has been a continuous decrease of forest areas around the world. It is estimated that 10 thousand years ago there was 6 billion hectares of forest area worldwide [2]. The amount of decrease in forests in the recent past is even higher. This situation has led to the emergence of the concept called deforestation. According to FAO, deforestation is considered as the conversion of forest to other land uses (agricultural land, pasture, settlement, etc.).

The net amount of forest lost worldwide in the last thirty years, after deducting the renewed areas, was 178 million hectares. While this loss rate was 7.8 million hectares annually between 1990 and 2000, it decreased to 5.2 million and 4.7 million hectares respectively, in the other ten-year periods (Figure 3).

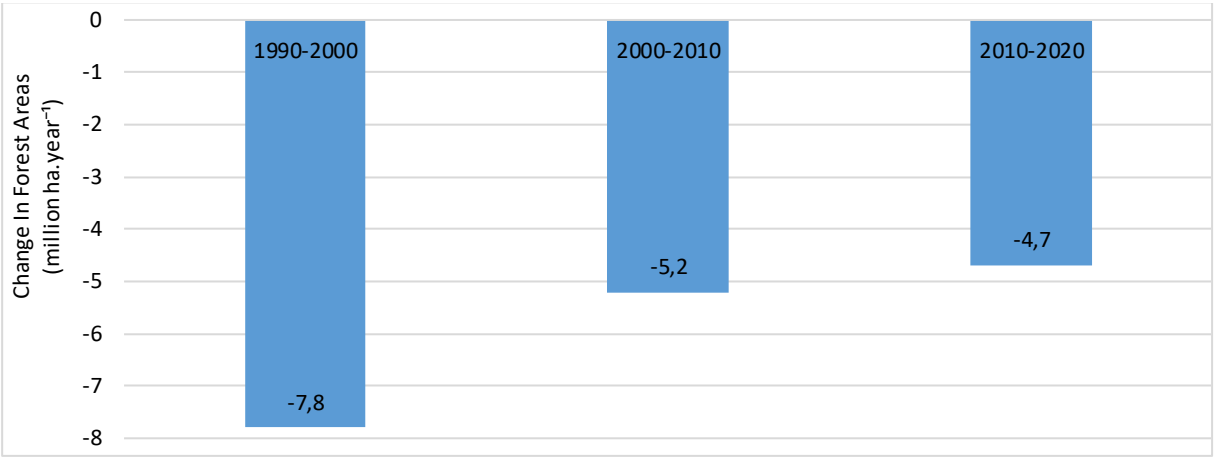



*Figure 3. Annual average net change in forest areas over the ten-year period between 1990 and 2020 [1]*

Although the clear changes seen in forest areas are seen as a decrease in some regions, there are areas where an increase is seen due to afforestation and protection measures. The change, which manifested itself as a decrease in Africa and South America, was seen as an increase in the Asian and European continents (Figure 4).

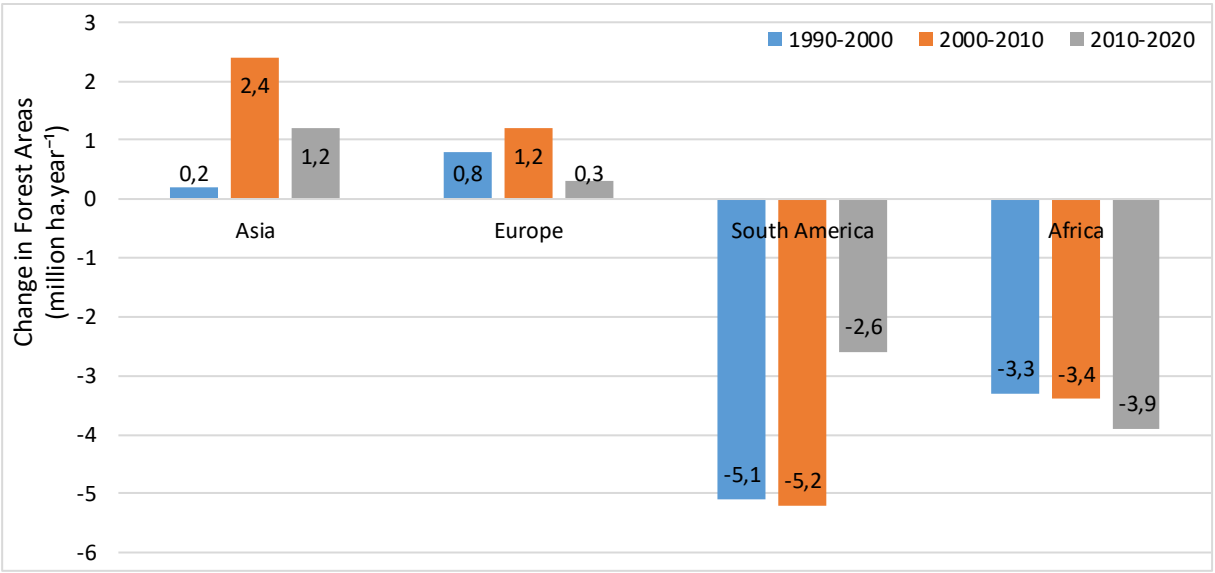



*Figure 4. Annual average net change in forest areas according to regions and periods [1]*

The ten countries with the highest increase and decrease in forest areas on a country basis are given in Table 1. Accordingly, while China was the country that increased its forest assets the most, with an area of approximately 2 million hectares annually, the opposite situation occurred in Brazil, with a forest loss of approximately 1.5 million hectares.

*Table 1. Countries in terms of annual average net gain and loss in forest areas between 2010 and 2020 [1]*

| No | Increase | | | Decrease | | |
|---|---|---|---|---|---|---|
| | Countries | Annual Net Change | | Countries | Annual Net Change | |
| | | 1000 ha.year$^{-1}$ | % | | 1000 ha.year$^{-1}$ | % |
| 1 | Chinese | 1,937 | 0.93 | Brazil | -1,496 | -0.30 |
| 2 | Australia | 446 | 0.34 | Congo | -1101 | -0.83 |
| 3 | India | 266 | 0.38 | Indonesia | -753 | -0.78 |
| 4 | Chile | 149 | 0.85 | Angola | -555 | -0.80 |
| 5 | Vietnamese | 126 | 0.90 | Tanzania | -421 | -0.88 |
| 6 | Türkiye | 114 | 0.53 | Paraguay | -347 | -1.93 |
| 7 | USA | 108 | 0.03 | Myanmar | -290 | -0.96 |
| 8 | France | 83 | 0.50 | Cambodia | -252 | -2.68 |
| 9 | Italy | 54 | 0.58 | Bolivia | -225 | -0.43 |
| 10 | Romania | 41 | 0.62 | Mozambique | -223 | -0.59 |

Forests, which are one of the most important carbon pools in the terrestrial ecosystem, undertake an important task by taking carbon dioxide from the atmosphere and keeping it in these pools. Carbon can be stored in living and dead tissues in forests and a significant amount is also retained in forest soil. The total forest carbon stock on a global scale is estimated to be 662 million tons (Table 2). The largest part of it is stored in forests in the American continent.

*Table 2. Forest carbon stocks by continents [1]*

| Countries | Forest Carbon Stock (million tons) | | | |
|---|---|---|---|---|
| | 1990 | 2000 | 2010 | 2020 |
| Africa | 94,274 | 90,137 | 85,913 | 80,886 |
| Asia | 77,093 | 78,564 | 81,938 | 84,733 |
| Europe | 158,744 | 162,457 | 168,069 | 172,442 |
| America | 304,949 | 299,048 | 293,489 | 290,964 |
| Oceania | 33,338 | 33,111 | 33,077 | 33,063 |
| Total | 668,399 | 663,316 | 662,485 | 662,088 |

44.48% of the carbon stored in forests is in living biomass, 45.24% is in soil organic matter. The remaining part is located in the dead wood and the cover layer on the soil (Figure, 5).

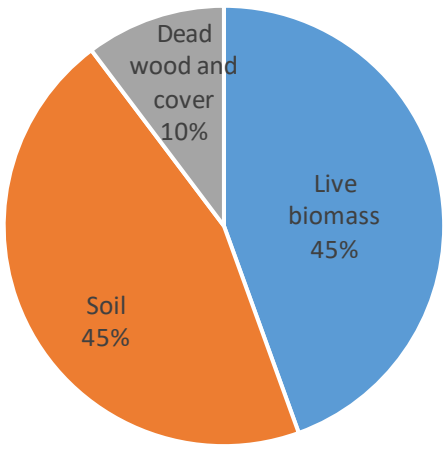



*Figure 5. Forest carbon stock in carbon pools, 2020 [1]*

Carbon sequestration in the forest ecosystem occurs through photosynthesis. $CO_2$ taken from the atmosphere by plants is primarily bound in the form of carbohydrates and then converted into other organic compounds [3].

The carbon stored in plants either mixes with the litter on the soil or returns to the atmosphere through the respiration of animals that consume these plants. While the $CO_2$ released as a result of the decomposition of organic matter in the litter returns to the atmosphere, some of these decomposition

products leak into the soil and mix. As a result, it becomes possible to store organic carbon in the soil [4].

With the addition of all kinds of dead organisms, the carbon accumulated in the sub-forest soil continues to decompose in the soil with the help of soil creatures such as bacteria and fungi. As a result of decomposition, some of the carbon returns to the atmosphere in the form of $CO_2$. This phenomenon is called soil respiration. If forest areas are converted into agricultural lands, the amount of carbon stored in the soil decreases. The main reason for this is the disappearance of the organic matter source with the destruction of the soil cover, faster organic matter decomposition as a result of soil processing and the transportation of topsoil containing high organic carbon, which becomes vulnerable to erosion [5].

It is obvious that climate change, which occurs due to the increase in greenhouse gases in the atmosphere, is one of the biggest threats faced by the world. Forest ecosystems are one of the most important tools for reducing $CO_2$ in the atmosphere, with their high carbon storage potential in both soil and biomass. Capturing existing greenhouse gases as well as reducing greenhouse gas emissions into the atmosphere is an important approach to reduce the effects of climate change. Because;

•To take measures to protect forest assets on a global scale,

•To make degraded forest areas productive,

•To prevent clearcutting,

•To prevent construction and opening of agricultural areas in forest lands,

•To prevent damage from illegal cuttings and grazing,

•Measures such as afforestation in suitable areas are vital for a more livable world.

## Desertification

Desertification is defined in the United Nations Convention to Combat Desertification (UNCCD) as land degradation caused by the complex interactions between physical, biological, political, social, cultural and economic factors, including climatic changes and human activities, in countries affected by severe drought and/or desertification in arid, semi-arid and dry sub-humid areas.

Degradation of soil which can be seen everywhere, is considered desertification if it occurs in arid, semi-arid and dry sub-humid lands. Desertification occurs more frequently and its impact is greater in environments where total precipitation is low, there is insufficient water resources, long and recurring drought events happen and there are thin soil layers, covered with sparse and sensitive vegetation. Factors linked to climate change may lead to an increase in the vulnerability of land to desertification and an acceleration of desertification processes [6].

Desertification is not limited to irreversible forms of land degradation; It represents all forms and levels of land degradation occurring in drylands. The aridity index (AI) is usually taken into account in the classification of drylands (Figure 6). When calculating the drought index, the ratio of the annual average precipitation amount to the evapotranspiration amount is used. According to estimates, the proportion of dry areas on a global scale is estimated to be around 46% [7]. Arid climate is a long-term climate feature characterized by low average precipitation and is different from drought, which is a temporary climate feature. Extremely dry areas with a drought index below 0.05 are excluded from the definition of desertification [8].

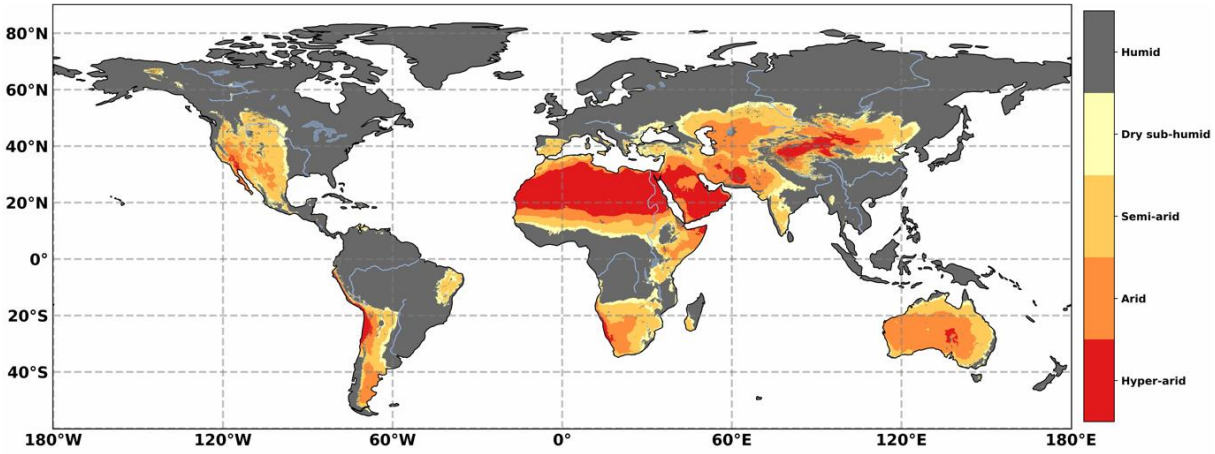



*Figure 6. Geographic distribution of dry areas determined according to drought index (AI). Humid: AI > 0.65, Dry sub-humid: 0.50 < AI ≤ 0.65, Semi-arid: 0.20 < AI ≤ 0.50, Arid: 0.05 < AI ≤ 0.20, Hyper arid: AI < 0.05. Data: 1980-2015, [9]*

Today, many countries in the world face the danger of desertification. The United Nations Environment Program (UNEP) estimates the global cost of desertification at 42 billion dollars annually. About 70% of the world's dry areas are located in Africa and Asia (Figure 7). Apart from deserts, the largest land use on drylands is grassland, followed by forests and croplands [7].

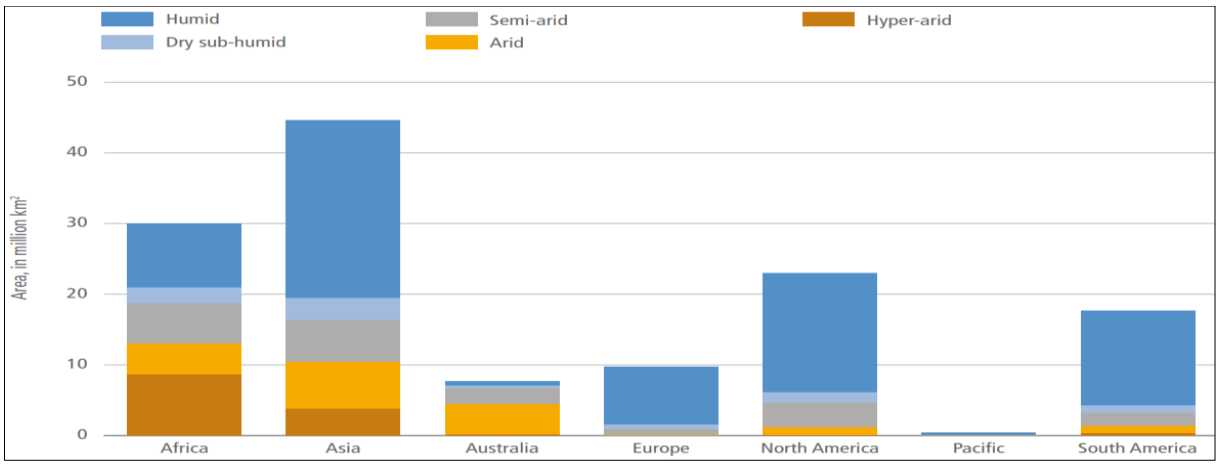



*Figure 7. Dryland categories by geographical regions, Data: 1980-2015, [9]*

While climate change is considered a factor that triggers desertification, it is possible that desertification can also cause a change in the local climate. The change that occurs locally as a result of this mutual interaction contributes to global climate change by increasing the atmospheric $CO_2$ level [10].

Interactions between climate change and land degradation and precipitation remain inextricably linked. Water resources in the world change depending on the climate. Water availability is predicted to increase by 10-40% in high latitudes and some humid tropics, while it will decrease by 10-30% in mid-latitudes and dry tropics. Changes in meteorological events such as temperature, precipitation and wind can exacerbate desertification [11].

The most important environmental and sociological effects of drought and desertification, which have many negative effects, are listed below [6]:

•Loss of biological productivity in ecosystems and decrease in agricultural production;

•The weakening and extinction of natural vegetation;

•Reduction of biodiversity;

•Creation of suitable conditions for the spread of foreign and invasive plant species;

•Strengthening of wind erosion;

•Water scarcity, lowering of groundwater levels;

•Poverty and hunger among the people of the affected region;

•Increase in climate or desertification nomads:

•Direct or indirect deterioration in the quality of life in the affected areas.

Although they vary greatly according to geography, important direct and indirect causes of desertification are listed below [6]:

•Forest fires and deforestation,

•Agricultural activities such as overgrazing, continuous tillage, intensive use of pesticides and fertilizers,

•Excessive consumption of all kinds of scarce resources,

•Excessive use of water resources and mistakes made in irrigation management,

•Construction of large dams and structures, changing and disrupting the flow directions of river channels and beds, excessive consumption of groundwater, drainage of wetlands,

•Climatic changes and variability that cause droughts and floods,

•Severe competition and problems caused by the widespread international trade regime due to the spread of globalization and market economy rules, etc.

In order to make a common and effective fight against desertification, the United Nations Convention to Combat Desertification (UNCCD) was signed in June 1994, to which many countries are part of. The aim of the convention is to minimize the effects of drought by combating drought and/or desertification in countries affected by it, especially in Africa, through effective actions at all levels.

## Erosion

Erosion can be defined as the loss of soil as a result of being carried by different forces such as water, wind and mass movements. The main factors affecting soil erosion are the amount and intensity of precipitation, wind speed, direction and strength, changes in land use, topography and soil properties [6].

Various climate models created due to climate change show that generally increasing precipitation intensity and increases in strong wind events may cause an increase in soil erosion, especially with increased drought events [12]. On the other hand, the impact of erosion on climate change through possible changes in the soil carbon cycle has not yet been adequately measured; because erosion can both increase and decrease $CO_2$ emissions due to increased mineralization and settling of sediments [13, 14].

Accelerated erosion resulting from excessive use of irrigation poses a major threat to soil all over the world. It is stated that 75 billion tons (Pg) of soil are eroded from arable agricultural areas globally every year through erosion and this corresponds to an economic loss of approximately 400 billion dollars per year [15].

The extent to which soils are affected by erosion around the world may vary. An assessment of global soil erosion is presented on a map from 2012 (Figure 8). In the creation of the study, 202 countries with a surface area of over 125 million $km^2$ were included and the estimates were created by estimating through a RUSLE-based modeling approach. On the map where approximately 84.1% of the world's soil is evaluated, soil erosion rates divided into seven classes symbolize increasing rates from green to red [16].

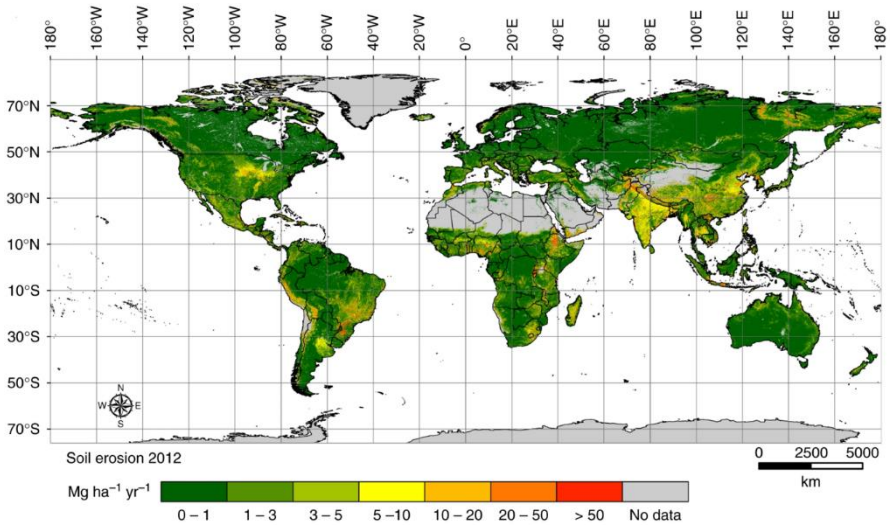



*Figure 8. Soil displacement rates due to water erosion, 2012 [16].*

Accelerated soil erosion is primarily due to changes in land use. Soils become more vulnerable to erosion, especially when forest areas are converted into agricultural land. Montgomery [17] stated that data obtained from a global research compilation confirm the claim that erosion rates in agricultural areas with traditional tillage are several times higher than in areas under natural vegetation. According to the researcher, although globally, soil formation and erosion in natural areas occur in a way that balances geological and climatic threats, agriculture based on traditional tillage increases erosion rates to the point of becoming unsustainable. Unlike traditional tillage, no-till agriculture is of great importance for sustainable agriculture as it will create erosion closer to the soil production amount.

When comparing soil erosion according to land use types, it shows great differences. It is estimated that soil erosion in cultivated areas around the world is 77 times higher than forest soils and approximately 7 times higher than natural vegetation soils [16].

It is possible to see a significant decline in soil erosion as a result of protective agricultural practices. For this purpose, in an evaluation made using modeling in the lands of 54 countries reported to FAO, an annual decrease of 7% in soil loss was reported [16]. It has been stated that, on a country basis, soil erosion has been reduced by a maximum of 33% in Argentina through protective agriculture practices. While the reduction rates in soil erosion were higher in less developed countries, the increases in reduction rates were lower in developed economies.

Soil is one of the world's most important natural asset that requires many years to form. The continued existence of life on Earth depends on its existence. Protecting soil as an asset and continuing its use in production will be possible by implementing environmentally sound approaches in human-soil relations, without wasting time. Some precautions that can be taken in this regard are listed below:

•Legal regulations must be made to protect soil and water resources and the deficiencies and problems in existing regulations must be revised and put into practice again.

•Soils should be classified according to their properties and land use planning should be made to ensure that the soils are used according to their capabilities.

•Protective measures should be taken in agricultural production, especially in areas prone to erosion. For this purpose, no-till or reduced tillage practices should be implemented and possible soil losses should be reduced by measures such as direct stubble-field seeding method or use of cover crops.

•Measures should be taken to protect and improve pasture areas. Also, excessive and uncontrolled grazing should be prevented.

•Since surface flows and soil losses will be high in areas with high slopes, agricultural production should be carried out after strips, contours, etc. applications are made in such places.

•In places with erosion problems, care should be taken in the selection of products to be grown and instead of hoe plants, production should be made with plants that require less tillage and grip the soil more tightly.

•Making drainage arrangements to prevent water accumulation in the areas which have problematic soils.

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MODULE 3

# Use of New Technologies in Irrigation for Sustainable Production and Protection of Water Resources under Climate Change Conditions

**Iuliana MOTRESCU**

## Outline

- Irrigation Under Climate Change
- Crop Irrigation Requirements
- Surface Irrigation
- Sprinkler Irrigation
- Drip Irrigation
- Irrigation Management and Scheduling
- Water Reuse for Irrigation
- Cloud Seeding

## Introduction

Water has an essential role in growing plants and obtaining high agricultural production independent of climatic conditions, having the most critical role in agricultural development. It ensures the transport of nutrients and photosynthesis products inside the plant, allows the solubilization of nutrients and their extraction from the soil by plant roots and is necessary for germination, sprouting and other functions. In modern agriculture, irrigation is used for multiple purposes. First of all, it has the physiological role of ensuring the water necessary for the growth and stabilization of agricultural production, in areas where precipitation is insufficient or unevenly distributed during the growing season. In addition to its main role, irrigation can be used for preventing crop compromise in fruit growing due to frosts or late spring frosts (this type of irrigation is known as anti-freeze irrigation), preparing the seedbed in good conditions after a prolonged period of drought (frequent situations during the summer period, before sowing the second crop, as well as in autumn, when sowing wheat), natural biological purification by irrigation of wastewater, thus avoiding expensive purification installations. In the culture of rice, flood irrigation is used (supplying plots and raising the water level in them) and for temperature regulation when sharp temperature drops occur (so-called thermal or thermoregulating irrigation). Also, using wash irrigation ensures the dissolution and washing of salts in the case of salinized soils. The efficiency of irrigation is still very low, with about half of the water being used by crops, which, under climate change conditions characterized by low water resources, needs considerable improvement for sustainable water management, sustainable agricultural practices and environmental protection. The lectures in this module present the existing technologies of irrigation as well as means for improved management of irrigation. We discuss the impact of irrigation under climate change conditions as well as the practices adopted for sustainable production and sustainable water management.

# IRRIGATIONS UNDER CLIMATE CHANGE

## Necessity and Scope

Irrigations refer to the operations and practices used to artificially supply the necessary water for the crops, especially during periods where there is not enough precipitation and soil has water deficit. These practices have been allowing people to have a food source independent of the reduced precipitations, such as during the dry season in tropical and subtropical areas. Irrigation seems like a simple procedure; however, many factors must be considered. First, the availability of water sources is crucial. Due to pollution and non-agricultural uses, sometimes finding a good water source for irrigation is challenging [1]. About 70% of the freshwater global resources are used in irrigation [2]. Water withdrawal from freshwater sources has been intensifying due to the increase in the demand for food. Among all regions, the most irrigations correspond to the highest populated countries (China, India) and the USA.

In this framework, it is necessary to adjust all agricultural practices, including irrigation such as it is adapted to climate change and does not induce climate change.



## Irrigation-Induced Climate Change

To overcome the need for food, either extensification of the arable area is done, or intensification of crop production on the existing land. The latter implies modern cropping technologies that make use of irrigation and increase production at least twice according to recent reports [4, 5]. On the other hand, with increasing irrigation, the depletion of freshwater resources increases, negatively influencing the biodiversity of these ecosystems.

The impact of irrigation on climate change is still not well known in all climate conditions, lacking observations in many agricultural areas. Some recent analyses of the evaporation patterns evidenced regional climate changes [6]. In agriculture, irrigations change the humidity and temperature near the surface of the soil. The impact of irrigation is scarcely studied, despite the extension of irrigation practices all over the world. The evaporation of the water in the atmosphere depends on several factors such as solar radiation, temperature, air humidity and wind, the extra amount of water in the atmosphere impacts the climate through a change in precipitations pattern and behavior, impacting further the availability of water resources in the ground. The heat fluxes at the soil level are strongly affected by irrigation. These changes are also believed to influence the production of convective precipitations, as it can be observed from the pattern of hail events in some areas for example, that became more extended in time and space. Overall, heat and water transfer in the atmosphere are changed in highly irrigated areas, having a powerful impact on the environment and changing the climate. Sustainable irrigation must consider all the factors starting from food security, the impact on the hydroclimate, the water quality, the impact on the soil and used energy.

An important issue is related to the water storage. The increase in water demand leads to a higher necessity for building infrastructures able to store water, such as reservoirs, dams. The water mostly comes from rivers flow, thus, its use in agriculture might influence not just the ecosystems but the hydropower production, might increase flood risks and implies extra operational costs thus water management is an important issue in this matter. At the same time, the lack of precipitation due to climate change affects and puts pressure on freshwater resources.

Intensification of irrigation results in increased application of pesticides and fertilizers that are leaching in the water cycle impacting the quality of the water. This influences the ecosystem and has great risks to human health affecting the quality of the water resources. Due to increased evapotranspiration, the salts concentrate at the surface of the soil, being then transported into water bodies, or just increasing the soil salinity and exposing the plants to salinity stress. Soil salinization leads to land degradation and decreased fertility which directly influences the yield since the amount of water that reaches the plants is limited by the salt accumulation in the soil. Planning the irrigation must also consider these aspects, for a better management of the water quality and a successful outcome of the irrigation of the crops.

A special case is that of the plants used as BECCS (bioenergy with carbon capture and storage). These are fast-growing species cultivated and their biomass is used to produce energy and, at the same time, is capturing a lot of carbon dioxide from the atmosphere. Overall, the growing process is assumed to have a good $CO_2$ sequestration potential, supplying important amounts of energy. On the other hand, growing such crops in climate - change conditions require large amounts of water, competing with other crops and inducing water stress. It is expected that biomass plantations will increase the water stress in the soil more than climate change by up to 20% up to about 90% of land areas in the future century [8], especially in highly populated areas and also in countries where large areas are cultivated with such plants. It is necessary to establish and implement water policies to limit the negative effects of intensive irrigation for biomass-producing crops.

## Impact of the Climate Change on the Irrigation

Due to global warming, rainfall patterns are altered, increasing water stress over a very large area that has been rainfed. Strong heat waves are also expected due to climate change, increasing the heat stress over crops and decreasing yield. At the same time, evaporation decreases and atmospheric $CO_2$ levels are increasing, such that in a warmer climate the crops would need more water. Thus, the highest sensitivity to climate change can be expected in the case of rainfed crops.

Studies have shown that only irrigation is not enough to mitigate climate changes. Even planned and highly controlled irrigation strategies were not able to lead to a maximum increase in yield in some areas [7]. Usually, irrigated crops give yields smaller than the potential yields because the plants are exposed to other factors, of which some are directly related to climate change (e.g., heat, drought and salinity stresses), some resulted from poor irrigation management practices that are not considering all the factors (e.g., availability of water sources, economic limitations).

The water requirement of plants changes under climate change conditions. Firstly, some factors modify the length of the plants' growth phases up to maturity, thus a change in the crop phenology affects the water demands and might influence the yield. This is why good management of irrigation is needed such as the needs of the crops are satisfied despite the climate conditions. We shall discuss in another chapter about best practices for irrigation management.

## Sustainable Irrigation

The water used for irrigation might have different sources and different methods are applied depending on the context. Freshwater ground sources are mainly employed (e.g. rivers, lakes), in some cases, the wastewater is treated such as it could be used for irrigation, or even the sea and ocean water can be desalinated for the same purpose. The technique of irrigation depends mostly on the crop, but

also on the energy requirements and other factors mostly cost-dependent. Therefore, the efficiency of the irrigation would also be different, it has been reported that the most efficient is drip irrigation, followed by sprinkler and surface irrigation.

The biggest issue in this situation is that most of the irrigation is not sustainable, meaning that water consumption strongly depletes the freshwater reserves. Among the results of unsustainable practices, we can name the negative effects on the aquatic ecosystems and degradation of soil and flows, which are threatening water and food security. Based on these effects, new measures should be considered to limit the negative effects, thus making irrigation more sustainable. These mitigation practices include reducing the water demand by adapting the crops and creating drought-resistant plants, increasing the efficiency of water use and keeping soil moisture by reducing evaporation and enhancing water infiltration (e.g. no-till farming technology, removing weeds, increasing the efficiency of the irrigation systems, implementing rainwater harvesting to supplement freshwater resources for irrigation, employing regenerable energy resources to operate the irrigation systems).

Two approaches are currently considered for the implementation of sustainable irrigation under climate change conditions:

•**soil-based solutions** - these are in connection with the physical factors that determine yield and crop efficiency. These solutions are meant to:

- increase the moisture of soil, by reducing evaporation and decreasing soil exposure to sunlight,
- improve the water retention in soil,
- use efficient irrigation techniques to keep mild water stress conditions for the plants and use alternative green energy sources to operate the irrigation systems as well as adopt techniques focused on the harvesting of rainwater,
- use technologies that improve the retention of water in soils,

•**crop-based solutions** - which are meant to:

- increase the resistance of plants to drought stress,
- improve the water productivity of crops,
- use crops that behave better under water stress,

The expansion of irrigation could negatively impact many levels, influencing food security, the environment (hydroclimatic feedback, water resources and quality, energy used, etc.), soil salinization and so on.

Another sustainable option for protected cultivation is represented by greenhouses that are managed by automatic systems that control water use and increase its application efficiency for maximum productivity.

## Conclusions

Many areas have been affected as a result of irrigation which led to a change in the precipitation and temperature pattern due to the increase in water evaporation. More water at the soil level increases the evapotranspiration rate changing the energy balance at that level, resulting in changing the temperature gradients and thus, the heat transfer in the atmosphere. Despite reducing the effects of high temperatures, the moisture resulting from irrigation produces a warmer climate due to the increased air humidity. This represents the hydroclimatic feedback of irrigation. Intensive irrigation might also induce increased salinity in the soil due to an increased evaporation rate, soil salinity having mostly a negative impact on the crops.

For sustainable irrigation systems, it is necessary to consider all the above-mentioned aspects related to external factors. Planning irrigation systems for different crops usually takes into consideration the type of crop and climate factors. However, in the frame of climate change, more aspects need to be considered to achieve sustainable irrigation practices, such as:

•Choose to grow plants suitable for the respective area considering the climate conditions and water resources for irrigation

•More attention should be paid to the hydroclimatic feedback and changing heat transfer patterns in the irrigated areas

•Consider the effect of other abiotic factors, such as heat stress and salinity stress and, if possible, use crops that have a positive response to this abiotic stress, crop rotation and diversification can also be mitigation measures

•Envision water storage infrastructures suitable for the respective area where irrigation is used such as to have a minimum impact on the ecosystem and other activities that make use of those water resources

•A better control of the application of different chemicals (e.g. pesticides, fertilizers) since these are expected to be found in soil and water in the irrigated area and not only

•From the economic point of view an estimation should be made to evaluate irrigation as cost-efficient practices

•The implementation of measures to mitigate the negative effects of climate change through irrigation must consider the combination of the above-mentioned factors, rather than individual actions.

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# CROP IRRIGATION REQUIREMENTS

## Necessity and Scope

Less than 65% of the water used for irrigation is actually used by plants. Moreover, different crops have different water requirements, depending on their development stages and some other parameters. In this lecture, we discuss about determining the needs for water of different crops, such as adopting sustainable irrigation practices and using suitable technologies [1].

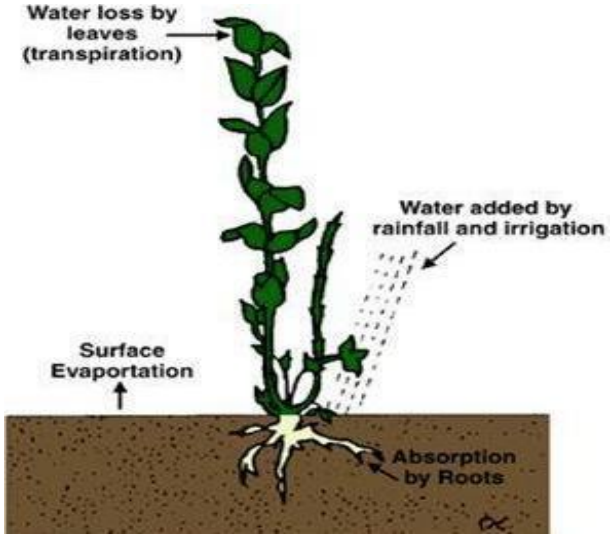



*Figure 1. Water loss and absorption in plants*

## The Crop Water Needs

The water needs of a crop represent the amount of water necessary for the plants to overcome the water loss due to evapotranspiration, such as the crop has optimum conditions for growth and the production reaches the maximum under the existing environment [1]. The parameters that determine the water needs of a crop are:

1. The climate (which directly influences the evapotranspiration process),

2. The type of the crop (different species need different amounts of water for their development),

3. The phenophase when irrigations are applied (during the last stages of development, the plants might require more water than during the first development stages).

## Influence of the Climate on The Water Needs of The Crops

The water necessary of a crop is strongly determined by the environmental conditions: temperature, humidity, sunshine, precipitation and wind. In humid climates, there is enough precipitation to satisfy the needs of the plants for water, here the issue lies with too much water existing on the field, a problem that can be solved with drainage systems. In sub-humid and semi-arid climates, there are still important precipitations but they are not always covering for the plants needs, especially during the dry season when irrigations are mandatory. In semi-arid, arid and dessert climates, growing any crop without irrigation is impossible. The irrigation water demands are defined by FAO-56 [1].

In hot, dry and windy areas, the crops need for water are the highest, while the lowest are in cool, cloudy and high humidity, with fewer wind zones. These factors are incorporated in a parameter called reference crop evapotranspiration (ETo), expressed in milliliters per time unit (e.g. day, month, season) [1, 2]. The reference crop is grass and thus, the reference crop evapotranspiration represents "the rate

of evapotranspiration from a large area, covered by green grass, 8 to 15 cm tall, which grows actively, completely shades the ground and which is not short of water" [1].

The reference crop evapotranspiration rate can be determined experimentally (using an evaporation pan), or it can be theoretically calculated, based on climatic data (e.g. Blaney-Criddle method). Experimentally, several evaporation pans are used, such as Class A or Sunken Colorado pans. The pan is installed in the field and a known quantity of water is placed in the pan (the pan surface and water depth are known or measured), the water evaporates during a time interval (e.g. 24 h), and the remaining quantity is measured at the end of the time interval (including the eventual precipitations). The evaporation in the pan has to be multiplied by a pan coefficient to determine the reference crop evapotranspiration, as follows: ETo = Kpan × Epan where ETo is the reference crop evapotranspiration, Epan is the pan evaporation and Kpan is the pan coefficient [1]. In case the level of water drops very much, then water is added by measuring its depth before and after the addition, the same is in the case of precipitations. The pan coefficient depends on the type of pan, location and climate, the values varying between 0.35 and 0.85 for the Class A evaporation pan and 0.45 and 1.10 for the Sunken Colorado pan.

A theoretical method can also be used to determine the reference crop evapotranspiration rate, namely the Blaney-Criddle method. It is based on the mean daily temperature: ETo=p(0.46 Tmean + 8) where p is the mean daily percentage of annual daytime hours and Tmean is the mean daily temperature. The mean temperature is evaluated as the average between the minimum and maximum average temperatures during the month. The mean daily percentage of annual daytime hours can be found depending on the approximate latitude of the area. The accuracy of this method is low, in extreme climatic conditions being just a rough estimation of the order of magnitude. Depending on the climate and mean daily temperature, the value of the reference crop evapotranspiration rate changes as it is shown in Table 1 [1].



*Figure 2. Circular pan for the estimation of the reference crop evapotranspiration*

*Table 1. Estimated values for the reference crop evapotranspiration rate*

| Climatic Zone | Mean Daily Temperature | | |
|---|---|---|---|
| | Low (<15℃) | Medium (15-25℃) | High (>25℃) |
| Arid | 4-6 | 7-8 | 9-10 |
| Semi-arid | 4-5 | 6-7 | 8-9 |
| Moist | 3-4 | 5-6 | 7-8 |
| Humid | 1-2 | 3-4 | 5-6 |

2. The influence of the type of crop can be introduced in the formula by the crop factor, $K_c$, to determine the evapotranspiration rate of a specific crop. The formula is as follows: ETcrop=ETo × Kc

The crop evaporation rate is measured in the same units as the reference evapotranspiration rate. The crop factor depends also on some factors: the type of crop (e.g. some plants have larger leaves, thus the evapotranspiration rate is increased and the crop factor is higher than the unit because this specific crop uses more water than the reference grass, for other species that use less water, the crop factor

is smaller than the unit), the phenophase (e.g. the crops usually use more water when fully developed compared to those in the first phenophases), and the climate (e.g. the climate determines the phenophases and, thus, growing period, such as in colder climates the plants grow slower than in warmer ones). The crop factor depends on specific parameters such as the duration of growing season and the also the duration of some important phenophases. The first one can be determined by knowing the species, climate conditions and planting date. Just for example, carrots have 100-150 days growing period, maize 120-180 days, green onions 70-95 days and rice 90-150 days [3-8].

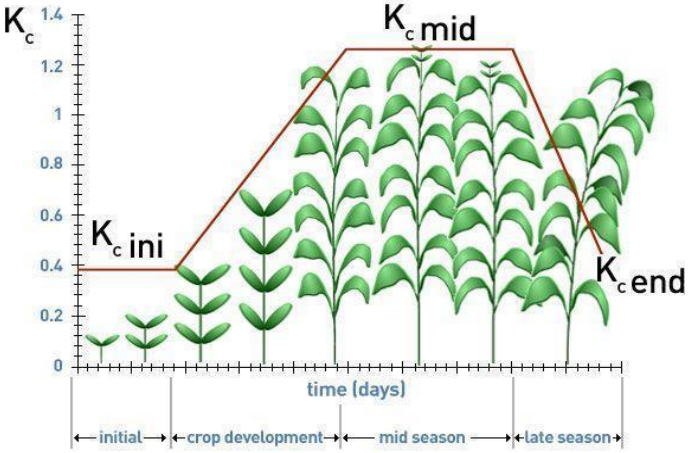



*Figure 3. Crop factor change during the growing stages*

In the frame of the above-discussed information, the growing period is divided into 4 stages:

•stage 1 - the initial stage - from sowing or transplanting of the crop until it covers 10% of the ground

•stage 2 - crop development stage - from the end of the initial stage until the crop will totally cover the ground

•stage 3 - mid-season stage - from the end of the crop development stage until the plant reaches maturity

•stage 4 - late season stage - from the end of the mid-season stage until the crop is harvested.

Because the crop factor changes each month, thus the crop evapotranspiration rate changes in time, making it necessary to calculate it monthly. There are also some special cases. For example, alfalfa and clover are regularly cut, thus after cutting they will be again in the initial stage. One way to overcome such situations is to consider the average values for the crop factor. Rough estimations are done for different types of crops to determine the crop water need and sensitivity to drought [3-8].

## Irrigation Water Needs of Crops

Usually, the water necessary for the crops is provided by rainfall. When this water is not available due to a lack of precipitation, the irrigation water need (IN) equals the crop water need. When there is still some precipitation, then the irrigation water need would be the difference between the crop water need (ETcrop) and the water from precipitation effectively used by the plants, named effective rainfall, (Pe), thus: $\mathrm{IN} = \mathrm{ET}_{\mathrm{crop}} - \mathrm{P}_{\mathrm{e}}$

The effective rainfall can be determined from the difference between the total quantity of precipitation and the evaporation, runoff and percolation amounts, representing the quantity of water that remains near the roots of the plants.

As a result of the above-discussed estimations, in order to determine the irrigation water needs of some specific crop, all the discussed factors should be first evaluated, as previously discussed and finally, the irrigation water need of the respective crop can be determined. This is called the FAO56 method and uses a very simple approach to determine the evapotranspiration of a crop. The standard

crop factors are tabulated. However, they refer to standard climates and need to be adjusted to local climates. In such conditions, the standard potential ETc is replaced by the actual crop evapotranspiration, ETact and the standard Kc is replaced by actual crop factor Kc act which is the product between the crop factor, Kc and a stress coefficient, Ks, which corresponds to the water or salinity stress and can be extended to other types of stress as well.

Crop water requirements (CWR) represent the amount of water that a crop needs to achieve its potential production under some known environmental conditions. The net irrigation requirements (NIR) represent the quantity of water that needs to be applied to satisfy its water requirements and is calculated by subtracting the precipitations, capillary rise and soil water storage variation from the CWR and adding the deep percolation from the soil root zone (DP) and the runoff (RO). In this way, the gross irrigation requirements can also be defined as follows [3]: $\mathrm{GIR} = \frac{\mathrm{NIR+LR}}{\mathrm{BWUF}}$

where BWUF is the beneficial water use fraction, also called application efficiency, or combined conveyance, distribution and application efficiency when the operational losses in canals are considered.

## Crop Water Stress Detection

Plant water stress can be detected as a decreased soil water content or a physiological response of the plants to water deficit [8-14]. A rough estimation of the crop water necessities is not enough for sustainable and efficient irrigation. There are several methods used to quantify the crop water stress in order to implement optimum irrigation scheduling.

1. Soil water measurements include:

•the gravimetric method (the soil is dried and weighed before and after to estimate the amount of water),

•soil moisture sensors (neutron probe, TDR and FRD based on the difference of the dielectric constant of water and soil),

•tensiometers (measure the water potential),

2. Soil water balance approach (the soil moisture is determined through calculations)

3. Plant-based approaches

•stomatal conductance,

•leaf water potential,

•relative water content,

•sap flow measurements,

•stem and fruit diameter,

4. Remote sensing

•infrared thermometry (the canopy temperature increases as a result of water stress),

•spectral vegetation indices: structural indices (the reflectance indices in VIS and NIR spectral range are measured), xanthophyll indices (measures the photochemical reflectance index linked to the xanthophyll cycle), water indices (measures the reflectance in NIR region to determine the canopy moisture content) [5].

Conventional methods used to monitor water stress are based on moisture measurements and meteorological data. The soil near the roots is sampled and the water depletion is estimated. The method is not very accurate because it assumes a uniform plant density, the same transpiration rate for all the plants. The evapotranspiration methods described above are time-consuming giving

sometimes unreliable information. Other methods use stomatal conductance and leaf water potential to give an image of the plant water status.

Remote sensing is a newly proposed method to detect water stress in plants through spectral reflectance indices. Such a technique is more related to irrigation scheduling and we shall detail it in another lecture. These technologies have been proposed for many years, but with the latest development in high-resolution thermal cameras, they have become more popular [5]. Some recent papers also suggested the integration of remote sensing data with soil water balance to optimize water management in irrigation. The spectral properties of the leaves do not depend only on the water status, the soil background, canopy structure, leaf thickness and age and some other similar factors can influence the spectral response related to plant water status. Currently, there is undergoing research to increase the precision of such methods since remote sensing allows real-time monitoring of water stress in plants, can cover large areas and allows fast processing of the information, thus, offering the possibility to take action fast [12-14].

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# SURFACE IRRIGATION

## Measuring the Amount of Water Consumed by Irrigated Crops

Due to the increase of the population and climate change, the demand for freshwater resources has been considerably increasing, the irrigations depriving other industrial sectors of water resources. Thus, it is very important focusing on ways to make the use of water more efficient for sustainable agricultural production. Such practices comprise at least the following optimal irrigation scheduling (which makes use of smart irrigation systems, controlled remotely, coupled with monitoring systems for soil, plants and water, etc.) [1]. Precision agriculture provides solutions for different issues related with the resources used by farmers, including freshwater for irrigations. Conventional irrigation systems do not care so much about the changes in soils and weather changes that determine the evapotranspiration, leading sometimes with a larger than needed quantities of water, fertilizer leaching, surface runoff, ponding, deep percolation, plant stress. Knowing when and how much water to apply, is directly determining the efficiency of the water use. To do that, a deep understanding on the water use of the plants is necessary, with deep connections to the characteristics of the soil and climate conditions. In this framework, determining the amount of water consumed by crops is a crucial element. This can be done by the following techniques [2]:

1. Using lysimeters

2. Evaluating the water balance

3. Evaluating the soil moisture depletion

The total water consumed from vegetation covered soil includes both evaporation from the soil and evapotranspiration of plants. At the surface of the soil, water evaporation depends on environmental factors (saturation deficit, temperature, radiation, wind) which determine the atmosphere requirements for water and factors depending on the soil (soil humidity, the presence or absence of water sources, properties related to the movement of the water in soil). For agriculture, the evaporation of the water from the soil is unproductive.

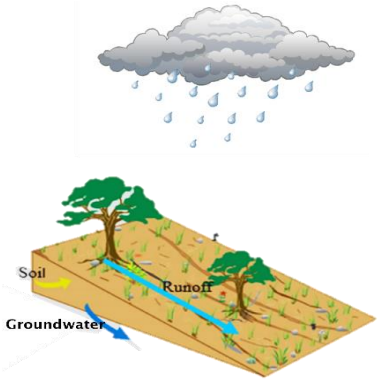



*Figure 1. Schematics of water circuit*

## General Considerations Related to the Evapotranspiration

Soil water is also consumed through evapotranspiration which contributes to the formation of the vegetal mass of the crops. The biomass incorporates a little over 1% of the water consumed through evapotranspiration, the rest of the water is translocated from the soil through the plant contributing to different physiological processes such as regulation of the temperature, absorption, assimilation, etc. The transpiration depends mainly on the soil moisture and the water requirements of the atmosphere. If the soils are well provided with water, the intensity of transpiration is regulated according to the water content of the atmosphere, but if the soil does not have enough water, the transpiration rate decreases rapidly. At high water requirements (over 3 mm per day) the transpiration

rate decreases even if the soil has good moisture and the process is done by the reduction of the size of stomata. Of course, the transpiration depends on the type of the plants and its development state, as previously discussed in the chapter regarding crop water needs.

In agricultural practices, an important parameter is the total amount of water lost by evapotranspiration, ET. Generally, in temperate climate conditions in the northern hemisphere, the highest water consumption is recorded in July when most crops have maximum biomass, the soil and air temperatures are high and nebulosity low. The average daily consumption strongly varies depending on the dynamic of plant growth, the succession of the vegetation phases and climate condition changes, especially the temperature. In spring crops that have long vegetation, the daily consumption increases in time reaching the maximum value during the critical phases for humidity - flowering, forming of the seeds, ripping - when the plants are fully developed and maximum transpiration. These phases also correspond with high evaporation needs of the atmosphere due to increased temperature, saturation deficit of water vapor and wind. After the critical phases of the plant growth, the total water consumption decreases.

Evapotranspiration can be expressed using several quantities:

•Potential evapotranspiration (PET) represents the amount of water that would be evaporated and transpired by a specific crop, soil or ecosystem if there is enough water available. It defines the water consumption in soil when its moisture is closed to field capacity and the land is covered with an active and well-developed vegetative cover of about 15-20 cm. In this state, nor the soil moisture nor the development stage of the plants limit the evapotranspiration which mainly corresponds to the evapotranspiration requirements of the atmosphere.

•Maximum evapotranspiration (MET) represents the water consumption of the soil when it is well provided with water and the plants (a specific culture) covers the land. In this situation, the plant is the only factor influencing the evapotranspiration.

•Optimum evapotranspiration (OET) represents the water consumption, between the field capacity and minimum moisture content which favor obtaining an economically efficient crop and the plants are in the vegetative development stage. In this case, the influence of the soil moisture on the evapotranspiration is negligible, the only limitation comes from the water consumed by the plant depending on the needs during the respective vegetative state.

•Real evapotranspiration (RET) expresses the water consumption in normal conditions, meaning when the soil moisture corresponds to the normal local meteorological conditions. Its value is influenced by the soil moisture and by the plant as well.

The relationship between these four evapotranspiration parameters is: RET≤OET≤MET≤PET

## Evaluation of Irrigation Water Needs

To determine the irrigation water needs, direct and indirect methods can be used. Direct methods make use of field calculations based on the evaluation of the water balance in soil using parcel method or lysimeter vessels [3].

The method of optimal irrigation of a parcel of land is a reference to determine the water needs of an irrigated crop and consists of establishing some irrigation parcel of lands where an optimal irrigation regiment is adopted. In this way, all through the vegetation season, the optimum moisture is ensured in the soil on a depth corresponding to the size of the roots of the culture. The dynamics of soil moisture between seeding and harvesting of a specific culture is followed closely, with measurements made every ten or fourteen days and after precipitation or irrigation events. The irrigation water needs are determined and expressed as the average daily consumption (in $m^3/ha \cdot day$) using the following equation: $OET = Ri + Pv + M - Rf$

Where OET is the water consumption during the studied time frame, Ri is the water reserve in soil at the beginning of the time interval, Pv represents the precipitation during the considered time frame, M is the sum of irrigation quantities or the supplementary amount of water distributed to the plants to maintain the soil moisture between the field capacity and the minimum moisture content and Rf represents the water reserve in soil at the end of the considered time frame.

This method has the advantage of allowing a precise estimation of the irrigation needs of a specific crop. It also has some drawbacks due to the high volume of work necessary to sample and measure the moisture, as well as the impossibility of a precise evaluation of water leaks mostly through percolation under 1.5 m depth.

The lysimeter method uses some parallelepipedal or cylindrical vessels, with a surface of 1 to 4 m² and the depth of 0.8-1.2 m, made of a metal sheet of 2-3 mm thickness or concrete. The bottom has a drain which allows the excess water to be collected. On the bottom of the lysimeter there is a drainage layer of 30-35 cm on which the soil is placed to cultivate a specific crop for which the water needs are determined.

Lysimeters are placed in the field, in batches of 3 for each crop, within an irrigated parcel of land of about a quarter of a hectare to ensure the same microclimate as the crop. All operations are made in the same conditions as for the field crop. A schematic of a lysimeter is presented in Figure 1.

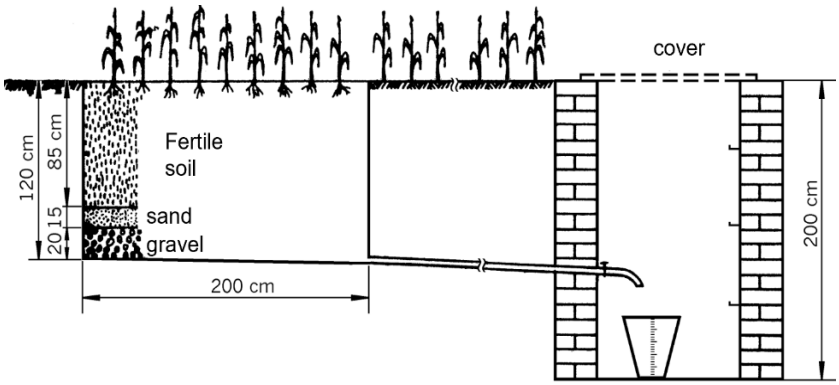



*Figure 2. Schematic representation of a lysimeter*

The necessary of water in the lysimeter is ensured either from periodical wetting or from a reservoir with constant level placed over the drainage layer through the principle of communicating vessels. For periodical wetting, which is the easiest way to provide the necessary water, the time interval of applying is usually 5 days. Wetting is applied such as to ensure slightly higher water amounts than the retention capacity of the soil. The extra water evacuated through the drainage at the bottom of the lysimeter is measured and recorded. Soil moisture before starting the crop and at harvest time are measured from soil samples. In this case: MET = Ri + Pv + M - Rf - D

where all the parameters as those previously mentioned and D represents the amount of water from drained from the lysimeter.

The estimation of irrigation needs through the lysimeter method allows a precise calculation of the maximum evapotranspiration on short time spans allowing the monitoring of water needs variations during different vegetation stages, critical phases and as function of special meteorological conditions such as very high temperature, heavy rains and so on.

Indirect methods are based on the dependance of the plant water consumption on some climatic factors, are operative and economical with reasonable results. The connection between crop water needs and climate factors is expressed through empiric formula that are used to determine the evapotranspiration. Some of these indirect methods are also based on measuring the evapotranspiration using atmometers or evaporimeters. The most appropriate formula proposed by

Thornthwaite expresses the potential evapotranspiration as function of the average monthly air temperature, multiplied with a correction coefficient depending on the latitude:

$$\mathrm{PET} = 160 \cdot \left(\frac{10 \cdot \mathrm{t_n}}{\mathrm{I}}\right)^{\mathrm{a}} \cdot \mathrm{k_\phi}$$

where $PET$ is the potential evapotranspiration, $t_n$ is the average monthly temperature for which the PET is calculated, $I$ the annual thermal index of the area, equal to the sum of monthly thermal indexes $\mathrm{I} = \sum_{\mathrm{n=1}}^{12} \mathrm{i_n}$, $\mathrm{i_n} = \left(\frac{\mathrm{t_n}}{5}\right)^{1.514}$ is the monthly thermal index (for negative monthly average temperatures, the monthly thermal index is considered zero),

a = 0,000000675.I³ - 0,0000771.I² + 0,01792 I + 0,49239 and $\mathrm{k_\phi}$ is a correction coefficient for the latitude of the place [5]. To determine the values of OET, the values of PET are multiplied with correction coefficients characteristic for a specific crop and climatic area.

The method based on measuring the evapotranspiration is largely used for determining the irrigation needs. The evapotranspiration is measured using Piche and Bac A class evaporimeters. To determine the OET, the evapotranspiration rates are multiplied just as the values calculated based on the Thornthwaite equation, with empiric correction coefficients, specific to a crop, month and climate area. The coefficients are established based on following the water consumption (through the optimum irrigated parcel method) in parallel with estimating the evaporation using evaporimeters and making the ratio of the two average consumption values, depending on the crop and on some specific time intervals: $\mathrm{K_p} = \frac{\mathrm{OET}}{\mathrm{E_p}}$

where Ep is the water collected in the same interval in an evaporimeter. Using such devices to estimate the water consumption of crops has advantages, because these are simple instruments that can be made with low costs, on one hand and are easily maintained without the need of a specialist.

The Piche evaporimeter is presented in Figure 3. It consists of a graduated tube with a length of 30 cm, filled with distilled water and inverted on a disc (3 cm diameter) made out of filter paper. The device can be hung from a stand. It measures the evaporation rate of the water from the surface of the paper disc that is kept wet constantly. The readings are made daily at the same time.

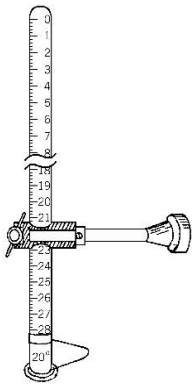


*Figure 3. Piche evaporimeter*

Bac class A evaporimeter (Figure 4) is composed of a cylindric vessel of 120.65 cm diameter and 25.40 cm height, made out of hard metal sheet of 1.5 mm thickness, painted in white color. It is placed on a wooden grid of 5×10 cm, with a bitumen treated plank placed over a horizontal well compacted soil. The evaporimeter is placed under a rectangular cage (16×16 m) where perennial plants are cultivated, always cut at the height of the vessel. The readings are done inside a metallic cylinder with a micrometric device having a 0.02 mm precision. This cylinder has the role to ensure higher precision of the readings, without any errors generated by waves. At the beginning of the season, the evaporimeter is filled with clean water, 5 cm under the top of the vessel to avoid water losses and provide a reserve for the water accumulated from precipitations.

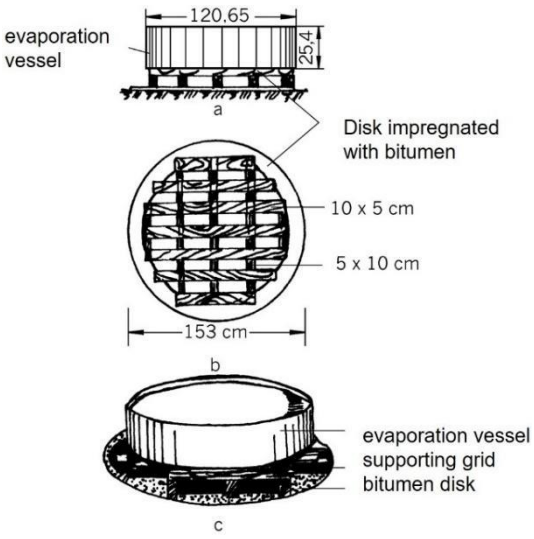



*Figure 4. Bac class an evaporimeter.*

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# SPRINKLER IRRIGATION

We have previously shown that surface irrigation, the method widely used, is very inefficient and not sustainable. As newer modern alternatives there are sprinkler irrigation and drip irrigation. Sprinkler irrigation or "artificial rain" has good application efficiency that depends on the climate conditions (e.g., wind, temperature, humidity). The water is firstly distributed with pressure in a system of pipes, then spreads on the soil surface. The method is suitable for small and large fields as well and for all types of crops. The watering equipment can be mobile, semi-fixed, or fixed. It can also be used for moistening, as antifreeze and with thermal purposes, as well as for improving the quality of fruits [1-4].

## Operation Principle

The sprinkler irrigation has many variants, from simple gear-drive sprinklers used to irrigate lawns and gardens, to industrial equipment. A sprinkler system has the following components:

•pump unit - it is usually a centrifugal or turbine pump that provides pressured water (from the water source) into the pipe system. The use of a specific type of pump is chosen depending on the water source, when the source is a deep well, a turbine pump is preferred. Centrifugal pumps are preferred when the distance between the pump and water source is small (less than 8 m)

•main-lines, sub-main-lines and laterals - main and sub-main lines are pipes that take water from the pump to the laterals, being sometimes buried. The laterals are mobile pipes that take the water to the sprinklers. These pipes are usually made of aluminum or PVC for portable systems and cement, PVC, wrapped steel for buried laterals or main lines.

•sprinklers - the sprinkler head has the important role of uniformly distributing the water over the field, without runoff or water loss due to percolation. The sprinkler heads can be either fixed or rotating, depending on the necessities, with different distance operation ranges (10-70 m). Sprinklers are made of metal, plastic, or a combination of the two. The type, working pressure, sprinkling area, mobility and other parameter differentiate between the sprinklers [5-7].

•optional equipment - to operate a sprinkler irrigation system in optimum conditions, optional equipment can be used. Different information collected can be transmitted remotely, or some parts such as the water flow can be also controlled remotely.

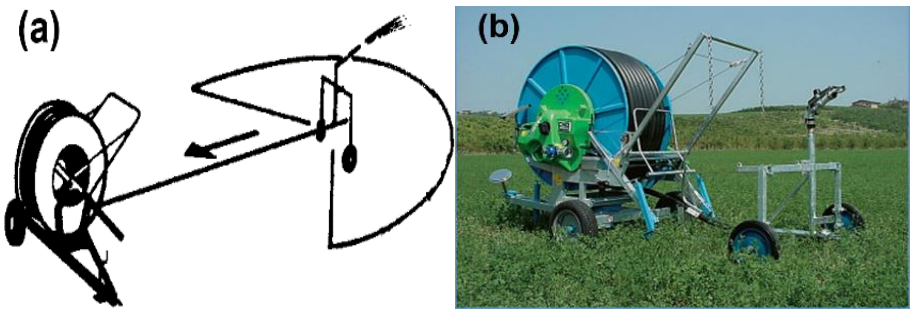



*Figure 1. (a) Schematic representation and (b) real equipment of drum and hose sprinkler system*

The mobile sprinkler equipment can be built as in-ground sprinkler systems with the following configurations:

a) where high pressure buried ducts are used, for which the pressure necessary to sprinkle the water is created by the sprinkling equipment coupled with hydrants at the pressure duct system

b) where low pressure buried ducts are used, the pressure in the sprinklers being given by some pumps connected to the main-lines and that push the water in the laterals

c) with channels, the working pressure in the laterals being produced with pumping equipment that takes the water from the channels either directly to the laterals or to the mainline.

The sprinkler system with drum and hose (Figure 1) is a mobile system that ensures the water needs for any crop. It has the following component parts:

•the metallic frame is equipped with two wheals such as it can be easily moved, it has two supporting legs and an adjustable jack.

•the frame holds a drum, the mainline, a hydraulic system used to operate the drum, suspending frame for the truck and a brake system

•high density polyethylene hose, with a length of 300 to 750 m, an external diameter of 75 to 160 mm and a wall thickness of 8 mm, the hose is rolled on the drum

•the sprinkler system consisting of two reactive sprinklers, ARS-2, placed on a four wheels truck, that spread the water in a circle sector



*Figure 2. Sprinkling irrigation system with center pivot.*



*Figure 3. Round areas irrigated with center pivot systems.*

When the device has a fixed position, it can irrigate an area with the length equal to that of the hose and 54 m wide. In each working position, before the sprinkling, the hose is spread along a corridor with no plants over a 2.1 m distance, operation performed by moving the metallic supporting truck using a tractor [5]. When the sprinkling starts, the hose is also pulled back to the drum due to the hydraulic engine, which determines the move of the sprinkler support system. Because the irrigation takes place on circle sectors, the truck rolls on dry soil. When the sprinkling system reaches the drum, the water circuit is automatically stopped. The average speed can be tuned depending on the water necessary, working pressure and the types of sprinklers.

Self-moving sprinkling systems with central pivot (Figure 2) can be used in different configurations made of circles or/and circle sectors, as shown in Figure 3. The length of the wing can vary from 150 to 700 m, while the covered area can be of 5 to 250 ha. The system has a center pivot, with several pipe segments connected together and supported by trusses (spans), and mounted on wheeled towers. The water comes from the main line in the central pivot, that also supports the system. The sprinklers used work at low pressure and are different as function of the irrigated crop. To ensure the uniformity of the water distribution, the systems have pressure regulators in between the spans. The control panels are based on the Computer Aided Management System (CAMS) technology for remote monitoring of the system. In such way it is possible to adjust the intensity of the sprinkled water as function of the speed of the wind, introducing fertilizers or pest control chemicals and reversing the movements of the system. When the engines start, a system of transducers that estimates the angle between spans controls their operation, based on the information from the transducers the movement of the trucks starts. The speed of the spans can be adjusted to achieve a specific intensity of the rain. There are operational variants for which the center pivot can be moved as it can be seen in Figure 4. In both case the principle is the same, the only difference is the automatic/manually operated movement of the center pivot [5-9].

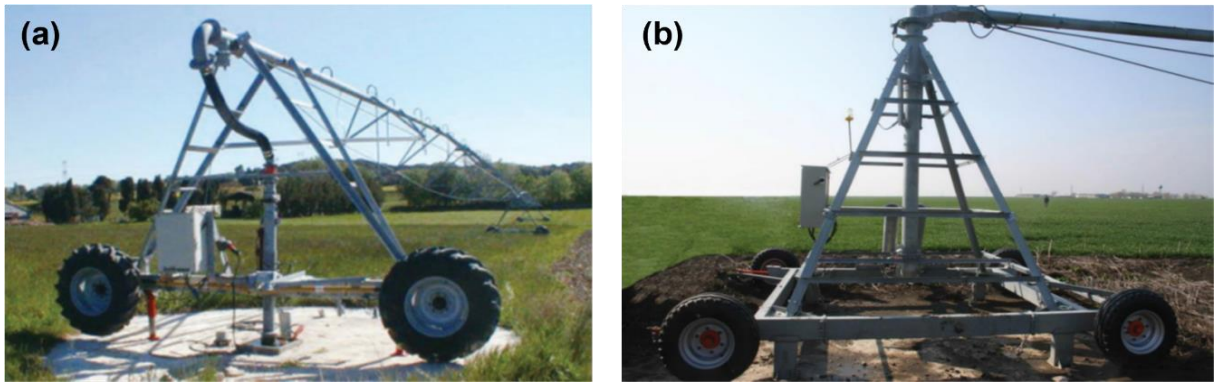



*Figure 4. Center pivot with (a) automatic movement system and (b) non-automatic movement system.*

This sprinkler system can be also used for fertigation, in this case there is a special reservoir in which the fertilizer is placed. The reservoir is connected to the irrigation water. Spreading the fertilizer during the vegetation period is advantageous because it decreases the costs, irrigation and fertilization being done simultaneous, the leaves and/or roots assimilate better the nutritive elements dispersed in water, increasing the efficiency of the fertilizers.

Fertigation is advantageous especially for the crops that behave better if fertilizers are applied during the vegetation but due to vegetation it is hard to perform the process using other mechanical means [10, 11]. Fertigation should be performed at specific times, the most important conditions being as follows:

•should be applied for crops with high minerals and water requirements during the vegetation stage. As an example, maize in the second crop, can be fertigated in all growing stages starting sowing.

•application mostly of nitrogen-containing fertilizers, because during the vegetation stage the plants usually behave better to addition nitrogen doses than phosphorus or potassium. In sugar beet crops, potassium-based fertilizers applied through fertigation favour the increase of sugar content of the roots.

•using highly soluble fertilizers is wanted, due to the fact that undissolved matter can clog the sprinklers

•the span of applying fertilizers should be short, 30 to 60 minutes, to ensure the controlled and uniform distribution. Moreover, the fertigation should take place at the end of the irrigation period, but before it ends such as the nutrients have the possibility to be absorbed and to avoid damages of the system through corrosion

•the sprinkler rain should have a good uniformity; thus, the fertigation should not be performed during windy periods.

The fertigation equipment is shown in Figure 5. It is a tank with two flexible pipes, one to introduce the water and the other to inject the water in the sprinkler system. The amount of fertilizer is calculated as function of the concentration of active substance and the dose to be distributed over the soil surface.

The sprinkler systems can be automatized such as to assess the water need in real time and activate/stop the water flow. Variable rate irrigation (VRI) is an automatic irrigation technology based on a matrix of sensors that detect the soil humidity. It is employed in precision agriculture to optimize the irrigation mainly by using center pivots. The change in the water amount is done by controlling a system of valves. Thus, optimized irrigations are performed, reducing the water consumption and increasing the production. VRI can be successfully be applied for fertigation and other chemigation methods with the use of supplementary equipment that inject the chemicals in the mainline and a pump system to send the solution at the correct pressure [12-14].



*Figure 5. The fertigation equipment to be used in center pivot sprinkler irrigation system.*

Linear move irrigation systems ensure high uniformity and efficiency, being suitable for rectangular shape fields. The system moves back and forth across a field. The water source can be diverse from lakes, rivers to channels and pipes. Several spans are connected in line, the system is moved by two or four carts. Compared to center pivot systems, they also cover the corners of the field. The movement of the line spans can be done also using cables. Water can be provided from the sides or from the middle of the system through high density polyethylene hoses.

There are several types of linear systems. The ideal system is a two wheeled linear, usually used in small size fields. A dich feed system uses the water from an earth ditch or canal as water source. Such a system is ideal for large fields, are easy to operate since the system is moving along the water channel. Hose feed uses water from a pressurized system. Due to the presence of the hose, it is more suitable for smaller than larger fields.

## Erosion Due to Sprinkler Irrigation

In the case of sprinkler irrigation, the water hits the soil at some speed, thus making possible the detachment of soil aggregates and fragments, which are then transported in the overland flow, and, at some points they are deposited. To avoid this situation, it is necessary to properly design and operate the sprinkler systems. Centre-pivot systems apply water with high debit which increases the potential to cause runoff and erosion. The most important component involved in erosion is the sprinkler type. The use of low-pressure sprinklers reduces the runoff, but only the application rate is reduced. The size of the water drops is also important. For the lateral moving systems, the runoff is common in wheel tracks if they run in parallel with the slope of the field. To limit or avoid erosion,

many measures could be taken, such as attention in choosing the sprinkler type, the pressure, diameter (that determines the size of water drops), to decrease the flow rate and limit the erosion without decreasing the efficiency of irrigation. Overall, this might be a difficult task.

## Advantages and Disadvantages of Sprinkler Irrigation

Implementing a sprinkler irrigation system does not require terracing or field levelling, being independent of the field topography [15-19]. The water necessity of the plants can be easily covered for any type of crop and soil, being also possible to simultaneously make fertilizer or pesticides treatments [20-21]. The use of a pressurized system requires a large amount of energy consumption, larger than the other irrigation technologies, as well as a considerable investment in equipment. Plants are prone to diseases since the water wets the surface of the leaves. The water consumption efficiency decreases in windy areas due to the water increased evaporation from the surface of the soil. Same as for drip irrigation, the system can experience clogging.

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# DRIP IRRIGATION

## Introduction

Traditional surface irrigation methods are not efficient and thus, new irrigation technologies have been developed to satisfy the water need of plants and have increased productivity. One of these methods, based on pressurized irrigation, is drip irrigation. Also called trickle irrigation it works with slow flows of water that is dripping on the soil near the roots of the plants. The technology can be easily adapted to different kinds of soils and fields with different slopes. It is a very efficient method since water is distributed only in the immediate root area of the plants [1-4].

Drip irrigation also offers the possibility to be used in combination with a water treatment plant. The amount of water needed is lower than for the other technologies by up to 50%, which is beneficial also since there will be reduced weed growth. The system can be also used to apply fertilizers, in this case, the technique is called fertigation [1-5].

## Basic Principle

The water flows through a distribution pipe system in which water circulates and reaches the soil through some special slow-release devices, located on the circulating pipes at different distances (Figure 1). In this way, water is efficiently applied to the plant roots, it limits evaporation and the problem of drainage. A very important part of the drip irrigation is a filter system for water because it ensures the flow without any clogging. Because there is a small flow rate of water application, the irrigation is done more frequently than with the other methods [5].



*Figure 1. Example of a drip irrigation system*

A typical drip irrigation system consists of a pump that ensures the right pressure for the water to be delivered through the pipe system, a control head, which is composed of a filtering system, a water measuring system and a valve system that regulates the pressure, some could also have a tank for the fertilizer, as we shall later discuss, mainlines, sub-mainlines and laterals that guide the water into the field and drippers, some devices used to control the water discharge to the plants. The distance between the emitters depends on the type of crop and is given by the spacing of the plants in the field. The schematic representation of a drip irrigation system is represented in Figure 2.

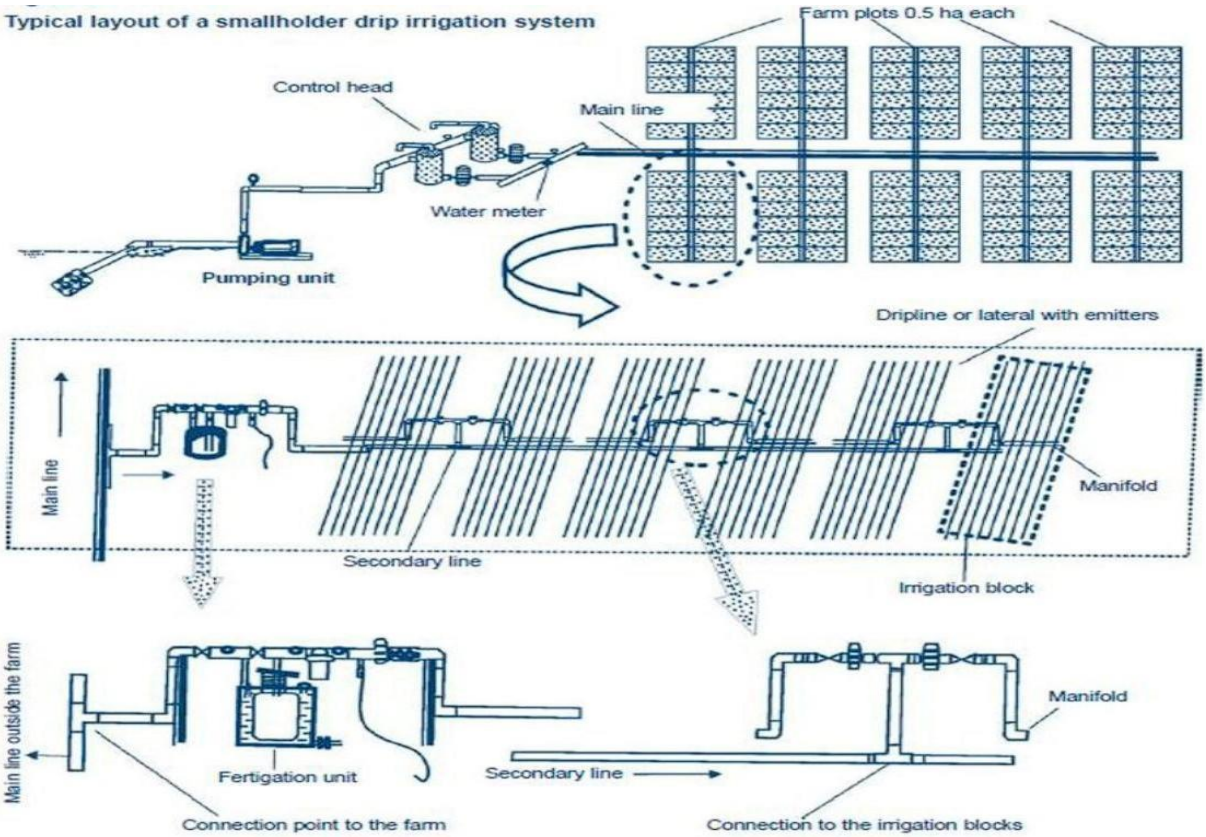



*Figure 2. Typical schematics of a smallholder drip irrigation system*

The emitters control the amount of water as well as flowing rate delivered to the plants, being an essential part of the irrigation system [5]. They can be divided into two large categories, depending on their connection to the lateral (Figure 3):

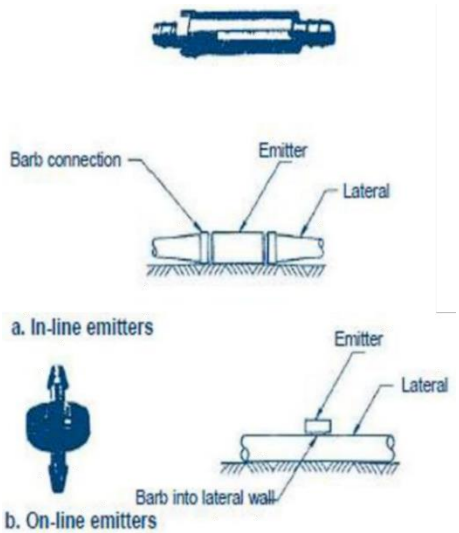



*Figure 3. Schematics of (a) in-line emitters and (b) on-line emitters*

1. on-line drippers are found on top of lateral pipes, mostly used in groves, orchards and sometimes for in-pot irrigation, they can have different diameter sizes (12 to 22 mm) and are usually mounted on top of polyethylene pipes through manual punch.

Depending on the mechanism used to dissipate the pressure (Figure 4), the emitters can be:

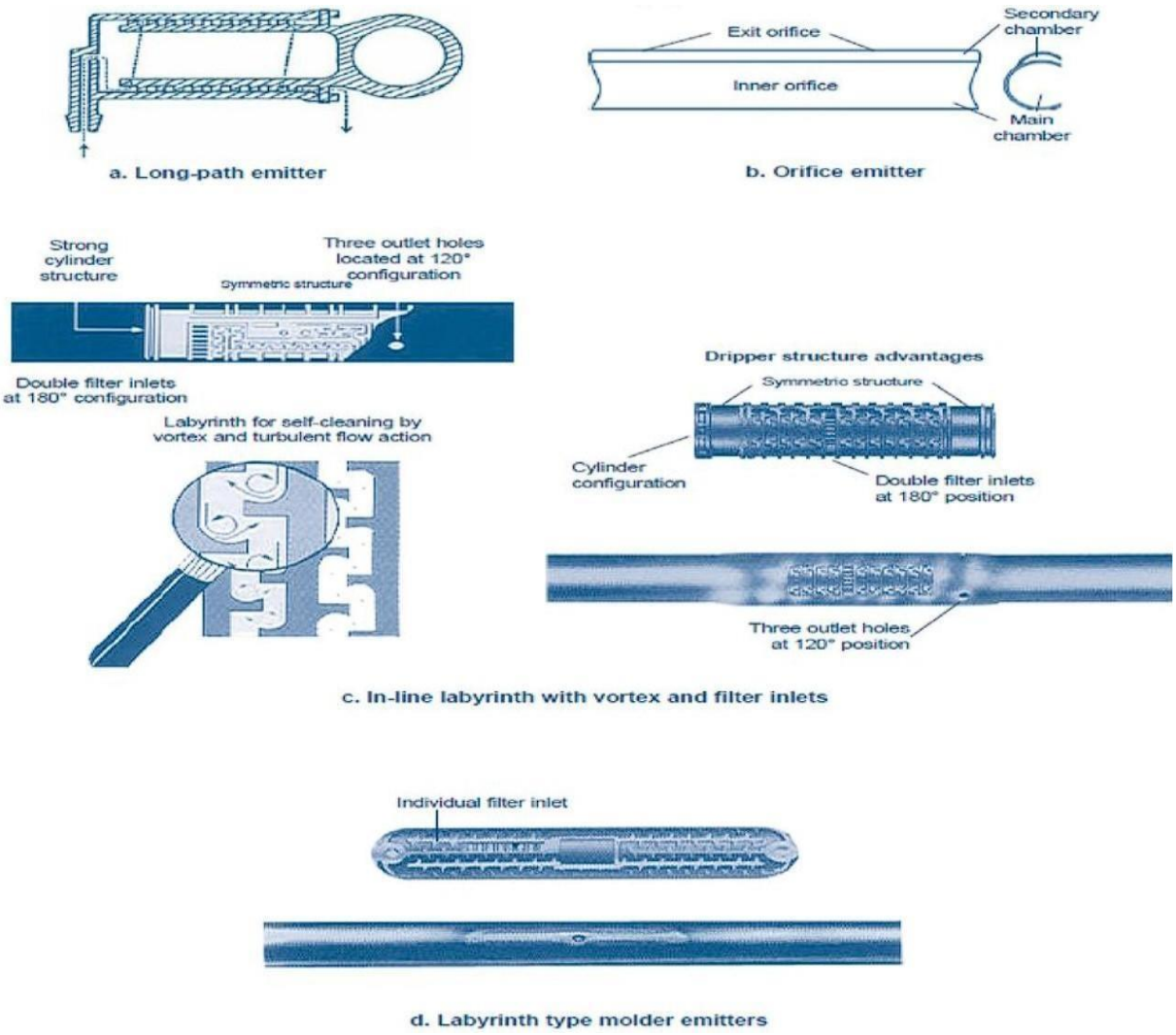



*Figure 4. Different types of emitters used in drip irrigation*

•long-path emitters - large-size emitters that have long water paths circling around a centre point. They are characterized by a laminar flow

•short-path emitters - the water path is shorter and these emitters work well in small pressure systems allowing the fall of water due to gravity

•turbulent flow emitters - they have relatively long flow paths or short paths but large cross-sections such as the flow regime is turbulent

•vortex emitters - the water flows through a round cell that produces a circular flow and, thus, the pressure is reduced, decreasing the rate of flow drops. The circular motion takes place because the water enters tangential to the outer wall, producing a fast rotation movement that creates a vortex. That is why it is called a vortex emitter. This configuration allows the use of large openings, thus, the system is less susceptible to clogging

•diaphragm emitters - these emitters use a flexible diaphragm, sometimes with holes, which reduces the flow and pressure. A disadvantage is that the membrane can become distorted in time

•adjustable flow emitters - design wise they are similar to short-path emitters, allowing a high flow rate than the other types

•mechanical emitters - use a chamber that fills with water and then it releases it at specific times

2. in-line drippers, also called “driplines” - are an actual part of the laterals. These emitters are used in fields where there is a high density of plants such as different crops, dense orchards and underground irrigation. They come from the factory with specific flow rates and release intervals.

•low-density polyethylene piping (LDPE) - this type of pipe is the most expensive but also the most professional one, they have a cylindrical shape and are found inside the drip lines (see Figure 3-c).

•flat LDPE - to save space during transportation, sometimes the pipes come in flat or oval shape. These emitters have a small profile and thus they do not affect the flow.

•drip tape - is used in large fields, mostly for field crops and also can be employed in underground drip lines.

Sizing the emitters is necessary because the plant needs for water depend on many factors as previously discussed in another lecture (e.g., plant development stage, climate, soil parameters). Except for these parameters, one should also consider the spacing of the emitters, the length of the pipe system, the topography of the field and crop spacing, the least. Considering these facts, the type of emitters can be optimally chosen.

Despite the fact that all emitters are able to regulate the pressure, there is another classification:

1. pressure-compensating emitters - these are emitters that can discharge the water at a uniform rate on a large range of water pressure. Diaphragm emitters are part of this category. A silicone membrane restricts the flow cross-section as the value of the pressure is increasing. This type of emitter is useful when there is a high elevation difference (>0.5 m) or when long drip pipes are used.

2. non-compensating emitters - when the water pressure variates, these are not able to regulate it as the pressure-compensating emitters do

Drip irrigation technology can be applied to most of the crops, with high performance. A simple drip system can be realized using a water tank placed at some height above ground level to ensure the pressure and water flow in the system. First, the water is filtered and reaches the mainline, then the secondary lines, which can be made by simple PCV pipes or other local materials such as bamboo. The flow is regulated with a valve. For small farms, the costs are relatively low, while the systems for big farms with industrial productions need very expensive systems. Maintenance is mandatory, the drip hoses must be lifted from the ground such as soil particles do not enter the system clogging it. In order to remove any clogging agents, the analysis of water must be performed before deciding on the appropriate water treatment. Periodically flushing the system is also a good practice to ensure its optimum functioning, as well as periodically monitoring the flow and pressure [5].

The clogging of the emitters is a serious problem that can have a multitude of causes:

•physical clogging due to the presence of sand, silt, metallic flakes, plastic chips

•chemical clogging due to the precipitation of salts, iron, fertilizers, etc.

•biological clogging due to the growth of algae and bacterial slime.

Most of the time there is a combination of these clogging sources, especially when using surface water or when the water is pumped from opened reservoirs, or when saline water and fertilizers are used. Saline water contains a lot of cations and anions that can easily precipitate and deposit. From the chemical point of view, high pH, high concentrations of ions and increased hardness are prone to create issues.

## Subsurface Drip Irrigation

There is a variant of drip irrigation that uses buried drip pipes (Figure 5). Regulating the phreatic levels (sub-irrigation) is suitable only for areas where the phreatic layer is relatively shallow (1-4 m). By supplying water, brought through a network of pipes or channels from an external source, the water

table can be raised in such a way as to ensure the water supply of the plants by capillary ascent. Also, the method is recommended in the version with drains or perforated watering lines buried in the soil at the base of the root system of the plants, for irrigation using waste water.

The method is more efficient than simple drip irrigation, saving water by reducing water evaporation and the incidence of different pests and providing uniform wetting in the area of the plant roots. A subsurface drip irrigation system is suitable in areas where the water evaporation increases due to climate conditions (arid, high temperatures, high wind), and mostly on sandy-type soils. The application of water underground eliminates several of the issues of surface irrigation such as soil water saturation, ponding, runoff and soil erosion.



*Figure 5. Example of sub-irrigation system*

The technology can be adapted to any kind of crop; however, it is used for high-value vegetable crops, turf and landscape. If it is used with plastic mulches, it was shown to considerably enhance production. Compared to surface drip irrigation, the use of underground piping makes them less exposed to sunlight and other factors that can destroy them. The technique can be used much closer to the cutting date because the surface of the soil remains dry all the time and thus can be easily managed. In some cases (alfalfa) subsurface drip irrigation can stimulate germination as well.

The layout of a subsurface irrigation system is similar to the simple drip irrigation one. For easy drainage, a system with vacuum pumps and valves is used to release the trapped air that can disrupt the water flow. The tubes are put below the surface of the soil at about 12 to 50 cm, depending on the crop and type of soil. Placing the system underground also facilitates the tillage of the soil. The emitters are installed upward. The system needs a filtration unit as well for the reasons already discussed for drip irrigation.

Both drip and sub-surface drip irrigation methods have been studied in parallel to determine the most efficient one. Analyses have been made regarding the properties of the soil, the water use efficiency, cropping techniques, irrigation scheduling, yields and other parameters. From all the studies it seems that sub-surface drip irrigation is more efficient than drip irrigation method, with higher production, improved plant quality, water saving (up to 20%), which recommends it to be used in areas where the water resources are scarce and need to be conserved.

Fertigation represents the use of fertilizers combined with the water for irrigation. In such a way, not only the water and fertilizers are reaching the plants, but there is less leaching of nutrients. Except for the water needs of the crop, in this case, some other things must be also considered for efficient fertigation such as the ability of the crop to uptake the nutrients, how much nutrients are in the soil at a specific time and how much nutrients should be in the water used for fertigation.

## Conclusions

Drip irrigation is an efficient irrigation method, involving relatively low costs and small labour, that can be used for fields with irregular shapes without any need to level it as required for example in surface irrigation, can use recycled water, the water can be distributed very uniformly over the field, it operates al low pressure, meaning that the energy costs are reduced and it implies reduced loss of fertilizers due to local application of water, thus reducing the erosion as well [3-6]. Despite the many advantages, a drip irrigation system requires high initial costs and needs high maintenance, especially of the filtration system. The pipe system can be affected by the sunlight, shortening its life, thus in some cases sub-surface irrigation is preferred.

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# IRRIGATION MANAGEMENT AND SCHEDULING

•The presence of water in the soil is important from many points of view:

•ensures the necessary amount of moisture for seed germination and growth,

•decreases the temperature of soil and surroundings,

•deals with the salts accumulated at the surface, diluting and washing them out,

•aids tillage by making the soil softer,

•irrigations help the crops grow even during the lack of precipitation.

Most of the water in soil comes either from precipitation or underground waters. Most of the time the existing moisture is not enough for successful agricultural use of the lands and to ensure agricultural production, the water deficit could be overcome by supplying water artificially through irrigation. Sometimes it is difficult to supply exactly the necessary amount of water, thus several issues appear, such as the soil being saturated in water, a situation when the excess is damaging the crops. To overcome this issue, drainage systems are used, if natural drainage is not present [1]. Keeping the optimum amount of water in the soil means balancing between irrigation and drainage.

Applying irrigation at the optimum moment in connection to the plant needs, is one of the major desiderata of any irrigation practice. The moment is established as a function of many factors, starting with the type of irrigation system. In the case of local irrigation systems where the water distribution is discontinuous and on-demand, the optimum moment is determined by the farmer responsible for the irrigated crop based on observations and measurements performed on the crop field. For very large irrigation systems, the moment is established by the technical irrigation advisory centre coordinating the respective system.

Establishing the time of the first irrigation application of the season during the crop vegetation or the start of the irrigation campaign is done in strong correlation with the soil water content and does not depend on the type of irrigation system. To determine the optimum moment for irrigation, there are approximative methods (empirical) as well as more precisely (using scientific data).

## Empiric Methods Used to Establish the Timing of Irrigation Application

Empiric determination of the ideal moment to start the irrigation of a specific crop is based either on the vegetation stages of the crop or on the analysis of some morphological indicators of the plants.

The first method, based on the phenological stages, considers that, for each plant, the water need is higher in some vegetation phases, called critical phases [2]. For example:

•For wheat, the critical phases for water needs are floral initiation (double ridge), terminal spikelet, stem extension, heading and ripening,

•For maize: 6-8 leaves, kernel development, grain filling,

•For sugar beets: leaves development, thickening of the roots, sugar accumulation.

It was observed that the crop state directly depends on the soil moisture during the critical development stages, making an irrigation plan that gives water to the crops a short while before such a stage starts seems to be a rational decision, as long as the whole crop can be irrigated in 2 to 3 days.

Despite being empirical, only based on observations with no measurements, this technique has the advantage of obtaining a production comparable to that on fields where the irrigation schedule is strictly determined through rigorous criteria. The disadvantages are related to the increased water use, labour and equipment involved.

Establishing the irrigation schedule based on the observation of the general aspects of the plants due to the lack of water (turgescence loss, changing the colour of the leaves, flower falling, etc.) is not efficient because once these changes are observed, the plants have already been suffering, a fact that influences the yield and quality of the crop.

## Scientific Methods to Establish the Irrigation Schedule

The scientific way to establish the irrigation schedule is based on information gathered from measuring the soil moisture and water holding capacity, some physiological indices of the crop or the average daily water need [1, 2].

Establishing the irrigation schedule according to soil moisture is a rational method if the water content can be measured precisely, fast and involving low costs. The water content of the soil can be determined by different methods such as thermal, electromechanical, neutronic, etc. To do this, some control areas are established which are equal to the crop surface or with the surface occupied by the crop that is irrigated.

## Studying the technical and functional parameters of soil tensiometers

To determine the water moisture of the soil, two types of methods can be used:
1. Volumetric measurements which represent the measurement of water percentage of some volume of soil,

2. Tensiometric measurements which measure the soil water tension, meaning the physical force necessary to retain water in soil, measured in centibars (cbar) or kilopascals (kPa) of water tension in soil.

In irrigated fields, the suction can be highlighted with the tensiometer. The tensiometer (Figure 1) consists of a porous vessel filled with water, in hydraulic connection with a vacuum meter that registers the depression created inside the instrument to balance the soil suction, when the porous vessel is inserted into the soil. Tensiometers work well, ensuring the precise determination of soil suction, in the range of humidity easily accessible to plants.



*Figure 1. Irrometer tensiometer*



*Figure 2. Watermark sensor*

The Watermark sensor (Figure 2), also known as a granular matrix sensor, detects the quantity of water absorbed through a combination of carefully chosen materials. This mixture is a buffer for the sensor against different environmental factors such as salinity and has a long life. The measurements from the Watermark sensors are calibrated to correspond to the levels that a tensiometer would measure. They do not need maintenance, have an estimated lifetime of more than 5 years, and, compared to the tensiometers, can maintained on the field all the time. The Watermark sensors are suitable for recording data or IoT devices and require a minimum amount of operational power to read.

*Table 1. General characteristics of each sensor.*

| Sensor Type | Soil Texture | Crop Sensitivity | Tension Range (cbar) |
|---|---|---|---|
| SR | Light to medium | Medium | 15-75 |
| LT | Coarse or sandy | High | 5-20 |
| Watermark | Medium to heavy texture | Medium to tolerant | 30-200 |

The readings in Figure 3 are used as basic guidelines as follows for Irrometer equipment or the Watermark sensors as follows:

•In the range of 0 to 30, centibars, the soil is suitably moist (with the exception of coarse sands, which dry out).

•The typical range for irrigation on most soils is 30-60 centibars.

•The typical range for irrigation in heavy clay is 60-100 centibars.

•100-200 centibars of pressure means that the soil is dangerously dry

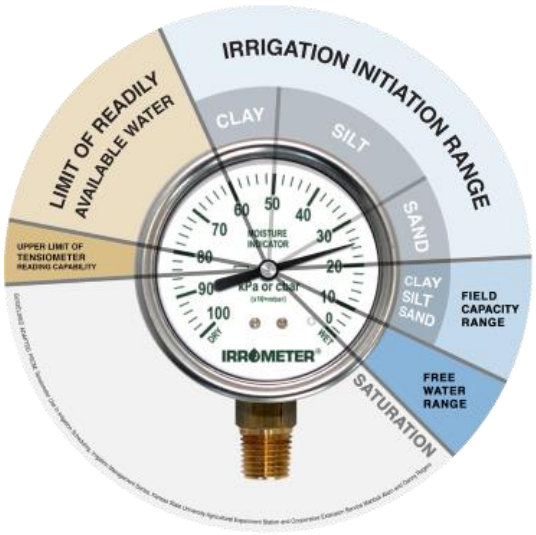



*Figure 3. Choosing the appropriate sensor range for each sensor based on the general soil properties*

Beyond broad recommendations, taking the effort to read and comprehend the data results in more precise irrigation thresholds and a more realistic picture of what is occurring in the root system of the specific crop to be irrigated. To make a correct interpretation of the data, it is crucial to understand a few fundamental ideas:

•The volume of water that remains in the soil after extra water has been drained out and the velocity of downward movement has slowed down is referred to as the **field water capacity**.

•The amount of water in the soil that a plant must have in order to avoid withering is known as the **withering coefficient**. Its standard normal value is 1500 centibars/kPa.

•The range between field capacity and wilting point is typically used to determine useful (available) water capacity, which is the amount of water that can be stored in a soil profile and that is available to growing crops.

•The amount of water that can be reduced before irrigation and is necessary to minimize crop stress is known as **allowable depletion**.

## Choosing management thresholds

Thresholds are benchmarks that specify upper and lower bounds for controlling permissible depletion. This range depends on the type of soil, the crop, how plants develop and the cultural practices used to

manage fields, but a reasonable starting point is to regulate available water depletion between 10% and 40% wet and dry, respectively.

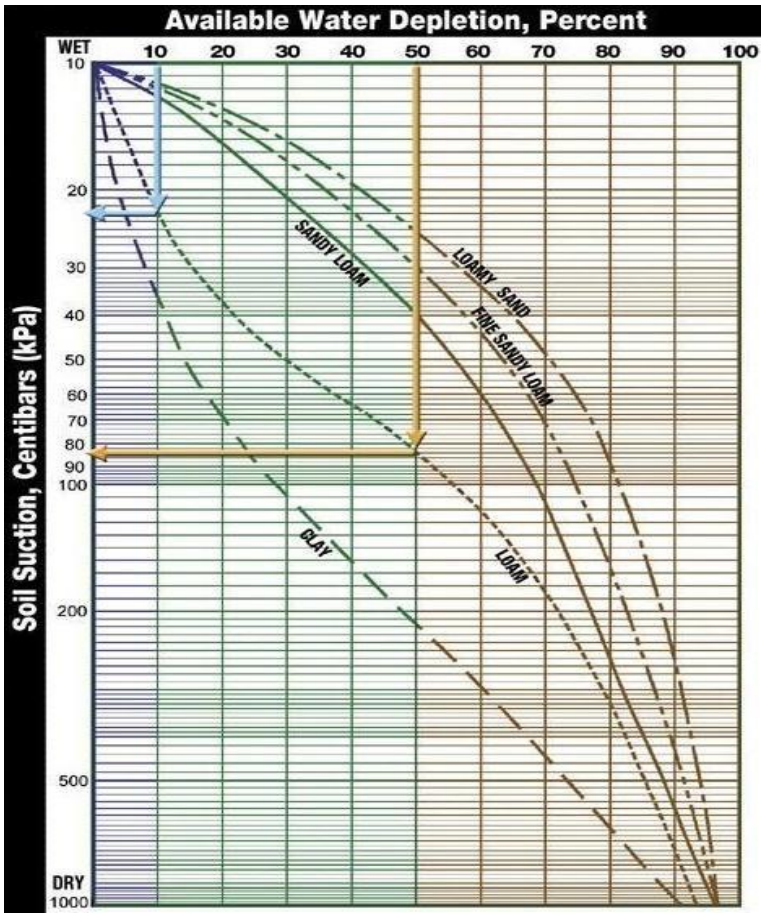



*Figure 4. Suction curves for various types of soil.*

Each type of soil has a variable range of stress due to its different capacity to retain water, hence the amount of water accessible varies for each soil type. In other words, 84 centibars of soil water tension would represent 50% depletion in a pure clay and 40 centibars in a sandy clay. These interactions are represented graphically in the graph shown in Figure 4, which also serves as a guide for choosing the right threshold values.

Based on this chart, a calculator created by Cambridge University can be accessed online where one may choose a soil type, enter an acceptable run-off level and then input sensor readings to determine whether irrigation is advised. Similar calculators providing information on the soil in different regions are available as apps.

The graph in Figure 4 illustrates the connection between soil water tension and permissible depletion. One should choose the soil type that most closely reflects the field from the chart to use. The soil type curve and the left axis with the label "soil water tension" are connected vertically at 10% available water depletion (shown by the blue/green boundary) to get the UD reference value. The lower (wetter) threshold line will be determined by this. This value would be 23 in this example of clay soil (shown by the blue arrow).

Next, a vertical line is built from the curve for the soil type down to the 50% available water depletion (shown by the green/brown border), and then a horizontal one across the left axis designating soil water tension to arrive at the DRY reference value. A higher (dryer) threshold line will be the result of this. This value would be 84 in this example of clay soil (as shown by the brown arrow). The 50% threshold is a general suggestion, it should be highlighted. Normal depletion thresholds range from 30% to 50%, with irrigation techniques that use less water per irrigation (such as center pivots) favoring

the 30% to 40% range. For the best recommendations, agronomic expertise and knowledge are required.

## Tensiometer Types

The industry standard for precise soil moisture monitoring is the Irrometer tensiometer (Figure 1), which offers farmers a low-cost and trustworthy way to gauge soil moisture for irrigation scheduling. The Irrometer is unaffected by salinity and doesn't require on-site calibration because it offers a real measurement of soil water potential. Depending on the rooting depth of the particular crop, the Irrometer can be found in a variety of versions with typical lengths of 6", 12", 18", 24", 36", or 48". On request, further lengths are available.

The preferred tool for usage in medium to heavy soils is the "SR" Irrometer. The device features a reservoir, an airless measurement chamber and a changeable threaded tip. In order to help producers increase irrigation effectiveness, the SR Irrometer was developed and produced first in 1951. Regardless of the type of soil, this instrument gives the user precise information on the soil moisture state. Centibars (cb) or kilopascals (kPa) are used by the instrument to measure soil water tension. The indicated value reflects the power expended by a plant's root system to draw water from the ground. Understanding soil moisture activity enables the user to plan irrigation systems intelligently, improving output and quality while saving money on water, fertilizer, labour and energy.

Operational method: The Irrometer functions similarly to a tensiometer, which gauges soil water tension. As a plant takes in the water it needs, the plant applies to the soil a tension. Centibars (cb) or kilopascals (kPa) of tension are used to measure this force, with a high value signifying the dry end of the scale and a low reading signifying the wet end.

A sealed tube that is filled with fluid and has a porous ceramic tip and a vacuum gauge make up the Irrometer tensiometer. The tips are inserted into the ground at the specified depth of the root zone during installation. The fluid is extracted from the tool when the earth dries out (tension increases). As a result, the liquid volume decreases and a partial vacuum is created, which is recorded on the gauge. The gauge measurement rises as the earth becomes drier. This process is reversed by irrigation or precipitation. Lower gauge readings are the result of tension being released into the soil and into the instrument as the water flows back into the soil (and into the Irrometer). The gadget actually shows how hard the roots are working. Under typical operating conditions for various soil types, the Irrometer's unique operating principle means that no calibrations are necessary. Whether the crop is sown in sandy or clay soil, the roots are removing the same quantity of moisture, according to a reading of 50 cb (kPa).

Applications include the manual assessment and monitoring of the soil moisture state for the majority of soil types using Model SR Irrometers. Measurement and tracking devices with optional electronic output and data logging capabilities can be automated. Electronic measuring alternatives or automatic switching devices that can turn on auxiliary equipment at appropriate soil water tension levels can be used in place of the model's conventional vacuum gauge. For simple field maintenance, the SR model employs a replaceable tip. It is intended for widespread use with fields, trees and rows of crops.

The LT (low tension) Irrometer is made for conditions in which tensions greater than 30 cb (kPa) are infrequently anticipated. It works best for very coarse soils, non-soil container media, or when it's important to keep track of sudden changes in the water status of the soil. The instrument features a reservoir, an airless measurement chamber, as well as a Quick-Flo replacement threaded tip.

The LT model was created to function on soilless growth media and coarse sandy soils. This instrument, which has a range of 0-40 centibars (cb) or kilopascals (kPa), is designed for use in conditions where forces greater than 30 cb (kPa) are infrequently anticipated. When finer precision close to saturation is required, measurement increments of 1 cb (kPa) are advantageous. This instrument model is also

ideal for situations where soil moisture requirements must be satisfied despite rapid changes in those conditions. For simple identification, the "Quick-Flo" ceramic tip is coloured blue.

Applications include the manual assessment and tracking of soil moisture conditions in crop situations and coarse sandy soils using Model LT Irrometers. Measurement and tracking are automatic when using optional electronic output and data-logging devices. This model's low tension vacuum gauge can be changed out for electronic metering alternatives or automatic switching mechanisms that can turn on auxiliary equipment when the soil water tension is at a particular level. For container media like peat, bark, sand, perlite and vermiculite, the LT model is the best option. When moisture is regulated near to field water capacity, it can also be employed in any soil [1].

The "MLT" (Miniature Low Tension) Irrometer is made for uses that are comparable to those of the "LT" variant previously mentioned. The tool works best when used with media for soilless containers and very gritty soils. It is the finest option for greenhouse applications because of its small size and interchangeable "Quick-Flo" tip.

Technical details: To help with irrigation scheduling decisions, the Irrometer Model MLT Soil Moisture Indicator combines soil moisture indicators. According to the tensiometer concept, the soil moisture indicator must display the soil water tension in units of centibars (cb) or kilopascals (kPa), depending on the application. It must feature a ceramic sensing tip, a stainless-steel indicator and a sturdy plastic tube that is resistant to chemical attacks from soil. It must be made with the greatest accuracy possible for low tension applications. All connections between ceramic and plastic must be secure.

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# WATER REUSE FOR IRRIGATION

The circular economy is becoming, day by day, an increasingly current concept. What was long treated as waste is beginning to be seen as a source of raw materials. This happens in agriculture as well. One of the new ideas is the use of wastewater from cities for irrigation. The advantages can be multiple. Moreover, on June 26, 2023, the provisions of a new European Regulation regarding the minimum requirements for the reuse of water for agricultural irrigation will become applicable [1, 2].

## Nitrogen and Phosphorus Would Come for Free

The idea of using wastewater from the city to irrigate the agricultural land in the vicinity is not new. Recently, a group of researchers proposed a project that consisted of not completely purifying the wastewater, such as to preserve the nitrogen and phosphorus in it. These two substances are essential nutrients for plants. Farmers typically spend large sums of money to procure and then distribute them to crops. By using the water that already contains them as waste, they could achieve significant savings. On the other hand, city officials would, in turn, achieve significant savings, not spending money on the energy and materials needed to extract nitrogen and phosphorus residues from water, thus, being an idea that everyone would benefit from. If the wastewater is treated properly, according to European regulations, it can represent an effective alternative for covering the water demand of the agricultural sector [3].

Thus, applying such a solution around cities could provide the water needed to irrigate tens, even hundreds of thousands of hectares of agricultural land. Added to the water would be the associated fertilization, which would mean significant energy savings and a significant reduction in pollution. Moreover, the sludges collected from sewage treatment plants are already used in agricultural practice as fertilizers and soil amendments.

According to statistics from the European Commission, the amount of treated urban wastewater that is currently recycled each year is around 1 billion cubic meters, or 2.4% of treated urban wastewater effluents and less than 0.5% of the EU's annual freshwater withdrawals. The EU's potential, however, is six times greater and is thought to be over 6 billion cubic meters. Both the northern Member States, like Belgium, Germany and the United Kingdom and the southern Member States, like Spain, Italy, Greece, Malta and Cyprus, have already put in place a number of programs on water reuse for irrigation, industrial purposes and aquifer recharge. While Greece, Italy and Spain only recycle between 5% and 12% of their effluents, Cyprus and Malta already reuse more than 90% and 60% of their wastewater, respectively. This clearly shows the enormous potential for additional uptake.

## Water Reuse - A Solution to the Looming Crisis

Water scarcity is a growing problem in Europe. This was the context in which, at the end of January 2020 the deputies of the European Parliament (EP) met with the representatives of the Commission. MEPs wanted, among other things, to secure the EU's freshwater sources including by promoting the reuse of water in agriculture.

The demand for Europe's water resources is predicted to increase as a result of climate change. One prediction state that by 2030, water scarcity may affect half of the river basins in Europe. Members of the Environment Committee of the EP adopted an informal agreement with the Council on a proposal to reuse wastewater on January 21 in order to secure Europe's fresh water supply for years to come. To become law, the new regulations still need to be approved by the Council and the Parliament. The new regulations are designed to encourage the use of treated wastewater for irrigation, which uses around half of the water used annually in the EU. Water reuse in agriculture could be increased to assist close the deficit.

The new regulations mandate minimum water quality standards, frequent monitoring and the creation of risk management strategies by wastewater treatment facilities in order to guarantee the protection of crops. The authorities of the Member States are responsible for authorizing treatment plants and monitoring regulations compliance.

## Pollution in the Irrigation with Wastewater

## The health issues related to wastewater irrigation

The wastewater discharged from the sewage systems of the cities, from various large industries as well as from animal farms and fattening, can be used for irrigation after they have been properly purified in order not to harm humans, animals, crops, or land not to pollute the environment. In Romania, at the level of 1996, there were over 60,000 ha of wastewater irrigation systems, coming from animal husbandry complexes, included in about 30 irrigation systems. Currently, they are no longer functional. It is appreciated, however, that in our country, an area of about 1,330,000 ha can be irrigated with wastewater.

The dangers generated by the use of these waters for irrigation depend on a number of factors [2-4]:

●the presence of pathogens in these waters,

●the presence of elements such as: sodium, heavy metals (Cu, Pb, Cr, Cd, Ni, etc.) in addition to other substances that can cause soil degradation and crop depreciation,

●the way of development of different organisms, located in the irrigation water,

●the viability of pathogens and their ability to survive purification treatments,

●the possibility that pathogens can survive in the soil.

There are some wastewaters that have a high content of nitrogen, phosphorus, potassium and other nutrients (such as those from the fertilizer production industry, alcohol, etc. presented in Table 1) stimulating plant development. They have the ability to extract about 75% of the nitrogen in the irrigation water, phosphorus up to 100%, potassium 60-10%, etc. It is estimated that 50-100 m³ of wastewater can contain as many nutrients as a ton of manure and especially corn, wheat, soybeans, potatoes, alfalfa and clover absorb significant amounts of nutrients from irrigation water.

*Table 1. Characterization of some industrial wastewater according to $CBO_5$ size and nitrogen content*

| Wastewater From Industry | $CBO_5$ ($MGO_2$/L) | $N_{TOTAL}$ (MG/L) |
|---|---|---|
| Sugar | 1200-4600 | 20-70 |
| Dairy | 1000-5000 | 50-180 |
| Alcohol | 12000-25000 | 360-1300 |
| Beer | 600 | 160 |
| Meat | 900 | 150 |
| Pulp and paper | 200-1000 | 5-20 |
| Colours | 100-800 | 5-50 |
| Oil processing | 1800 | 300 |
| Chemical fertilizers | <100 | 1500-5000 |

Research has shown that using wastewater does not involve major health issues. On a depth of 0.9 to 1.2 m, all the bacteria are filtered. The soil retains on the first centimeter of depth about 90% of the total microbial load and on the first millimeter 62 to 64%. Intestinal bacteria that reach in soil along with the wastewater are mostly adsorbed by soil colloids and destroyed by saprophytic bacteria [5]. Wastewater that was naturally filtered by the soil reaches the phreatic layer free of microbiological pathogens. In the case of wastewater irrigation, the most important microorganisms are listed in Table 2.

The soil "gets tired" if wastewater irrigation is used for a long time, a reason for which is recommended that the water should be treated before being used. Due to the very diverse chemical content, wastewater treatment should be processed to avoid destroying crops, soil salinity, etc. Improving the quality of reused wastewater is recommended through dilution with clean water, decreasing the content of sodium, reducing the salt from animal diets, adding gypsum to substitute sodium carbonate and so on. The existing research indicates that the reuse of wastewater for irrigation lead to an increased in yield, mainly due to the increased soil moisture and fertilization.

*Table 2. Most important pathogens found in wastewater.*

| Type | Microorganisms | Disease |
|---|---|---|
| *Helminthes* | Ancylostoma duodenale | Ankylostomiasis |
| | Ascaris lumbricoides | Ascaridiasis |
| | Schistosoma hasmatobium | Parasitosis |
| | Schistosoma japonium | Parasitosis |
| | Schistosoma manaoni | Parasitosis |
| | Taenia raginata | Taeniasis |
| *Protozoa* | Entamoeba histolytica | Amoebic dysentery |
| *Bacteria* | Leptospira icterohemorrhagiae | Leptospirosis |
| | Mycobacterium tuberculosis | Tuberculosis |
| | Sallomenella typhi | Typhoid fever |
| | Sallomenella paratyphi | Paratyphoid fever |
| | Shigella Shigae | Dysentery |
| | Shigella Sonnei | Dysentery |
| | Shigella Flexneri | Dysentery |
| *Virus* | Vibrio cholerae | Cholera |
| | Hepatic virus | Infectious Hepatitis |
| | Plioviruses 1, 2, 3 | Paralytic poliomyelitis |
| | Coxsackievirus A | Aseptic meningitis |
| | Coxsackievirus B | Aseptic meningitis |
| | Echovirus | Enteric diseases |

For soils with good permeability, sub-surface irrigation methods are preferred, due to the reduced and very efficient water use, as well as due to the protection of the surrounding areas especially when wastewater are used. Cleaned wastewater can be also used in the fertigation of crops grown in greenhouses, through sub-surface irrigation. They are also recommended for technical plants (such as sugar beet), pastures, vegetable crops that are consumed after thermal preparation (potatoes), ornamental plants and flowers, with the condition that the irrigation is stopped a month before harvest.

## Negative effects of wastewater irrigation

Wastewater irrigation requires serious management and control of soil properties such as to avoid the deterioration of soil. It is mostly recommended for soils with good permeability for water and air, favoring the mineralization of the organic matter and pathogen destruction. Soil self-purging depends mostly on the microbiological load of the soil (bacteria, actinomyces, fungi, protozoa, larvae) and consists of:

•The mineralization of the organic matter in anaerobic conditions - the sugars are decomposed in methane, water and carbon dioxide, proteins are transformed into amino acids and the fat is reduced to glycerin and fatty acids, as a result of fermentation and decomposition, some strong-smelling compounds are produced such as ammonia, hydrogen sulfide, methane.

•The nitrification - autotrophic bacteria and archaea produce the oxidation of some inorganic compounds leading to the formation of nitrite. It is an aerobic process.

Applying wastewater irrigation in an uncontrolled manner can lead to some drawbacks such as [2-4]:

•**Soil fatigue** - can appear after years of wastewater irrigation and it is evidenced by increased concentrations of microelements (e.g., Zn, Cu), increased concentrations of harmful compounds (e.g., chloride, sulfate, fatty acids), levigation of potassium and iron at high depts, degradation of the soil structure, insufficient aeration. As a consequence, the plants will exhibit chlorosis and the development process of some plants will be affected. It was proved that the main cause of these drawbacks is related to the increased irrigation due to population increase and water consumption, with 60.000-70.000 cubic meters per hectare as compared to the optimum values of around 3000 cubic meters per hectare, as well as the use of unprocessed wastewater and unsuitable soil management.

•**Soil clogging** - is due to the increase of organic matter usually accompanied by the increase of nitrogen content which partially stops the plant development. When the wastewater has high nitrogen content, good results have been obtained by keeping the water in oxidation ponds-a very good treatment because the organic matter is decomposed by microorganisms in the presence of oxygen. The method is used in many countries such as Australia, North America and Israel.

•**Secondary soil salinization** - is produced especially on clay soils, with low permeability, due to an increased in soluble salt concentrations in soil above the critical value. The presence of sodium and other cations in large quantities leads to the destruction of structural aggregates of soil and reduced water permeability.

•**Soil acidification** - intensifies the solubility of calcium and magnesium salts, leading to deficiencies in plant nutrition, this phenomenon takes place when the wastewaters have a pH lower than 6.5.

•**Soil contamination** - can appear due to irrigation that uses industrial wastewater contaminated with harmful chemicals such as heavy metals (e.g., As, Cu, Ba, Ni, Cr, Zn, Co), phenols, different salts and detergents. In a very small concentration, they can trigger the stimulation of plant growth but over some limit, they can inhibit the development. Moreover, they could be absorbed by the plants entering the food circuit and posing threats to animal and human consumption. It is not recommended to use for irrigation water that has arsenic over 1 mg/L, copper, over 7 mg/L, nickel and cobalt, over 2 mg/L, sodium, 80 mg/L, $SO_4$ over 250 mg/L. The presence of tensio-active substances (detergents) affects nitrification, also influencing respiration and photosynthesis due to the formation of a pellicle over the surface of the leaves.

•**Soil infestation with pathogens** - can happen when there is an abusive use of wastewater without any prior treatment.

Other disadvantages of using wastewater in irrigation are:

●the fertilizers could lead in some conditions to excessive vegetative development, detrimental for the yield (fruits, grains, etc.), for the microbiological activity of the soil,

●when silt from wastes is used as organic fertilizer, there might be a reduction of soil water content,

●wastewater irrigation is a problem during the winter.

## Advantages of using wastewater in agriculture

Rational use of wastewater in agriculture has many economic advantages among which the most important are:

●Elimination of the issues related to wastewater evacuation,

●Reduced expenses to ensure the water for irrigation in the areas where other water sources are scarce,

●Partially adding to the underground water resources, lifting up their level,

●Is a technical and economical solution for the biological cleaning of wastewater,

●Allows the extension of the irrigated areas, even in the zones with fewer water sources,

●Contributes to increased yield,

●It is a good way to fertilize the soil,

●Make accessible to the plants useful elements found in this water,

●Offers the possibility of reducing the use of expensive fertilizers, the wastewater from animal farms is a very good nitrogen-potassium-phosphor fertilizer,

●The elements are easily assimilated by the plants,

●On unstructured soils, irrigation using wastewater from the cellulose industry, rich in sulfites, improves the soil structure, thus, increasing the water permeability,

## Soil protection during wastewater irrigation

The measures for the protection of soil irrigated with wastewater impose that:

●the transportation and distribution of water should be carefully done,

●the quantities of water used to be rationally calculated,

●the wastewater treatment should be done previous to its use in irrigation,

●the contents of toxic chemicals and pathogens should be under the recommended limits,

●the concentrations of salts should be within normal limits, such as they don't have a negative effect on the physical and chemical properties of the soil, plant growth and yield,

●the pH should be between 6.5 and 8.5,

●the irrigation with wastewater should consider the overall quantity of substances in the water, the physical and chemical properties of the soil, the irrigation regime, the phreatic level, the irrigation schedule and the harvesting moment,

●perform regular drainage of the irrigated fields,

●the fields used for wastewater irrigation should have small slopes, with good soil permeability, without soils with fractured rocks and deposits or in the vicinity of a water source,

●to avoid secondary salinity, the irrigation should be done once every other year, the wastewater should be diluted with clean water in a ratio of 1/2 to 1/5 and small quantities of water should be used.

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# CLOUD SEEDING

As a result of climate change, the precipitation pattern has been affected, making vulnerable many countries due to the decrease of water resources. Drought has become a regular event in many parts of the world, thus governments around the world have been focusing on plans for drought management, since the drought has more than an agricultural impact, but strongly affects communities, health, education and nutrition. It adversely influences the moisture of the soil, surface runoff and all water resources with social and economic negative consequences.

As we discussed in previous chapters, water reserves are scarce and new technologies and methods are being targeted to provide agriculture with the water needs. One way to achieve this is to stimulate the production of precipitation by cloud seeding [1-7]. Some areas in the world, such as the United Arab Emirates, have already been using this method commonly. In other parts, such as Australia, Russia, China, India, Israel, the United States, but also Romania, the implementation was started a short time ago [3]. On one hand, cloud seeding stimulates the production of precipitation, and, on the other hand, can help avoid the production of hail which is another major problem for agriculture resulting from climate change, with potential negative impact, especially for cultures that take a couple of years to be productive such as vineyards and orchards.

Modern weather modification technology started in the 1940s when Schaefer and Vonnegut found that supercooled water droplets could be turned into ice after seeding. In warm clouds, the rain was initiated using large, hygroscopic particles [4]. Not all the available moisture from the clouds is transformed into precipitation, but a small amount, fact that presented the possibility of exploring increasing the water supply by cloud seeding. Despite the research performed in the past century, the complexity of the atmospheric processes directly influences the repeatability of cloud seeding experiments. Considering the high costs involved due to the necessary equipment, the cost-to-benefit ratio is influencing the undergoing research programs regarding cloud seeding.

## Explanation of The Process

Precipitation occurs after evaporated water in the atmosphere collects through condensation around particles in the atmosphere, leading to the saturation of the air when it can't hold the moisture and the droplets formed fall.

Cloud seeding represents the dispersion of artificial substances into a cloud to change its development or increase its precipitation. Enhancing the precipitation is done by making several weather modifications to increase the number of condensation nuclei in the atmosphere by providing aerosol particles into the clouds, beyond the natural background population which can be scarce and have smaller size. The water content of the cloud condenses into liquid droplets, increasing the depth of the cloud, lifetime and intensity of the rainfall.

The process is very complex. The substances introduced in the clouds serve as cloud condensation nuclei, aiding the formation of precipitation. Based on the ice-nucleating abilities of the glaciogenic materials (silver iodide and dry ice), several types of cloud seeding modes have been proposed [2]:

•In the **static mode**, condensation nuclei (usually silver iodine or dry ice) are added to increase the rainfall. These crystals act as condensation nuclei for the moisture already present in the clouds, increasing the efficiency of dispersing the water in the cloud. Experiments have shown that the opportunity window for this seedling method is limited at least by the availability of supercooled water in the cloud. The success rate of cloud seeding in static mode is variable since the environmental conditions are hard to replicate.

•In the **dynamic mode**, the vertical air currents are enhanced by adding a much larger quantity of condensation nuclei to the cloud. This concept is based on seeding supercooled clouds with huge quantities of nuclei (about 100 times more condensation nuclei) to produce the rapid formation of ice

particles, the released latent heat increasing buoyancy invigorating the cloud updrafts and resulting in the growth of the cloud and yielding more precipitation. The latter could produce strong downdrafts and interactions with the environment leading to a more active convection phenomenon. Dynamic seeding is a more complex process than static one, depending on several events, about 11 stages of the process being identified [6]. Any interference with the sequence of events can seriously affect the final result, making the method less reliable than static cloud seeding.

•In **hygroscopic seeding**, the nuclei are salt crystals on which water condensates until they are large enough to cause precipitation. It is associated with warm cloud seeding. The promotion of rainfall is due to the enhanced coalescence process. In the initial form, the method had some drawbacks, such as the large salt quantity of salt needed, which had to be dispersed over areas large as the cloud inflow. Moreover, the growth rate of rain particles must match the updraft profile. Later on, the approach changed to seeding the warm clouds below using pyrotechnic flares producing under micro-meter sized salt particles, resulting in a broader size spectrum. This approach makes use of smaller quantities of salt, while the target area can be easily determined at the base of the cloud.

The methods for cloud seeding can be (Figure 1):

•airborne - planes are used to spread the nuclei in the clouds with special pyrotechnic equipment (cartridges and blocks)

•ground-based systems are used for the same purpose as planes. Such systems can be generators, rockets, pyrotechnic flares, hail cannons, artillery seeding, etc. A reagent is burnt and then reaches the clouds by updraft currents.

Besides the technological means necessary for direct seeding, others are required as well to monitor the clouds (radar systems, satellite image transmission networks, meteorological stations, etc.) and rainfall.

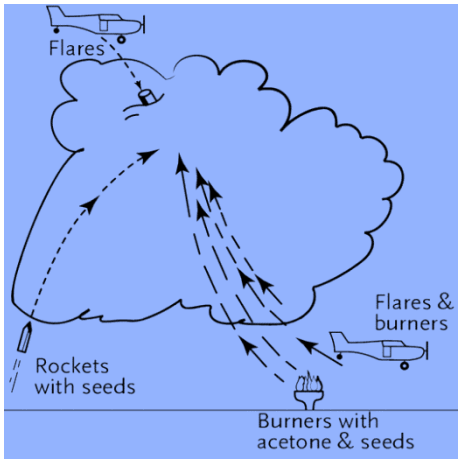



*Figure 4. Schematic of cloud seeding methods*

The natural background of condensation nuclei is represented by dust particles, sea salt, soot and other particles coming from natural processes or have an anthropogenetic nature. The water molecules in a cloud condense on these nuclei, or so-called cloud seeds and the size of the cloud drops increases as they accumulate more water by condensation or collision with other drops. The artificial cloud seeds speed up the process and give the water more material on which to condense, particles growing faster and precipitation being facilitated.

The seeding can be done by two methods as also shown in Figure 1:

•in the upper area of the cloud by directly injecting the nuclei using flares containing a hygroscopic ($CaCl_2$ nanoparticles) or glaciogenic (AgI) substance, mounted on the belly of a plane

•at the lower part of the cloud by spreading seeding nuclei using fixed stations that shoot rockets, or from torches mounted on the wings of a plane.

The substances used for cloud seeding have high ice-forming capacity in the presence of supercooled water and consist of ice-forming aerosols and reagents for cooling. Some of these are hygroscopic, used mainly for warm clouds. Powder reagents are mainly used for the dissipation of convective clouds, through the introduction of strong downdrafts. The most common ice-forming substance is silver iodine (AgI), it has a crystalline structure similar to the ice crystals, being very effective as an ice nucleus at temperatures lower than -4°C. The combustion of 1 g of mixtures containing 8% AgI leads to the production of $5 \cdot 10^{12}$ nuclei at a temperature of -10°C [7].

Other substances used as seeding nuclei are as follows:

•for cold clouds: AgI, liquid propane and liquid acetone, dry ice ($CO_2$)

•for warm clouds: urea, cement, fine salt

•for complex clouds: AgI, NaCl, KCl, $CaCl_2$

The powder reagents have different efficiencies depending on their composition, hydrophilicity (influences the ability to interact with the cloud droplets), dispersion (the optimum value is 3000 $cm^2/g$), specific weight (determines the distribution and behavior inside the cloud due to the currents) [7].

The seeding effects can vary from a couple of minutes to longer periods, depending on the seeding delivery method. The direct injection is immediate but requires the use of a plane flying at high altitude which might be expensive. In the case of updraft seeding at the base of the cloud, the seeding substance needs to be carried out by the updraft current into the cloud to become effective, taking a longer time.

Convective clouds are seeded from the top using aircraft, when their top is above the service level of the used planes, the reagent is dispersed in the cloud at the maximum flight height of the aircraft. When a multitap convective system is seeded, up to tens of cartridges are used, the seeding for each top being similar to that for one cloud. When stratiform clouds are seeded to produce rainfall, the seeding takes place on a perpendicular line to the movement direction, the seeded zone being a couple of km, the reagent being transported by the turbulent phenomena in the atmosphere. Thus, the precipitation will be also limited in the targeted area.

The effectiveness of cloud seeding has been continuously increasing. World Meteorological Organization (WMO) reported that airplane seeding has become more effective than most ground-based methods. Still, evaluating the efficiency is complicated due to the complex properties of the atmospheric phenomena, mostly cloud evolution. Multiple experiments have been conducted and a statistical approach has been applied, in control-target models. The rainfall is recorded in control areas while there is no seeding of the clouds and a regression equation is used to emulate the natural rainfall. Then, the potential seeding impacts can be evaluated by comparing the regression model with the observed phenomena. Using this approach, it was determined that the annual precipitation increased by up to 10% as a result of the cloud seeding.

To study in detail the atmospheric phenomena involved, radar detection is paramount. It can offer a high-resolution, real-time measurement of clouds and estimation of precipitation; thus, it is used to aid in the seeding process and also in its study.

## Case Study - UAE Cloud Seeding Program

In the United Arab Emirates, cloud seeding is a governmental strategy to deal with the climatic conditions of the country. The program has been implemented since 2002 by the National Center of Meteorology of UAE and it follows a conventional approach: natural salts, mainly potassium chloride

(KCl), are launched using flares at the base of convective clouds in the vicinity of the updraft core [1]. A target-control regression method was applied and found a mean annual increase of 23% in rainfall, with increases in the storm echo volume of up to 159%, area cover of about 72%, and lifetime of about 65% [1]. UAE case is a special one, with about 300 seeding missions yearly and a goal to optimize the effectiveness of the process towards the benefit of water security in the country. The program is necessary since the average annual precipitation is below 100 mm, with rising temperatures and shifting weather patterns.

## Impact and Perspectives of Cloud Seeding Technologies

Environmental implications from the pollution point of view haven't been found, even in the case of silver iodine aerosols or other particles such as cement and clay [2, 6, 7]. The concentration of silver in the rainwater is much below the acceptable environmental value of 50 µg/L. There is also no impact on climate change, the seeding modifies individual clouds or groups of clouds with only local effects. The disadvantages of the technology are that it is not foolproof and involves high costs.

Cloud seeding technology has great potential for precipitation enhancement, being strongly linked to water resources management. It is important to consider the potential agricultural benefits of precipitation enhancement through cloud seeding. It can significantly improve the living conditions in arid areas, regulating precipitation through hail prevention. The research so far has shown that cloud seeding can be used as a long-term water resources management tool, alongside with water storage and crop irrigation.

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MODULE 4

# Integrated Pest Management Recommendations to Cope Climate Change Challenges Learning Module

**Boštjan MATKO, Stanka KLEMENČIČ**

## Outline

- Integrated Pest Management (IPM)
- Pest Control Measures (Prevention, Non-Chemical Control)
- Optimisation of the Use of Plant Protection Products In Agriculture
- Increase Knowledge and Willingness to Adapt and Use IPM Techniques
- Promoting Advanced IPM Strategies
- Reducing The Use of Pesticides in Agricultural Production
- Decreasing Negative Impacts on The Environment and People
- Increase Local Agricultural Production and Food Self-Sufficiency

## Introduction

Integrated Pest Management (IPM) represents a holistic approach to managing harmful organisms in agriculture, moving beyond reliance on chemical substances alone. It involves a systematic combination of biotic, cultural, physical, biotechnical and chemical methods to promote plant health while minimizing economic, environmental and health risks. In Slovenia, integrated plant production is rigorously supervised, ensuring adherence to stringent standards for certification. Central to IPM are principles like preventive measures, monitoring of harmful organisms, consideration of economic thresholds and targeted use of plant protection products. Emphasis is placed on reducing reliance on chemical control and fostering natural mechanisms of pest regulation. Despite requiring greater knowledge and coordination, IPM offers numerous advantages, including reduced health and environmental risks, long-term financial savings and enhanced agricultural sustainability. However, challenges such as initial costs and the risk of uncontrolled pest development must be addressed. Compliance with regulations governing the use of plant protection products is essential, emphasizing proper application, monitoring and record-keeping. IPM relies on a range of measures, including mechanical, biotic, biotechnical and chemical methods, with chemical intervention as a last resort. By integrating diverse strategies tailored to specific contexts, IPM offers a promising path towards sustainable agriculture while mitigating risks to human health and the environment.

Integrated plant protection involves systematic and planned management of harmful organisms using various approaches such as biotic, physical, biotechnical and chemical methods. The aim is to reduce the risk to agricultural production, human health and the environment while promoting natural plant protection mechanisms. Various regulations and acts govern integrated plant protection, ensuring that users comply with preventive measures, monitoring harmful organisms and using plant protection products responsibly. Certification processes are in place to verify compliance with integrated production standards. The text outlines eight fundamental principles of IPM, including preventive measures, monitoring of harmful organisms, setting thresholds and using non-chemical methods

whenever possible. Emphasis is placed on reducing the use of chemical pesticides to minimize risks to human health and the environment. Advantages of IPM include improved knowledge of harmful organisms, reduced risks to human health and the environment, financial savings and stable agricultural production. Disadvantages include the need for more time and knowledge, higher initial costs and a higher risk of uncontrolled development of harmful organisms. The requirements for integrated pest management are as follows: users must comply with regulations regarding the use of authorized plant protection products, record-keeping, application methods, safety measures to minimize environmental impact, preventive measures, crop rotation, use of tolerant/resistant varieties and cleaning of machinery. Pest Control Measures are various measures, including preventive actions, mechanical weed control, use of beneficial organisms and pheromone-based methods, are recommended to manage harmful organisms effectively. Basic substances and plant protection products permitted in organic farming can also be used in integrated production, provided they meet specific criteria and regulations.

The sustainable use of plant protection products (PPP) in agriculture is a critical aspect of modern farming practices, aimed at minimizing risks to human health, animal health and the environment. This abstract summarizes the key strategies and regulations implemented in Slovenia to optimize the use of PPP while ensuring environmental sustainability.

The European Parliament's Thematic Strategy on the Sustainable Use of Pesticides has provided guidelines for reducing risks associated with pesticide use, influencing the adoption of stringent criteria for PPP authorization and regulation in Slovenia. National action programs focus on reducing PPP-related risks to human health, animals and various environments through comprehensive measures and awareness programs. Slovenia has enacted laws to ensure the safe and specific use of PPP, including restrictions on multi-component PPP and periodic reevaluation of active substances for safety. The legislation aligns with EU directives on water protection, emphasizing environmental quality standards and groundwater protection. Mandatory education and certification for PPP users, along with regular inspections of application devices, ensure compliance with safety protocols. Key goals of PPP usage in Slovenia include reducing health and environmental risks, promoting integrated pest management and encouraging organic farming practices. The training curriculum covers legislation, risk identification, safe handling practices and proper waste disposal. The sale of PPP is regulated, requiring certification for purchases and strict oversight of distributors. Efforts to raise public awareness include information campaigns on PPP risks, proper handling and waste management. Improved application techniques, such as drift-reduced nozzles and suitable sprayers, minimize PPP reliance and environmental impact during application.

The adoption of Integrated Pest Management (IPM) practices in agriculture is vital for promoting sustainability and reducing the negative impacts of pesticide use on human health and the environment. Clear policies are crucial to provide the necessary framework and incentives for encouraging alternative pest management practices. Addressing social and psychological barriers, along with stakeholder resistance, requires targeted extension methods and training programs. In Slovenia, various measures are implemented to facilitate knowledge transfer and skill acquisition among agricultural stakeholders, including support for vocational training, practical demonstrations and advisory services. Collaborative efforts and cooperation among stakeholders accelerate the transfer of knowledge and innovations from research to practice. Investments in infrastructure and adaptation measures contribute to climate resilience and environmental sustainability. Adapting to climate change involves mitigating its effects through strategies such as proper choice of production technologies and investments in irrigation systems. Promoting organic farming and reducing greenhouse gas emissions further enhance environmental sustainability and industry competitiveness. Slovenia aims to foster IPM adoption and sustainable agriculture practices to mitigate pesticide-related risks and promote long-term agricultural resilience.

Integrated Pest Management (IPM) practices in agriculture are crucial for sustainable pest, plant disease and weed management. Decision Support Systems (DSS) play a vital role in assisting farmers

and consultants in on-farm decision-making processes related to IPM. These systems provide valuable insights into potential crop risks, allowing users to make informed decisions based on observational data and model results. In Slovenia, the development of advanced DSS for IPM is underway through projects like "IPM Decisions," which aims to provide growers with decision support tailored to integrated pest management. Additionally, initiatives such as the "IPMWORKS-Wide IPM Farm Demo Network" project promote the adoption of IPM strategies through knowledge sharing and demonstrations across Europe. By reducing reliance on plant protection products (PPPs) and promoting sustainable agricultural practices, these projects contribute to environmental protection and human health. Moreover, the integration of modern information and communication technology (ICT) and remote sensing techniques in agriculture enhances precision farming practices, leading to more efficient resource utilization and improved crop management. Remote sensing technologies enable the detection of pests and diseases, aiding in timely interventions and reducing the need for manual inspections. Electronic traps and monitoring devices further streamline pest detection processes, providing real-time data for informed decision-making. Overall, the integration of advanced IPM strategies, DSS and digital technologies is essential for promoting sustainable agriculture and mitigating the adverse impacts of pesticide use on the environment and human health.

Reducing the use of Plant Protection Products (PPP) through non-chemical plant protection methods is essential for sustainable agriculture. Physical measures, such as seed cleaning and heat treatment, soil disinfection and mechanical weed control, serve to limit the access of harmful organisms to crops without relying on chemical interventions. Biotechnical measures utilize natural reactions of pests to attractants, deterrents and food baits, including the use of pheromones for monitoring and population control. Biotic measures involve the introduction of beneficial organisms to regulate pest populations, offering a sustainable alternative to chemical pesticides. While biotic protection requires careful monitoring and knowledge of ecosystem dynamics, it offers numerous advantages, including reduced pesticide residues and environmental pollution. Additionally, the use of PPP based on microorganisms, plant extracts, pheromones and other low-risk substances provides effective alternatives to conventional chemical pesticides. Entomopathogenic microorganisms, such as fungi and bacteria, offer targeted control of harmful insect species, while beneficial microorganisms can suppress plant pathogens and enhance plant resistance. Plant extracts, like pyrethrin and neem oil, serve as natural insecticides with minimal environmental impact. Basic substances, approved for other purposes and not typically used as PPP, offer further options for plant protection without adverse effects on human health or the environment. Overall, the adoption of non-chemical plant protection methods represents a holistic approach to sustainable agriculture, promoting biodiversity, reducing environmental impact and safeguarding human health while ensuring effective pest management.

# INTEGRATED PEST MANAGEMENT (IPM)

Integrated plant protection has been developed with the aim of managing harmful organisms, which should not be based on and depend solely on the use of chemical substances. Integrated plant protection means the systematic and planned management of harmful organisms and combines various approaches to plant health, based on a combination of biotic, processing, physical, biotechnical and chemical methods of plant protection. Integrated plant protection also means reducing the risk to the economy of agricultural production, human health, environmental protection and reduction of negative effects on non-target organisms.

In the Regulation on the placing of plant protection products on the market, the concept of integrated plant protection is described on the basis of the FAO definition: The Integrated Plant Protection Program takes into account all available ways of plant health protection against harmful organisms and is also open to further integration of measures that prevent the development of harmful organisms, the use of plant protection products and other plant protection measures at the level necessary to keep the population and reduce the risk to human health and the environment. Integrated plant protection also aims to promote natural plant protection mechanisms against harmful organisms.

The Plant Protection Products Act (UL RS 83/12) states: Integrated protection of plants against harmful organisms means careful consideration of all available methods of plant protection, which results in the integration of appropriate measures that prevent the development of populations of harmful organisms. In integrated pest management, the use of plant protection products should be at an economically and ecologically sound level, with the aim of reducing the risk to human health and the environment. Integrated pest management emphasizes the growth of healthy plants with minimal impacts on agricultural ecosystems and promotes natural mechanisms for protection against harmful organisms.

Integrated plant production of crops, fruit, grapes and vegetables is carried out in Slovenia under constant professional supervision by organizations for the control and certification of integrated production. If the cultivation is carried out in accordance with all requirements, the organization for the control and certification of the grower issues a certificate, which is guaranteed that the labeled crops correspond to a higher standard of cultivation.

*Table 1. Number of growers and fields (ha) included in various schemes of integrated cultivation from 2008.*

| Years | Sadje | | Zelenjava | | Grozdje | | Poljscine | | Skupaj | |
|---|---|---|---|---|---|---|---|---|---|---|
| | st.pridel | ha | st.pridel | ha | st.pridel | ha | st.pridel | ha | st.pridel | ha |
| 2008 | 1080 | 3.273,97 | 356 | 1.075,95 | 2.594 | 6.910,60 | 1.882 | 44.357,92 | 5.912 | 57.618,44 |
| 2009 | 994 | 3.475,54 | 331 | 1.002,57 | 2.428 | 7.630,69 | 1.823 | 45.367,84 | 5.576 | 57.476,64 |
| 2010 | 963 | 3.485,13 | 343 | 1.068,77 | 2.351 | 6.552,63 | 1.776 | 45.757,61 | 5.433 | 58.864,14 |
| 2011 | 949 | 3.451,43 | 341 | 977,08 | 2.360 | 8.581,42 | 1.762 | 46.298,03 | 5.412 | 59.307,94 |
| 2012 | 819 | 3.124,20 | 336 | 994,49 | 2.131 | 6.333,68 | 1.674 | 45.965,30 | 4.960 | 58.417,67 |
| 2013 | 733 | 3.057,65 | 321 | 997,05 | 1.975 | 7.887,95 | 1.635 | 46.108,93 | 4.664 | 58.051,58 |
| 2014 | 714 | 2.973,32 | 307 | 959,69 | 1.928 | 7.856,42 | 1.622 | 46.223,55 | 4.571 | 58.013,18 |
| 2015 | 350 | 1.509,26 | 166 | 516,87 | 102 | 794,09 | 52 | 2.006,80 | 670 | 4.827,02 |
| 2016 | 307 | 1.210,05 | 163 | 555,03 | 71 | 822,85 | 34 | 543,43 | 575 | 3.131,36 |
| 2017 | 231 | 1.029,90 | 148 | 605,72 | 59 | 818,45 | 28 | 600,28 | 466 | 3.054,35 |
| 2018 | 227 | 875,24 | 134 | 455,65 | 44 | 808,29 | 25 | 418,02 | 430 | 2.557,20 |
| 2019 | 182 | 687,05 | 143 | 513,06 | 51 | 796,16 | 26 | 322,90 | 402 | 2.319,17 |
| 2020 | 161 | 623,10 | 94 | 258,70 | 50 | 630,60 | 25 | 209,90 | 330 | 1.722,30 |
| 2021 | 137 | 197,80 | 120 | 384,40 | 45 | 622,40 | 32 | 321,20 | 334 | 1.525,80 |

## Integrated Pest Management Principles and Guidelines

Integrated plant protection is a process based on knowledge and experience and is open to new ideas, scientific knowledge and technological advancement. It is based on the detection, identification and precise definition of the size of the population of harmful organisms and on the assessment of the economic damage that these organisms can cause.

Integrated plant protection should focus on the objectives of sustainable crop production, where non-chemical, environmentally friendly, plant protection methods and the targeted and cost-effective use of plant protection products are preferred.

The most important principle of integrated plant protection is that we do not decide on the use of plant protection products only when other pest control measures are not effective enough. In this regard, the helpers of "Observation and Forecasting Services", which are based on the on-going monitoring of harmful organisms, weather conditions and the development of plants, are helpful to growers.

Integrated plant protection requires a good knowledge and understanding of the farming system and the combination of smart knowledge of old, existing and new technologies, since the natural balance in crops cannot be achieved only by simply reducing the use of plant protection products.

Integrated plant protection is a process that is constantly being upgraded and incorporates many innovative solutions that are adapted to the place and time of crop production and significantly contribute to reducing the dependence of agricultural production on the use of plant protection products.

In the effort to reduce the negative impacts of the use of PPP on humans and the environment, most European countries have developed guidelines for integrated crop production. This is regulated by the Rules on integrated production of crops, vegetables, fruits, grapes and wine (UL RS 110/10). Each year the Ministry of Agriculture, forestry and food published detailed technological instructions for integrated production. Chapters dealing with plant protection mainly contain brief technological instructions and data on authorized plant protection products for the control of individual diseases, pests and weeds.

## Basic Principles of Integrated Pest Management

Integrated plant protection instructions prepared in most countries are similar to those of some international organizations dealing with plant protection (IOBC-International Organization for Biological Control), mainly refer to the eight so-called basic principles that are also defined in European legislation (Directive 2009/128/EC).

## Preventive Measures

With proper selection of the site (location of the site, soil structure...), appropriate ring and method of production (soil treatment, sowing time, sowing / planting density, cut, educational forms, weed control techniques, sowing of mixed or intermediate crops (where applicable use of resistant / tolerant cultivars, planting or sowing of certified planting / seed material, appropriate fertilization, liming, irrigation or drainage, hygiene measures, creating conditions for the development and dissemination of useful organisms, e.g. creating so-called ecological niches), we take care of the good condition of plants and contribute to their better resistance to harmful organisms.

## Monitoring of Harmful Organisms

Regular inspection of crops or monitoring the occurrence, development and spread of harmful organisms is one of the key elements of integrated plant protection. The acquisition of information on

the health status of agricultural plants and the development of harmful organisms, the size of the population, the extent of the attack / infection and the biological and potential economic impact of the harmful organism is carried out with producer direct observations directly on the ground and with the help of information "Observatory forecasting services for plant protection" agricultural advisors. In determining the time and space of the most effective integrated plant protection measure, the correct identification (identification) of a harmful organism based on morphological characteristics or in more complex biological, chemical or genetic analyzes is of paramount importance for the selection of the appropriate. On the basis of officially collected biotic data, weather conditions and on the basis of information and warnings from the "Observation and Forecasting Plant Protection Service", we decide when and when and how we will act.

## Thresholds of Harm

Integrated plant protection programs are based on the consideration of economic thresholds of harmfulness, critical numbers (if available). Based on the results of the monitoring of harmful organisms and taking into account the levels of harm, producers decide whether to act at a given moment or not.

## Use of Non-Chemical Methods of Plant Protection

Biotic, physical, biotechnical and other non-chemical methods of plant protection have priority over the chemical control of harmful organisms, prior to the use of the plant protection product in case they provide sufficient management of harmful organisms. It is only in cases where, despite the use of non-chemical methods, the level of a harmful organism is unacceptable for the normal production of agricultural plants, we use the use of chemical plant protection products.

## Targeted Use of The Plant Protection Products

Any use of plant protection products should be targeted as far as possible (use of specific plant protection products) and minimize harm to human health, non-target organisms and the environment.

## Reducing The Use of Plant Protection Products to The Lowest Extent

The use of plant protection products, including other plant protection measures, is limited to the level strictly necessary to ensure adequate plant health (e.g. reduced doses of plant protection products, reduced spraying frequency, partial or target application of plant protection products-eg in species). In doing so, the risk to agricultural crops, as well as the risks to the development of potential resistance of harmful organisms, should be acceptable. Synthetic plant protection products should therefore only be used, when necessary, when all other possible methods of controlling harmful organisms, these are ineffective from the point of view of the economy of crop production.

## Anti-Resistance Strategy

The use of an "anti-resistance" strategy, based on the use of plant protection products with different methods and spectrum of action, is particularly important in cases where there is a need for repeated (repeatedly) pest control and for organisms that have already emerged resistant biological breeds.

## Observation, Monitoring, Recording and Verification

Through regular and thorough monitoring of harmful organisms and keeping records of the use of plant protection products and other measures of protection, growers regularly check the effectiveness of the plant protection measures applied.

# Advantages and Disadvantages of Integrated Pest Management

## Advantages of integrated pest management

•A more in-depth knowledge and monitoring of harmful organisms and cultivated plants allow a timely and appropriate selection of appropriate measures,

•Due to the reduced use of plant protection products or the use of eco-toxicologically more suitable and narrow-acting plant protection products is a reduced risk to human health, the environment and non-target organisms and reduced exposure of plant health providers,

•Reduced use of plant protection products in the long-term leads to financial savings in comparison with conventional plant protection,

•Favorable environmental impacts lead to more stable agricultural production in the long term,

•Integrated plant protection reduces the likelihood of the occurrence of resistant pests of pests against plant protection products.

## Disadvantages of integrated pest management

•Integrated plant protection requires more time and knowledge compared to conventional plant protection,

•Greater coordination and the efforts of operators to ensure proper and effective plant protection,

•Integrated plant protection is initially more expensive than conventional plant protection,

•Higher risk of uncontrolled development of harmful organisms.

## Requirements For Integrated Pest Management

•Only authorized plant protection products may be used,

•Authorized plant protection products should only be used in the prescribed manner and at the prescribed doses,

•The entry of plant protection products must correspond to the maximum prescribed number of treatments in relation to the preparation,

•Withholding periods must be taken into account,

•About the plant protection products used, producers are obliged to keep records and keep accounts where all the PPPs that have used them must be entered,

•The application of plant protection products must comply with the standards in these instructions and adapted to the growing form and the state of vegetation,

•It is necessary to ensure that the loss of the spray broom due to drift, evaporation or leakage of the sprinkler slurry on and into the ground is minimized,

•Appliances for the application of plant protection products must be tested,

•The users of the PPP must have a valid certificate of acquiring knowledge from phytomedicine,

•Proper storage of plant protection products and the management of their waste. waste packaging,

•The purchase of plant protection products in foreign countries, as well as their use, are not permitted under the Plant Protection Products Act.

The rules on the duties of users of plant protection products (Official Gazette of the RS, no. 62/03, 5/07, 30/09, 83/12-ZFfS-1, 43/14 and 71/14) stipulate that the user must ensure that the plant

protection product does not come into direct contact with humans and that the spray slurry does not get into watercourses, lakes and other waters, into groundwater, into facilities for drinking water supply, neighboring cultivated plants, land and warehouses of agricultural products, into storage facilities and processing of plants, facilities for breeding and care of animals, if such use may endanger human and animal health. Plant protection products should be used in accordance with the instructions for use, observing the indications and warnings on the label. When spraying is had to be done, it is necessary to use the method that is most appropriate from the point of view of good agricultural practice and environmental protection. The user must handle with plant protection products in such a way as to comply with the provisions of the regulations governing safety and health at work. When spraying at night in the vicinity of settlements, regulations governing public order and peace must be observed. Spraying must be carried out in a way that prevents reliance on neighboring plots or neighboring cultivated plants, taking into account the speed and direction of the wind. If the field is adjacent to a road or path, where people are walking or transporting bees during the spraying period, who may be exposed to the negative impact of plant protection products, the user must temporarily stop spraying. Users, whose fields are adjacent to kindergartens, schools, children's and sports playgrounds, medical facilities, retirement homes or other similar facilities must notify the local administration of the facility in writing at least 24 hours before using the plant protection products. The notification must include the trade name of plant protection product, method, date and estimated time of spraying. Tractor sprayers and motorized backpack sprayers must be used at a distance of at least 20 m from the apiary, buildings from the previous paragraph, or residential buildings and their functional lands where people stay or agricultural crops are grown. The flowering undergrowth in permanent orchards must be mowed during the spraying with plant protection products, which are dangerous for bees, or must be prevented in some other way so that the plant protection products can reach it. The use of systemic, bee-dangerous plant protection products is prohibited during the flowering period of cultivated plants. The use of contact, bee-dangerous plant protection products is allowed during the flowering of cultivated plants at night from two hours after sunset to two hours before sunrise. The user of plant protection products must observe the restrictions of use on certain soils due to the protection of groundwater and groundwater, as shown in the label and instructions for use of plant protection products and the use of plant protection products in certain areas in accordance with the regulations governing the protection of water. Spraying, preparation of the spray mixture and washing of plant protection products application devices are not allowed in the immediate vicinity of springs, watercourses, lakes, other waters and drinking water supply facilities. It is not allowed to flush plant protection products residues into wells, cesspools (outlets), septic tanks and sewers. The water used to clean the devices must be sprayed on the already treated surface or on another, biologically active surface. When spraying fields are located near water, the safety zone have to be determined in accordance with the regulations the protection of water and the information on the label or in the instructions for use.

## The Prescribed Measures in Integrated Pest Management

•The purchase of plant protection products in foreign countries, as well as their use, are not permitted under the Plant Protection Products Act.

•**Mechanical measures:** removal of infected parts or whole plants, removal of parasitic plants, mechanical weeding of weeds, use of blinds and covers...

•**Biotic measures:** The producer creates favorable living conditions for the development of beneficial organisms by: preserving and planting hedges, shrubs and other varieties of plants, cultivates a variety of underpasses, for the shelters of useful animals they are regulated by rocks and piles of branches, sets hatcheries for useful birds, installing high poles to attract birds of prey, observing, introducing and controlling a useful fauna (especially predatory mites, mates, tremors, tanners, swarms, pickles...).

•**Biotechnical measures:** use of pheromone baits, acoustic appliances, methods of confusion and other possibilities of catching insects (e.g. mass catches).

•**Chemical measures:** Where, despite the application of the above-mentioned measures, the threshold of harmfulness is exceeded, plant protection products may be used.

## References


1. IPM Portal: https://www.ivr.si/.
2. IPM: https://www.gov.si/teme/integrirana-pridelava/.
3. Rules on integrated pest management: http://www.pisrs.si/Pis.web/pregledPredpisa?id=PRAV11530.
4. Rules on the responsibilities of users of plant protection products: http://www.pisrs.si/Pis.web/pregledPredpisa?id=PRAV3724.
5. Rules on the proper use of plant-protection products: http://www.pisrs.si/Pis.web/pregledPredpisa?id=PRAV11541.

# PEST CONTROL MEASURES

## Integrated Pest Management (IPM)

Pest control measures are sets out by Regulations on integrated protection of plants against harmful organisms (Official Gazette of the Republic of Slovenia, No. 43/14). Every user of plant protection products must enable healthy plant growth and control of harmful organisms by implementing integrated plant protection measures (using a combination of preventive measures, low-risk plant protection methods, use of plant protection products, etc.). In addition to these measures, he must also regularly inspect his orchards and crops, monitor the appearance of harmful organisms and, based on his own judgment and experience, choose the most suitable method of plant protection.

For the control of harmful organisms, the user of plant protection products takes into account the information on the harmfulness threshold (if available), the appropriate time of use of the plant protection product and advices for use of plant protection products. The used plant protection product should be as specific and effective as possible in relation to the purpose of use and should have as few adverse effects on human health, non-target organisms and on the environment, as possible. If are available, low-risk plant protection methods can also be used. The user of plant protection products can obtain this information from public plant health care advisers and on the website of the Ministry of Agriculture, Forestry and Food.

Every user of plant protection products for professional use must observe and implement permitted measures of integrated plant protection on all cultivated areas (own and leased areas).

## Measures For Prevention the Appearance of Harmful Organisms

## Preventive measures

Every user of plant protection products for professional use must plan and carry out the cultivation of plants by implementing preventive measures with the aim of preventing the development of harmful organisms (disease and pest) and weeds.

## Location

The requirements in integrated crop production regarding the choice of location are: in a certain location, we can only grow types/cultivars of crops that are suitable in terms of climatic characteristics, the possibility of additional water supply, soil and relief properties.

The recommendations are: depending on the specific conditions of the location, it is necessary to ensure protection from winds and ensure biotic diversity and its positive effects on the environment. Depending on the location (sloping terrain, groundwater, open watercourses, etc.), special attention is needed regarding additional negative impacts on the environment (soil, crop rotation, assortment, fertilization, plant protection, economy of cultivation).

A choosing of a location for growing vegetables, it is necessary to take into account climatic conditions (amount of precipitation, risk of frost, air humidity), type of soil (depth, nutrient content, availability of nutrients, humus content, biological activity of the soil), relief (slope and exposure of the terrain), water supply (depth of groundwater, possibility of irrigation, soil retention capacity) and infrastructure from an ecological point of view (protection against wind, protection against erosion, preservation of biotopes, water protection).

## Soil management

Prohibitions in integrated crop production are:

•treatment of frozen soil,

•basic and pre-sowing treatment of too wet and too dry soils,

•burning of harvest residues (straw, corncobs, etc.) is prohibited on the fields,

•year-round lack of soil coverage (most of the spring and summer, the soil must be purposefully sown and cared for).

The required measures in integrated crop production are:

•mechanical weed control at least 1x in each crop (use of "tined weeder" or other methods of mechanical soil treatment),

•land use methods that do not significantly reduce the population of beneficial soil microorganisms (earthworms, etc.) in the long term,

•cultivate the soil in such a way as to prevent soil compaction,

•soil cultivation that preserves soil structure (cultivation of suitably moist soil),

•ensuring sufficient content of humus,

•soil cultivation on sloping fields transverse to the slope (prevention of erosion),

•use a cultivation strategy based on the reduction of residues of plant protection products (crop rotation, compliance with the rules of integrated plant protection),

•create a nutrient balance, check nitrogen needs (fertilization),

•according to the texture of the soil and the requirements of crops, take care of the appropriate pH value of the soil,

•mulching and plowing of crop residues is mandatory already in autumn (e.g. with corn and sorghum due to European corn borer - *Ostrinia nubilalis*).

The recommendations in integrated crop production are:

•in case of regulated water-air regime, suitable weeding and availability of machines, from time to time, instead of classic ploughing, carry out treatment without a plow (conservative soil treatment) or direct sowing,

•equip tractors and machines with tires or attachments that prevent soil compaction,

•sowing of winter and non-winter cover crops.

The requirements in integrated vegetable production are:

•all soil cultivation measures must be aimed at maintaining or improving soil fertility and structure, a balanced balance of humus in the soil and ensuring a diverse and balanced crop rotation.

Prohibitions in integrated vegetable production are:

•year-round lack of ground cover,

•use of herbicides in protected areas,

•chemical disinfection of the floor in greenhouses,

•an open system of hydroponic vegetable production in greenhouses.

The measures in integrated vegetable production are:

•prevention of soil compaction,

•implementation of deep loosening,

•soil cultivation on inclined surfaces transverse to the slope (prevention of erosion),

•plowing crop residues as late as possible, in autumn,

•plow the winter furrow, if it is necessary, as late as possible,

•prevention of winter fallow (over the winter unsown area),

•cultivation that preserves the soil structure,

•ensuring sufficient humus content.

Soil supply requirements in integrated fruit production are:

•the grower must maintain a system of well-kept fallow in the interspecies space, with some exceptions (peach and apricot orchards on land without the possibility of irrigation in Primorska region, young orchards before the final formation of the fruit volume, peaches up to 3 years of age, cherries, cherries, plums and plums up to 5 years of age, persimmons up to 6 years of age, olives up to 7 years of age, Actinidia orchards up to 4 years of age and strawberry orchards),

•soil cultivation must be shallow (cultivation, shallow ploughing), from October to the end of February the soil is not cultivated,

•the growers have to leave the cutted grass in orchard due to the closed cycle of substances,

•in new orchards, with some exceptions, immediate weeding is mandatory.

•mowing of terrace embankments in orchards on terraces is mandatory.

•limiting the spread of unwanted weeds is possible by natural greening of bands with low plants that have shallow roots, by covering bands under trees with organic materials or foil, by mechanical or thermal weed suppression, by regular mowing or mulching and by using approved herbicides.

•in the row, the use of herbicides (herbicide band) is allowed, which must not exceed 1/3 of the inter-row distance (in the case of strawberries, the restrictions regarding the herbicide band are not applied).

•exceptions to the width of the herbicide band are allowed in some cases (for multi-row apple and pear orchards planted before 1991, in walnut and hazelnut orchards, only during fruit ripening, the width of the herbicide band is allowed up to 2/3 of the inter-row distance, otherwise 1/3 applies).

The requirements for soil care in integrated grape production are:

•burning grass debris and banks is prohibited,

•weeds can only be removed mechanically in the band under the vines (if mechanical weed removing measures are ineffective, approved herbicides can be used),

•the width of the "treated" band under the vines may not to be more than 25% of the net area of the vineyard.

## Crop rotation

Implementation of crop rotation have to be done on at least 50% of all arable fields. An appropriate crop rotation is one that corresponds to the selected cultivation technology (at least a two-year rotation, at least a three-year rotation is recommended).

Prohibitions:

•sequential crop rotation of the main crops of individual crops and related plant species (same genus) is prohibited, except for hops,

•corn can be sown on the same field no more than twice in three years, but never twice in line up (consecutively),

•the field area must be "covered" (not only with weeds) after the harvest (over the summer),

•it is forbidden to have uncovered arable land during the winter in water protection areas and areas, exposed to soil erosion,

Required actions:

•taking into account the effects of crops in rotation on preventing the occurrence of diseases and pests, which may be the result of improper crop rotation,

•changing plant species,

•during the "break", i.e. before replanting hops on the same field, a break of at least two years is mandatory in the crop rotation (Fabaceae are desirable), except in the case of the appearance of verticillium wilt, where it is recommended to implement crop rotation with narrow-leaved plants that prevent the spread of verticillium wilt of hops (*Verticillium nonalfalfae* and *Verticillium dahliae*).

Recommendations:

•on fields, where grasses or grass-clover mixtures are plowed, a stronger attack of the click beetles (Elateridae) is expected, so it is recommended to first green the soil with plants that contain glucosinates (the most suitable plants are Brassicaceae: white mustard, canola, rapeseed).

## Tolerant and resistant varieties

Requirements:

•it is necessary to choose varieties that are as tolerant or resistant as possible to diseases and pests and those with the highest possible threshold of harmfulness due to harmful organisms,

•depending of the production, we choose varieties with certain characteristics (plants with upright leaves and the possibility of increasing the set of plants or plants with wider and drooping leaves with greater coverage-prevention of weeding, …).

Prohibitions:

•the use of genetically modified plants is prohibited,

•for sowing/planting, it is forbidden to use seed that doesn’t comply with plant health regulations,

Recommendations:

•it is recommended to use certified seed for sowing/planting,

At growing vegetables, the quality of seeds and seedlings directly affects the development of vegetables and the occurrence of diseases and pests, so it makes sense to use high-quality and healthy seeds or seedlings and to carry out strict selection when growing seedlings (eliminate infected and poorly developed seedlings). It is also recommended to save the label or plant passport after sowing or planting, so that in the event of the occurrence of a controlled disease or pest, the place of origin can be traced.

The use of tolerant and resistant varieties in fruit growing and viticulture is important in terms of the reduced occurrence of some harmful organisms and thus also the reduced use of plant protection products.

## Cleaning of machinery and equipment

Cleaning machinery and equipment after finishing work on the land or at the end of the working day to prevent the spread of harmful organisms (pests, plant diseases, weeds)

# Low Risk Plant Protection Methods

## Use of basic substances

Basic substances that can be used for plant protection are those substances that are not problematic in terms of causing hormonal imbalances and do not have neurotoxic or immunotoxic effects. They are authorized for other purposes and are not normally used for plant protection and are not placed on the market as plant protection products, but are nevertheless useful as plant protection products. Basic substances include those substances that meet the criteria for food.

The use of basic substances in the European Union is approved by the European Commission. The European Commission asks the European Food Safety Agency for technical and scientific assistance and an opinion on the application. Based on this opinion, the European Commission approves or disapproves the substance as a basic substance. The permitted basic substance is entered in a special part of the list of approved active substances-"EU Pesticides Database"-https://food.ec.europa.eu/plants/pesticides/eu-pesticides-database en#FFS.

*Table 1. List of basic substances*

| Latin or English Name | Permitted Use in Organic Production |
|---|---|
| *Equisetum arvense* L. | yes, but not as an herbicide |
| Chitosan Hydrochloride | yes, but not as an herbicide |
| Sucrose | yes, but not as an herbicide |
| Calcium hydroxide | yes, but not as an herbicide |
| Fructose | yes, but not as an herbicide |
| Lecithin's | yes, but not as an herbicide |
| *Salix* spp. Cortex | yes, but not as an herbicide |
| Vinegar | yes, but not as an herbicide |
| Sodium hydrogen carbonate | yes, but not as an herbicide |
| Diammonium phosphate | yes, but not as an herbicide |
| Whey | yes, but not as an herbicide |
| Sunflower oil | yes, but not as an herbicide |
| *Urtica* spp. | yes, but not as an herbicide |
| Hydrogen peroxide | yes, but not as an herbicide |
| Clayed charcoal | no |
| Beer | yes, but not as an herbicide |
| Mustard seed powder | yes, but not as an herbicide |
| Sodium chloride | no |
| Talc | no |
| Onion oil | yes, but not as an herbicide |
| Sodium chloride | yes, but not as an herbicide |
| L-cysteine (E 920) | yes, but not as an herbicide |
| Cow milk | yes, but not as an herbicide |
| *Allium cepa* L. bulb extract | yes, but not as an herbicide |
| Other basic substances from plant or animal origin and based on food | yes, but not as an herbicide |

## Use of plant protection product's (PPP's), that are allowed for organic farming

Pripravki, ki so dovoljeni v ekološki pridelavi se tudi lahko uporabljajo v integrirani pridelavi, seznam dovoljenih pripravkov v Republiki Sloveniji je dostopen na naslednji povezavi: http://spletni2.furs.gov.si/FFS/REGSR/FFS sezn.asp?L=1&S=2&top=1.

Plant protection product's, that are permitted in organic production, can also be used in integrated production, the list of permitted plant protection product's in the Republic of Slovenia is available at the following link: http://spletni2.furs.gov.si/FFS/REGSR/FFS sezn.asp?L= 1&S=2&top=1.

REPUBLIKA SLOVENIJA
MINISTRSTVO ZA KMETIJSTVO, GOZDARSTVO IN PREHRANO

UPRAVA RS ZA VARNO HRANO, VETERINARSTVO IN VARSTVO RASTLIN

**eznam FFS, dovoljenih v ekološki pridelavi** - Datum izpisa: 12.10.2022 15:19:29

| e FFS | Aktivna snov in vsebnost | Vrsta sredstva | Številka odločbe | Veljavnost registracije | Proizvajalec | Zasto |
|---|---|---|---|---|---|---|
| GREE WG | Bacillus Thuringiensis var. Aizawai (50%) | INSEKTICID | U34330-1/22/8 (28.03.2022), U34330-1/20/13 (26.03.2020), U34330-197/14/16 (22.01.2018), U34330-197/14/10 (19.05.2017), U34330-197/14/7 (11.04.2017), U34330-197/14/1 (24.11.2016) | 30.04.2024 | Mitsui AgriScience International S.A./B.V. | |
| MYLO - X | Bacillus amyloliquefaciens subsp. plantarum, sev D747 (25%) | FUNGICID, BAKTERICID | U34330-34/17/11 (12.03.2020), U34330-101/19/2 (04.02.2020), U34330-34/17/4 (26.10.2017) | 31.03.2026 | CBC (Europe) S.r.l. | KARS proiz Duto Ljubl |
| Q-10 | Ampelomyces quisqualis sev AQ10 (58%) | FUNGICID | U34330-172/14/29 (12.07.2022), U34330-172/14/24 (08.12.2020), U34330-101/19/2 (04.02.2020), U34330-172/14/15 (18.07.2019) | 31.07.2034 | CBC (Europe) S.r.l. | KARS proiz Duto Ljubl |
| RGOS | olje pomarančevca (84,32%) | FITOREGULATOR | U34330-81/20/17 (13.09.2021) | 31.07.2025 | Arysta LifeScience Benelux Sprl | PICO |
| ZATIN EC | azadirahtin A (2,6%) | INSEKTICID | U34330-57/19/5 (20.11.2020) | 31.05.2025 | Certis USA L.L.C. | Mitsu S.A./ |
| ZUMO WG | žveplo (80%) | FUNGICID | U34330-13/19/13 (22.06.2022), U34330-13/19/9 (03.12.2021), U34330-13/19/4 (14.08.2020) | 31.12.2023 | AZUFRERA Y FERTILIZANTES PALLARES S.A. (AFEPASA) | |
| ADGE WG | baker v obliki bakrovega oksiklorida (24,5%), baker v obliki bakrovega hidroksida (24,4%) | FUNGICID, BAKTERICID | U34330-91/14/26 (16.12.2020), U34330-91/14/22 (04.11.2019), U34330-91/14/13 (29.01.2019), U34330-91/14/11 (22.12.2017), U34330-91/14/5 (16.10.2017) | 31.12.2022 | ISAGRO S.p.A. | |
| ANARG | etilen (4%) | FITOREGULATOR | U34330-114/15/5 (22.02.2018) | 31.08.2023 | Linde AG | GTG |
| O PLANTELLA ARION PROTI OLŽEM (staro ime BIO ANTELLA PROTI POLŽEM) | železov (III) fosfat (0,98%) | LIMACID | U34330-53/19/11 (17.06.2021), U34330-53/19/3 (23.12.2019) | 31.12.2031 | Doff Portland Ltd. | UNIC |
| O PLANTELLA KENYATOX | piretrin (0,2%) | INSEKTICID | U34330-34/20/2 (21.07.2020) | 31.08.2023 | COPYR S.p.a. | UNIC |
| OTIP APHICID PLUS | piretrin (0,2%) | INSEKTICID | U34330-1/20/15 (04.06.2020), U34330-32/13/14 (30.01.2019), U34330-32/13/9 (21.12.2016) | 31.08.2023 | COPYR S.p.a. | BIOT |
| OTIP FLORAL | piretrin (1,82%) | INSEKTICID | U34330-1/20/15 (04.06.2020), U34330-99/15/21 (17.03.2017), U34330-99/15/16 (20.10.2016), U34330-99/15/6 (31.03.2016) | 31.08.2023 | COPYR S.p.a. | BIOT |
| OTIP SULFO 800 SC | žveplo (80%) | FUNGICID | U34330-29/18/19 (15.01.2021), U34330-1/20/34 (18.12.2020), U34330-29/18/10 (18.01.2019) | 31.12.2022 | CIECH Sarzyna Spółka Akcyjna | BIOT |
| OTIP UBIJ ME NEŽNO PLUS | piretrin (0,2%) | INSEKTICID | U34330-1/20/15 (04.06.2020), U34330-119/13/11 (30.01.2019), U34330-119/13/5 (19.12.2016) | 31.08.2023 | COPYR S.p.a. | BIOT |
| OTANIGARD OD | Beauveria bassiana, sev GHA (10,17%) | INSEKTICID | U34330-1/21/2 (28.04.2021), U34330-50/18/11 (13.11.2019), U34330-50/18/5 (07.05.2019) | 30.04.2023 | Mycotech Europe Limited | METI |
| OTANIGARD WP | Beauveria bassiana, sev GHA (22%) | INSEKTICID | U34330-1/21/2 (28.04.2021), U34330-49/18/15 (10.06.2020), U34330-50/18/11 (13.11.2019), U34330-49/18/6 (07.05.2019) | 30.04.2023 | Mycotech Europe Limited | METI |

*Picture 1. List of plant protection product's, allowed in organic production (Source: http://spletni2.furs.gov.si/ffs/regsr/ffs sezn.asp?l=1&s=2&top=1)*

# Non-Chemical Measures to Reduce the Occurrence of Harmful Organisms

## Mechanical or physical weed control (machine or manual)

Manual mechanical weed control can be carried out on smaller fields, on bigger fields are using machines (combs, weeders...).



*Picture 2. Mechanical removal of weeds in cereals-tined weeder (Source: https://eggmann-landmaschinen.ch/dienstleistungen/landtechnik)*



*Picture 3. Mechanical removal of weeds in maize (Source: https://www.moreki.co.bw/2020/07/28/mechanical-weed-control)*



*Picture 4. Mechanical removal of weeds in orchard and vineyard (Source: https://www.northernequipment.ca /kultkressvineyardfingerweeder)*

## Mechanical or physical removal of attacked or infected plants, or parts of plants or harmful organisms

It is a measure to remove infected parts of plants (leaves, shoots, cancerous formations, "mummies"...), whole plants and parasitic plants (example: white mistletoe-*Viscum album*). Example: In case of apple powdery mildew (*Podosphaera leucotricha*) or fire blight (*Erwinia amylovora*), infected shoots are removed by cutting, in case of Flavescence dorée (quarantine pest) grapevines must be removed.

## Use of beneficial organisms for biotic plant protection

Biotic plant protection is a method of plant protection in which living organisms are used to control plant pests. These living organisms can be "predators" (larvae and adult Coccinellidae, larvae of common green lacewings, Cimicomorpha, predatory mites, thrips, etc.), which help us reduce the population of harmful organisms. Parasitoids lay their eggs in, on or near pests and the larvae that develop from them then feed on the pests.

The use of natural enemies in the control of harmful organisms is regulated in Slovenia by the Rule on biotic plant protection (Ur. l. RS 45/06), an important component of this rule is the "List of native species of organisms for biotic plant protection", which currently lists 29 types of biotic agents (19

types of predators, 6 types of parasitoids and 4 types of entomopathogenic nematodes). These are organisms, that are widespread in our natural environment, either due to their nativeness or due to the fact that they were intentionally or unintentionally introduced to Europe from other continents in the past. In Europe, these organisms have proven to be effective natural enemies of pests, while showing no adverse effects on native natural enemies. Proposals for inclusion on the "EPPO List" are considered by members of the EPPO Panel for Biotic Plant Protection.

| **Koristni organizem** | **Ciljni skodljivi organizem** | **Uporaba (prostor locen od narave/na prostem)** |
|---|---|---|
| *Adalia bipunctata* | Aphididae | prostor locen od narave |
| *Aeolothrips intermedius* | Acarina, Thysanoptera | na prostem |
| *Amblysaius andersoni* | *Tetranychus urticae, Aculus schlechtendali, Panonychus ulmi, Tetranychus cinnabarinus, Aculops lycopersici,* Thysanoptera | prostor locen od narave/na prostem |
| *Amblyseius barkeri* | *Thysanoptera (Thrips tabaci, Frankliniella occidentalis),* Tarsonemidae | prostor locen od narave |
| *Anastatus bifasciatus* | Heteroptera *(Halyomorpha halys)* | na prostem |
| *Anthocoris nemoralis* | Psyllidae | na prostem (v sadovnjakih) |
| *Anthocoris nemorum* | *Caccopsylla pyri,* Thysanoptera | na prostem |
| *Aphelinus mali* | *Eriosoma lanigerum* | na prostem |
| *Aphidius ervi* | *Aulacorthum solani, Macrosiphum euphorbiae* in druge vrste iz druzine Aphididae | prostor locen od narave/na prostem |
| *Aphidius matricariae* | *Myzus persicae* | prostor locen od narave/na prostem |
| *Aphidoletes aphidimyza* | Aphididae *(Aphis gossypii, Myzus persicae, Macrosiphum* sp., *Aulacorthum* sp.) | prostor locen od narave/na prostem |
| *Chrysoperia camea* | Aphididae | prostor locen od narave/na prostem |
| *Coccinella septempunctata* | Aphididae | na prostem |
| *Diglyphus isaea* | Agromyzidae (*Liriomyza* spp.) | prostor locen od narave/na prostem |
| *Encarsia formosa* | Aleyrodidae *(Trialeurodes vaporariorum, Bemisia tabaci)* | prostor locen od narave |

*Picture 5. List of native species of organisms for biotic plant protection (Source: https://www.gov.si/teme/bioticno-varstvo-rastlin)*

## "Confusion" method (pheromone control system)

In viticulture and fruit growing, the method of "confusion" is used with the help of pheromone dispensers. The method is based on false pheromone signals that override the naturally released pheromones of females and thus confuse males when they are searching for females to mate with. The dispensers release the same pheromone that the females release and, in this way, confuse the males and therefore they are "confused" when looking for the female during the mating season. As a result, the females are not fertilized and lay infertile eggs from which the pest does not develop.

The list of permitted pheromones is on the following website: http://spletni2.furs.gov.si/ffs/regsr/ffs sezn.asp?l=1&s=4&top=1.



*Picture 6. "Isomate CTT" dispenser for the "confusion" method in fruit orchards, against codling moth (Source: https://www.karsia.si/isomate-c-tt)*



*Picture 7. Dispenser "Isonet L Plus" method of "confusion" in viticulture against vine moth (Source: https://www.karsia.si/isonet-l-plus)*

## References


1. Rules on integrated pest management: http://www.pisrs.si/Pis.web/pregledPredpisa?id=PRAV11530.
2. IPM: https://www.gov.si/teme/integrirana-pridelava/.
3. Basic substances for plant protection: https://www.gov.si/teme/osnovne-snovi-za-varstvo-rastlin/.
4. List of PPP, permitted in organic farming: http://spletni2.furs.gov.si/FFS/REGSR/FFS sezn.asp?L=1&S=2&top=1.
5. Biotic protection of plants: https://www.gov.si/teme/bioticno-varstvo-rastlin/.
6. List of PPP, based on microorganisms, extracts, pheromones: http://spletni2.furs.gov.si/FFS/REGSR/FFS sezn.asp?L=1&S=4&top=1.

# OPTIMISATION OF THE USE OF PLANT PROTECTION PRODUCTS IN AGRICULTURE

In 2002, the European Parliament adopted a Thematic Strategy on the Sustainable Use of Pesticides in the form of action programmes to reduce risks to human health and the environment from the use of pesticides. The European Commission has taken these guidelines into account and laid down strict criteria for the authorization of plant protection products (PPP), the collection of data on the sale and use of PPP and measures under legislation on the sustainable use of PPP. All measures shall be covered by a national action programme with the aim of reducing the risks of the potential impact of PPP on human, animal, drinking water, surface and groundwater and other environments.

The sustainable use of plant protection products (PPP) also includes the policies and measures that we are implementing as a result of the use of PPP with a view to reducing risks and impacts for human and animal health and the environment. PPP users shall be encouraged to use PPP, to implement integrated pest management and to use low-risk PPP. There is also regular information and public awareness of PPP, training of PPP consultants, PPP vendors and users and inspections of PPP application devices. The sustainable use of plant protection products directs the PPP user towards optimal use, towards preserving the environment and human health.

## Use of Plant Protection Products (PPP's) in Slovenia

In Slovenia, most of the older studies on PPP residues in the environment were carried out on crops, water or soil, to which plant protection products came with direct introduction to agricultural land.

When adapting legislation to the European Union, the Law on plant protection products has restricted the use of multi-component PPP due to the detection of residues in the waters and that the use of PPP must be safe (harmless to human health in direct or indirect contact), specific (effective for the control of specific harmful organisms acceptable to non-target organisms) and non-existent (to decompete into simple chemical components without harmful effects on the environment). The "old" active substances were also re-evaluated and dangerous substances were excluded from use. Registration-authorization to use a specific PPP is granted for a maximum period of 10 years with the possibility of renewal, if applicable. In the event that, on the basis of technical and scientific knowledge, there are reasonable grounds for suspecting that an PPP already registered constitutes a danger to human health and the environment, the Minister of Agriculture shall have the power to restrict or prohibit its use.

The application of the PPP is also governed at European Union level by legislation relating to water protection (Water Framework Directive (2000/60/EC), Groundwater Directive (2006/118/EC) and The Directive on Environmental Quality Standards in the field of water policy (2008/105/EC). In Slovenia, when adapting to this legislation with regard to the requirements of the European Union, two regulations were adopted-the Regulation on the state of surface waters (Official Gazette of the Republic of Slovenia, No. 14/09 and 98/10) and the Groundwater Status Regulation (Official Gazette of the Republic of Slovenia, No. 25/09 and 68/12). These two regulations lay down environmental quality standards for each type of pollution which pose a significant risk to the aquatic environment and to the abstraction of drinking water.

Since 2001, the Plant Protection Products Act requires all PPP users to provide compulsory education (without passing a phytomedicine examination and certificate of knowledge in phytomedicine PPP cannot be purchased and used) and the examination of PPP application devices on plants.

The measures are aimed at informing and informing users of the correct use of PPP (emphasis on the protection of groundwater and surface waters, protection of bees, safe disposal of waste and packaging waste of PPP), promoting integrated and organic production, both to test biotic protection and other non-nuclear methods, as well as to advise the use of less hazardous, less persistent and more degradable PPP and to better optimize the use of these PPP.

The goals regarding the use of phytopharmaceuticals in Slovenia are as follows:

•reduction of dangers and risks to human and animal health and to the environment due to the use of PPP, including the replacement of the most dangerous substances with safer ones,

•reducing the level of active substances harmful to health in food and drinking water, including replacing the most dangerous substances with safer ones,

•promotion of agricultural production in the sense that PPP are used according to the principles of integrated plant protection only when it is absolutely necessary or economically justified,

•regularly informing and raising awareness of users about the safe use of PPP, encouraging the development and introduction of organic agriculture and other so-natural agricultural practices,

•creating a transparent system for reporting on progress in achieving the strategy's goals and monitoring this progress, including the development of relevant indicators,

•ensuring the sustainable use of PPP for all types of plants while reducing the risk due to the use of PPP.

•the professionally justified use of PPP, which should be based on the improvement of the technological procedures for the production of cultivated plants, with the help of the prognostic service,

•improving the professional competence of PPP users,

•reduction of PPP residues in crops

•reduction of pollution of surface and underground waters due to the use of PPP,

•improved control over the use of PPP (for agricultural and non-agricultural purposes)

•improved control over the disposal of PPP waste packaging,

•establishment of systematic monitoring of PPP impacts on certain non-target organisms (bees, birds, fish...) and

•establishment of systematic monitoring of PPP impacts on the health of PPP users.

## Handling Training of Plant Protection Products (PPP's)

In Slovenia, the training system for users and distributors of PPP, including lecturers, has been in place for years since 2001 and is carried out in accordance with the Rules on professional training and knowledge testing in phytomedicine (Official Gazette of the Republic of Slovenia, no. 36/02, 41/04, 17/05, 92/06, 99/08, 83/12-ZPPP-1 and 85/13). The existing training system in phytomedicine is divided into the following groups: training of responsible persons and lecturers in phytomedicine and training of implementers of measures and sellers. The sets differ from each other in the duration of the training, purpose and partially also in content. When the training was established, the key contents were related to plant protection, the use of PPP and legislation in this area. The training material includes the following topics: pathogens and plant pests and the impact of weeds, human health and environmental impacts of PPP, PPP application technique and legislation.

The basic training consists of a course and a written test of knowledge:

•for PPP counselors (at least 35 school hours),

•for PPP sellers (at least 20 school hours),

•for implementers of plant protection measures or PPP users (at least 15 school hours).

Further training is carried out in the form of a course without a written knowledge test and lasts at least:

•for PPP advisors (at least 8 school hours),

•for PPP sellers (at least 6 school hours),

•for implementers of plant protection measures or PPP users (at least 4 school hours).

The content of PPP training includes:

•legislation in the field of PPP,

•fake PPP and methods for identifying them,

•dangers and risks associated with PPP and the way of identifying and controlling these risks in relation to risks for people (PPP users, residents, other bystanders, persons entering treated areas, persons handling treated plants or consuming treated plant parts-PPP poisoning symptoms and first aid measures,

•risks to non-target plants, beneficial insects, wildlife, biodiversity and the environment,

•strategies and techniques of integrated protection of plants against harmful organisms, principles of organic farming, methods of biotic control of harmful organisms,

•safe practices for storage, handling and mixing of PPP and disposal of empty packaging, other contaminated materials and excess PPP (including residual spray slurry),

•personal protective equipment of the PPP user,

•procedures for the preparation of PPP application devices, including their calibration and for their operation with the least possible risks to PPP users, other persons, non-target animal and plant species, biodiversity and the environment, including water resources,

•use of PPP application devices and their maintenance and special spraying techniques (preventing reliance on non-target surfaces- "drift"...),

•urgent measures to protect human health, the environment, including water resources, in the event of accidental spillage and pollution, as well as extreme weather events that could cause PPP to be washed away,

•management of data on the use of PPP-records of PPP use.

## Traffic With Plant Protection Products (PPP's) and Their Sale

The PPP sales system in Slovenia is regulated in such a way that users can buy PPP without presenting a certificate (for certain PPP, which can be sold without presenting a Certificate of Phytomedicine acquisition, only in specialized PPP stores-the list is available at http://spletni2.furs.gov.si/FFS/REGSR/FFS sezn.asp?L=1&S=15&top=1, or for certain PPP that are sold without presenting a Certificate of Phytomedicine acquisition in specialized stores with PPP and other stores with exclusively non-food products-the list is available at http://spletni2.furs.gov.si/FFS/REGSR/FFS sezn.asp?L=1&S=16&top=1) or by presenting the Certificate of acquisition of knowledge in phytomedicine. Distributors, who are legal and natural persons and are responsible for placing PPP on the market (including wholesalers, retailers, sellers and suppliers) deal with the trade and sale of PPP. They must meet the requirements regarding the education and professional qualifications of the staff, premises and equipment and must have permission from the administration to perform this activity. Distributors who sell PPP in flower shops and non-food stores must also meet the conditions and obtain a permit from the ministry.

The permit for PPP traffic is issued by the administration based on the report of the competent inspector on the fulfillment of the conditions of premises and equipment for PPP traffic and personnel. The administration maintains a register of PPP distributors. The administration reports data on PPP

traffic to the Statistical Office of the Republic of Slovenia for the purpose of collecting and processing statistical data on PPP traffic.

## Notification and Public Awareness

Informing and raising awareness of the public takes place in the form of the implementation of various activities of the competent ministry regarding the safe use of PPP, the issue of PPP use in relation to the risk to bees, the recognition of PPP fakes, the correct handling of PPP waste containing dangerous substances, etc. The regulation governing the handling of PPP waste containing dangerous substances already determines the obligations of persons who give or deliver PPP, packaged for final use, directly to the end user, regarding informing customers about the possibility of free delivery of waste PPP at the point of sale or in PPP waste collection points.

The obligation to inform end users is also imposed on PPP waste collectors, who must inform end users:

•on the purpose and goals of collecting PPP waste,

•correct handling of them,

•free broadcasting options

•about the methods of their reuse and disposal.

Information and awareness of users is defined in the Act on PPP in such a way that the Ministry adopts a program of information and awareness in relation to PPP, which includes measures to promote and improve information and awareness of the public about the impacts of using PPP and the impacts of improper handling of PPP waste containing dangerous substances, on human health, non-target organisms and the environment. The public is informed about the risk from the use of PPP and the possible acute and chronic effects of these agents on human health, non-target organisms and the environment. The interested public participates in the preparation of the program.

# Application Devices for Plant Protection Products (PPP's)

## Regular inspection of PPP applicators

Regular inspections of PPP application devices (tractor or self-propelled sprayers and tractor or self-propelled sprayers) are regulated by three regulations (Regulations on obtaining a certificate of compliance of plant protection devices for new devices, Rules on conditions and procedures that must be met and implemented by authorized inspectors bodies for regular inspection of devices for applying plant protection products to obtain authorizations from the Ministry of Agriculture and Forestry and Rules on the content and method of maintaining the register of devices of certified types that have successfully or unsuccessfully passed a regular inspection) on the basis of which the owner of the inspected device receives a control sticker on the flawless operation of the PPP application device.

Authorized organizations for inspecting PPP application devices organize field inspections of devices every year in the months of March and April, or before the start of the spraying season. For PPP applicators, the user of spray equipment must pass a device performance test every three years, with the exception of new equipment (the first inspection of the device is after five years and every subsequent one every three years).

## Introducing improved PPP application techniques

PPP users must be familiar with the general principles of good agricultural practice and before choosing a treated area, each user must assess the possibility of drift and apply PPP in such a way that the product does not rely on neighboring surfaces-"drift". Control organizations must not allow residues

of unauthorized PPP in crops, regardless of whether they are the result of reliance on PPP from the environment or their own improper use.

Improved PPP application techniques enable better coverage of the sprayed surface and thus greater efficiency (optimized use of PPP) and less reliance ("drift") of these agents outside the application area during the spraying itself. It is necessary to achieve as little direct drift as possible, which is the result of the movement of air currents during spraying (wind). The extent of drift is highly dependent on the size of the droplets and the wind that affects the path of the droplets to the target. PPP users can influence the reduction of reliance on spray slurry during spraying due to chemical processes and post-application atmospheric phenomena through the decision to use the PPP (at appropriate temperature, humidity, wind).

Drift-reduced nozzles (“anti-drift nozzles”) significantly (by 50 to 90%) reduce PPP drift on non-target surfaces. Drift can also be reduced by using suitable sprayers, where PPP drift can be reduced by 75 to 90% with the use of drift reduction nozzles, use of air barriers, consideration of ecological and weather conditions during application and different PPP application techniques.

## References


1. https://www.gov.si/teme/trajnostna-raba-fitofarmacevtskih-sredstev/.
2. Act on phytopharmaceuticals: http://www.pisrs.si/Pis.web/pregledPredpisa?id=ZAKO6355.
3. Order prohibiting the circulation and use of certain phytopharmaceuticals on the territory of the Republic of Slovenia: http://www.pisrs.si/Pis.web/pregledPredpisa?id=ODRE2109.
4. Regulations on integrated protection of plants against harmful organisms: http://www.pisrs.si/Pis.web/pregledPredpisa?id=PRAV11530.
5. Rules on the correct use of phytopharmaceuticals: http://www.pisrs.si/Pis.web/pregledPredpisa?id=PRAV11541.
6. Rulebook on the conditions for trade in plant protection products and on the management and transmission of data on the sale of plant protection products: http://www.pisrs.si/Pis.web/pregledPredpisa?id=PRAV11540.
7. Regulations on training on plant protection products: http://www.pisrs.si/Pis.web/pregledPredpisa?id=PRAV11537.

# INCREASE KNOWLEDGE AND WILLINGNESS TO ADAPT AND USE IPM TEHNIQUES

The increased use of pesticides in agricultural production poses a threat to human health and the environment. Integrated Plant Protection (IPM) is proposed as an alternative to conventional pest management practices. Implementation of IPM, however, faces several challenges, especially in developing countries. Challenges in implementing IPM programs and adopting IPM practices are closely related to policy, social and psychological factors, extension methods and training and knowledge. Government goodwill in terms of policy support for alternative pest management is crucial. Until clear policies are established, it will be impossible to promote the use of IPM. New technologies and practices encounter resistance from stakeholders, especially farmers and the implementation of IPM practices requires careful consideration of psychological and social barriers. Implementation of IPM also faces limitations in training and knowledge, which are mostly held by farmers and advisors. Challenges in IPM implementation influence extension organizations to increase their role in educating farmers on new practices. However, consulting organizations cannot work alone to address the challenges facing IPM and need the support of other stakeholders.

## Transfer of Knowledge and Innovations

Only effective transfer of knowledge and innovations can enable further successful development of Slovenian agriculture, forestry and food industry. These are skills such as: production and processing technology, services, knowledge in the field of environmental protection, all the way to knowledge in the field of entrepreneurship and the introduction of innovative non-agricultural activities on the farm. At the forefront of the transfer of knowledge and innovations is the user (for example, a farmer or forest owner), who must have the support of institutions (for example, public agricultural advisory services, faculties, etc.) that are able to answer his development questions.

Knowledge transfer and information activities take the form of support for vocational training and skills acquisition activities: support is intended for the implementation of courses, workshops, lectures, practical demonstrations or other knowledge transfer activities. Support for demonstration activities and information measures is support intended for practical training of persons active in the agricultural, forestry and food sectors, based on the demonstration of the use of mechanization, procedures, technologies, machines and practices.

## Knowledge Transfer and Information Activities

## Support for vocational training and skills acquisition activities

Support is intended for the implementation of courses, workshops, lectures, practical demonstrations or other knowledge transfer activities. It enables the acquisition of additional theoretical and practical knowledge for persons active in the agricultural, forestry and food sectors (e.g. farmers, organic farmers, forest owners). Attendance at trainings is free for participants. Courses, workshops, lectures, practical demonstrations or other similar knowledge transfer activities are carried out by persons who are suitably qualified for this. This measure is intended for training that is required upon entry or during the implementation of the obligations of the Agricultural-Environmental-Climate Payments (KOPOP), Ecological Farming (EK) and Animal Welfare (DŽ) measures. Support is also intended for training in many other areas that are important for the target groups, e.g. marketing, management, safe work in the forest, digital skills, processing... Training can include a theoretical and practical part. A special target group is young farmers.

## Support for demonstration activities and information measures

The support is intended for practical training for persons active in the agricultural, forestry and food sectors, based on the demonstration of the use of mechanization, procedures, technologies, machines and practices. It enables the acquisition of additional theoretical and practical knowledge for persons active in the agricultural, forestry and food sectors (e.g. farmers, organic farmers, forest owners). Attendance at trainings is free for participants. Demonstrations are carried out by persons qualified to carry out demonstration projects. The target group is people active in the agricultural, food and forestry sectors. This measure is aimed at practical training based on the demonstration of the use of machinery, procedures, technologies, machines and practices. The contents of these projects, with practical demonstrations, contribute to a higher level of knowledge, especially in the technological, economic and environmental fields.

# Advisory Services, Farm Management Assistance Services and Farm Replacement Services

## Support to help you use counseling services

The support is intended for the implementation of consultancy on agricultural holdings. The purpose of this support is to improve the specific knowledge and information of persons who wish to or have already joined the measures of KOPOP, EK and DŽ. Beneficiaries of this support are persons under public or private law who provide consultancy services to agricultural holdings and are suitably qualified for this. Counseling is free for the participant.

The measure "Support for assistance in the use of counseling services" is intended for the implementation of counseling for content that is a condition or requirement for the EC, KOPOP and DŽ measures. Within this framework, individual counseling is supported for: -creation of an animal welfare program, which is one of the conditions necessary for entry into the DŽ measure,

•creation of an activity program, which is one of the conditions necessary for entry into the KOPOP and EK measures,

•creation of an individual plan for the conversion of agricultural holdings from conventional to organic farming, which is mandatory for agricultural holdings that newly enter the EC measure,

•implementation of mandatory individual counseling for beneficiaries included in EC and KOPOP measures, at least once during the duration of the obligation.

## Cooperation

The goal of the "cooperation" measure is to speed up the transfer of knowledge and innovations from the research sphere to agricultural practice. The measure is implemented through:

•support for pilot projects and the development of new products, practices, processes and technologies,

•support for horizontal and vertical cooperation between participants in the supply chain for the establishment and development of short supply chains and local markets and for promotional activities at the local level related to the development of short supply chains and local markets,

•support for joint action to mitigate or adapt to climate change and for joint approaches to environmental projects and sustainable environmental practices,

•support for the diversification of agricultural activities into activities related to health care, social inclusion, community-supported agriculture and environmental and food education.

The measure supports various forms of cooperation, which will enable actors in rural areas to more easily overcome the economic, environmental and other limitations they face due to fragmentation and disconnection. The measure will be aimed in particular at promoting cooperation projects, which will aim to achieve higher productivity and, at the same time, greater sustainability in the field of agriculture. Within this framework, special emphasis will be placed on promoting technological development and reducing the negative impacts of agriculture on the environment, especially in the area of biodiversity and the quality of surface and underground water.

## Development of new products, practices, processes and technologies

The support is intended to accelerate the transfer of knowledge and innovations from the research sphere to agricultural practice through various forms of cooperation and integration. The aim of the support is to establish cooperation between various actors in the field of agriculture, food industry or forestry in the implementation of projects in the field of technological development and the introduction of innovations in agriculture, forestry or food industry, which will contribute to the achievement of the set goals of rural development.

Support is intended for:

•the development of new or improved products, practices, processes or technologies in the field of agriculture, food or forestry,

•transfer of knowledge into practice and

•dissemination of project results.

As part of this support, pilot projects and EIP projects will be supported, which will result in new achievements and solutions as well as innovative approaches in the field of technological development in agriculture, forestry or food. For the implementation of the pilot project, a partnership of at least 2 members must be established (agricultural holdings, consultants or researchers or an educational institution or a natural person registered in the register of private researchers), other agricultural holdings, legal entities, individual entrepreneurs can also join. or natural persons who are self-employed. For the implementation of the EIP project, a partnership of at least 3 members (agricultural holdings, consultants and researchers) must be established, other agricultural holdings, legal entities, individual entrepreneurs or natural persons who are self-employed can also join.

## Environment and climate change

The aim of this support is to establish cooperation between various actors in the field of agriculture, forestry, environmental protection, nature conservation or water protection in the implementation of projects in the field of environment and climate change, which will contribute to the achievement of rural development goals.

Support is intended for:

a) development and search for solutions, regarding:

•reducing the negative impacts of agriculture or forestry on the environment,

•implementation of joint approaches in the field of agriculture or forestry for the protection of biotic diversity,

•implementation of environmentally efficient agricultural production in water protection and other protected areas and

•reducing or mitigating or adapting to climate change in agriculture or forestry,

b) transfer of knowledge into practice and

c) dissemination of project results.

When implementing projects in the field of the environment and climate change, priority will be given to projects that will contribute to the achievement of environmental and nature conservation goals, in particular to training and improving the status of NATURA 2000 species and habitat types, as well as the care and effective management of natural values, as well as projects that will contribute to reducing the negative impacts of agriculture on surface and underground water quality.

For the implementation of the pilot project, a partnership of at least 2 members must be established (agricultural holdings, consultants or researchers or an educational institution or a natural person registered in the register of private researchers), other agricultural holdings, legal entities, individual entrepreneurs can also join. or natural persons who are self-employed.

For the implementation of the EIP project, a partnership of at least 3 members (agricultural holdings, consultants and researchers) must be established, other agricultural holdings, legal entities, individual entrepreneurs or natural persons who are self-employed can also join.

## Caring for the Environment and Adapting to Climate Change

The biggest challenge for farmers is how to maintain and increase their own productivity on their farm while taking care of the environment (water, soil, air, biodiversity) and successfully adapting to climate change (drought, floods, hail storms, frost, wind, ice).

Support for investments in agricultural holdings is intended, among other things, for investments in private irrigation systems intended for one user and the purchase of irrigation equipment (which can be intended for irrigation systems for one or more users), the purchase and installation of nets against hail, the purchase and installation greenhouses, investments in greater environmental efficiency and increasing resistance to and adaptation to climate change, further regulating permanent plantations from the point of view of introducing more marketable varieties and improving production technology, with the aim of agricultural holdings restoring their permanent plantations that were damaged in natural disasters or exceptional phenomena of the last few years (frost, drought, hail).

Support for investments in infrastructure related to the development, modernization or adaptation of agriculture and forestry is intended for the construction of irrigation systems and the technological modernization of irrigation systems intended for multiple users.

Support for investments for the prevention of wind erosion on agricultural land is intended for the establishment of wind defenses as a measure to prevent and adapt to climate change (reducing the consequences of wind erosion) and as a measure to strengthen biodiversity.

The measure "Agricultural-environmental-climate payments" is a KOPOP measure that encourages above-standard so-natural agricultural practices that are aimed at preserving biodiversity and the landscape, proper water management and soil management and mitigating and adapting agriculture to climate change.

The measure "Organic farming" supports the implementation of organic farming and the conversion to organic farming.

The measure "Payments to areas with natural or other special limitations" is allocated for the purpose of preserving and continuing agricultural activity in areas with natural or other special limitations (OMD), where the costs of farming and loss of income are higher compared to farming outside the OMD.

The sub-measure "Environment and climate change" pursues the goals of reducing the negative impacts of agriculture or forestry on the environment, implementing joint approaches in the field of agriculture or forestry for the protection of biodiversity, implementing environmentally efficient

agricultural production in water conservation and other protected areas, or reducing or mitigating or adapting to climate changes in agriculture or forestry.

## Adapting to Climate Change

Due to global warming, agriculture is facing increasingly frequent occurrences of extreme weather conditions such as hail storms, drought, heat stress and frost. All this is reflected in the quantity and quality of crops and the stability of production. One of the key successes in managing the consequences of climate change is adaptation. The purpose of adaptation is to reduce risks and damage to the environment and human health in a cost-effective manner.

Adaptation to climate change in plant production and livestock breeding is possible by implementing the following measures:

•correct choice of production technologies and varieties,

•appropriate selection of the sowing date, planting of less sensitive crops (e.g. part of the corn silage is replaced with fodder sorghum, planting of appropriate substrates for seedlings of perennial plants),

•modified cultivar,

•introduction of irrigation systems,

•diversification of production,

•proper fertilization.

At the Environmental Agency, we can also monitor the situation in agricultural production as a result of weather conditions. ARSO regularly publishes current data on changes in weather conditions in Slovenia and data on agrometeorological forecasts and prognostic notifications can also be accessed on the Agrometeorological Portal of Slovenia.

The public agricultural advisory service, which operates within the framework of the Chamber of Agriculture and Forestry of Slovenia, helps farmers with:

•preparation of technological instructions,

•advising on how to mitigate the effects of climate change and intense weather events,

•I am familiar with the expected climate changes as well as with the necessity of adapting to these changes and with the possibilities of mitigating the consequences,

•monitoring the condition of agricultural areas,

•preparation of the first rough assessment of the condition of agricultural crops in the field in the event of major adverse weather conditions and preparation of a report on their condition,

•informs the Ministry and the Administration for Protection and Rescue of the situation on the ground and treats the affected farms individually.

## Adaptation measures to climate change

Adaptation measures to climate change are encouraged and co-financed through the Rural Development Program or within other programs, projects or regular works and tasks carried out by public services in the field of agriculture. The most important measures for adapting agricultural production to climate change are:

•co-financing of insurance premiums,

•air defense against hail,

•implementation of measures regarding investments in irrigation and irrigation, investments in anti-flow networks and protected areas, agricultural-environmental-climatic measures such as crop rotation and conservation tillage, production and animal husbandry technologies and raising awareness, training and informing farmers.

## Mitigation of the Effects of Climate Change in Agriculture

Climate change is already happening, namely rising temperatures, changing precipitation patterns, melting glaciers and snow, rising sea levels and as a result there are more and more extreme weather events. Warming is most likely caused by the increased concentration of greenhouse gases in the atmosphere, which is the result of emissions due to human activities. If we want to mitigate climate change, we need to reduce or even prevent these emissions in the field of agriculture with quick and effective measures. Measures to reduce greenhouse gas emissions in agriculture directly contribute to better competitiveness of the industry.

Measures to reduce greenhouse gas emissions in agriculture

The most important measures for reducing greenhouse gas emissions are:

•agricultural environmental climate payments,

•organic farming,

•knowledge transfer,

•assistance in using counseling services,

•cooperation,

•introduction of husbandry methods that reduce greenhouse gas emissions,

•measures for more efficient nitrogen circulation in agriculture,

•operation of the public agricultural advisory service.

# PROMOTING ADVANCED IPM STRATEGIES

Implementing integrated pest, plant disease and weed management practices can be quite a challenge for farmers and consultants. Decision Support Systems (DSS) can assist in on-farm decision making (IPM). Decision support systems (DSS) are an important resource for the advancement of integrated plant protection. SPO helps growers and their advisors improve decisions based on information about potential crop risks. Most systems, especially tactical and operational systems, are intrinsically linked to crop monitoring, as observational data are usually required to run the model and the results often require more targeted monitoring to define the final result. Monitoring is already a key part of IPM, but it is time-consuming and can be expensive. SPO allows users to focus on monitoring crops or parts of crops that are most vulnerable and where effective protection would have an economic benefit. Such an SPO provides users with the confidence to know whether targeted crop monitoring is required and information on how to do so. This two-step decision-making process allows the use of all IPM techniques, whether preventive or curative. The development of advanced SPO for IPM usually takes the form of new pest-specific systems, so their use may be limited by region and/or access to resources (e.g. climate data). As part of the IPM Decisions project (H2020 No.817617), researchers are developing an online platform that enables wider access to current and future systems on a multinational scale. The "IPM Decisions" platform provides the grower with decision support in integrated pest management. It is a web-based framework that enables farmers, advisors and researchers to access a wide range of decision support systems and weather data from across Europe through a set of four dashboards. The platform makes it possible to evaluate the reliability and suitability of different decision support systems so that they can choose the ones that best suit their needs.

The aim of the "IPMworks-Wide IPM Farm Demo Network" project is to build a network of farmers across the EU to demonstrate and promote the adoption of IPM strategies through knowledge sharing and mutual learning. Currently, European agriculture is highly dependent on the use of plant protection products (FPS). In most European farms, the protection of crops against harmful organisms (insects, diseases, weeds and others) in order to avoid yield loss mainly (and sometimes exclusively) depends on the use of FFS. Such a high level of use of FFS has led to increased concern about their impact on the environment and human health. In addition, they can also cause long-term problems for farmers, as repeated use of FFS with the same mode of action often results in reduced efficacy due to the development of resistance. According to the European Green Deal, more precisely the farm-to-plate strategy, the EU plans to reduce the use of FFS by 50% by 2030. This is obviously a very ambitious goal that will be extremely difficult to achieve. At the same time and in accordance with the Directive 2009/128 / EC on the sustainable use of FFS (SUD), EU member states have formulated national action plans (NAP) aimed at reducing dependence on the use of FFS. In the coming years, therefore, reducing the use of FFS will be a major priority for agricultural policy across Europe and farmers will need to be at the forefront of this transformation. Farmers across Europe are already successfully trialing and implementing advanced IPM strategies with success, with less reliance on FFS. The challenge for European agriculture is to expand this group and promote more widespread adoption of advanced IPM strategies. The IPMWORKS project aims to achieve this goal by sharing "success stories", organizing peer-to-peer knowledge sharing activities, promoting farm demonstrations and training farmers and advisors on IPM. In the past, these activities have proven to be excellent tools for disseminating information.

IPMWORKS will coordinate existing networks that already exist in the field promoting advanced IPM strategies and also establish new farm hubs in regions or sectors where IPM pioneers are not yet involved in a relevant network. The project will involve farmers, advisors, policy makers, consumers and other key actors in Europe to demonstrate that IPM-based strategies adopted on real farms in different production systems reduce dependence on plant protection products and reduce exposure people. The project will demonstrate that IPM can maintain or improve economic profitability on a farm and reduce the environmental impacts of agriculture. The demonstration that "IPM works" will

take place both on the farm-with different production conditions, IPM options and communication tools-and at regional, national and EU level. IPMWORKS will work with farmers, consultants and other innovative actors and will focus on initiatives that will realize the European green offer and farming strategy.

## New Technologies and Digitization in Agriculture

The digitization system is being introduced gradually and in different areas. In recent years, modern information and communication technology (ICT), such as precision measuring equipment, sensors, probes, geo-positioning systems, drones, robotics, as well as Big Data (large databases), the Internet, has been increasingly used in the field of agriculture. things and artificial intelligence. "Smart agriculture" has great potential to achieve more productive and sustainable agricultural production, as it is based on a more accurate and efficient approach. The most important reason for introducing digitization is economic, but it is also introduced due to other needs. It can bring great benefits in relation to environmental issues, such as more efficient use of water, less use of fertilizers and pesticides, less fuel consumption, optimization of processing...

Agricultural holdings are provided with graphical data on agricultural plots and land use, which they can use to guide agricultural machinery based on the Global Positioning System GNSS, or to plan planting and crop rotation. Some farms also use aerial surveillance-analysis of satellite images or images obtained with smaller drones-to more quickly identify signs of plant diseases, nutrient deficiencies or lack of water in plants. Farms can also use accurate local weather data for irrigation purposes with the goal of reducing water consumption in agriculture and timely protection against pests and diseases. With timely action, they can reduce or even eliminate the consequences of drought. Effective digitization in agriculture requires basic digital records of the area, a well-developed network of agrometeorological stations, an efficient public plant health service that, with the help of various prognostic models and direct monitoring, predicts the development of diseases and pests and advises on the most suitable plant protection strategy. Remote sensing (satellite and aerial photography by drones) represents one of the central approaches for capturing data on crop status. The range of agricultural machinery that can record and/or use data for the implementation of precision agriculture (harvesters, mineral fertilizer spreaders, sprayers, seeders...) is gradually increasing and this enables a faster introduction of digitization in agriculture.

## Application of Remote Sensing in Plant Protection

Methods of controlling plant diseases and pests assume their uniform spatial distribution in the crop or in the plantation, but in practice they are most often distributed unevenly. Some pests and diseases first appear locally and only later spread over a larger part of the plantation or field. In practice, effective plant protection is connected with the most current and timely monitoring of visible signs of the appearance of diseases and pests, which requires regular inspection of plants. This monitoring or inspection is time-consuming and expensive and the effectiveness of suppression is related to the experience of the inspector and the timeliness of recognizing the first signs of the phenomenon. Remote sensing methods make it possible to detect the presence of diseases or pests on larger surfaces and in different stages of the phenomenon. In remote sensing, different sensors are used, which are mounted on different supports and allow time and spatial accuracy.

The most common groups of sensors are: RGB, hyperspectral, multispectral, thermal and fluorescence sensors. Although the detection of diseases and pests is possible with sensors of all five groups, the choice of sensor depends on the platform (greenhouse, drones, satellite...) and the desired accuracy. RGB sensors allow determining the presence of disease agents that cause changes in leaves, but their usefulness for determining infections before the development of visible symptoms is limited. The latter is made possible by multi and hyperspectral and thermal sensors. These four groups of sensors can also be used at greater distances (for example on an airplane), with natural lighting. Fluorescence

sensors enable accurate disease detection and are therefore suitable for use in limited areas, such as greenhouses and laboratories.




*Figure 1. Remote sensing sensors in agriculture*

## Remote Sensing Sensor Mounts Used in Agriculture

The most common carriers of remote sensing sensors used in agriculture are satellites, unmanned aerial vehicles ("drones"), aircraft, terrain, laboratories and greenhouses. Due to the heterogeneous spatial distribution of pests and diseases, remote sensing with optical sensors is the most suitable technology for providing information on foci and the extent of infections. Advanced data analysis methods are essential to effectively use remote sensing data to detect plant pests and diseases.




*Figure 2. Sensor carriers (platforms) of remote sensing in agriculture*

## Precision Agriculture and Digitization in Agriculture

For the best utilization of precision agriculture practices, we need suitable machinery and equipment, which is technically supported to enable us to carry it out. Smart machines (mineral fertilizer spreader, seeder, sprayer, grain combine, silo combine...) differ from classic machines by additional functionalities such as "Section Control", which automatically switches the "sections" on and off and thus prevents overlaps at the transitions in the fields and for side-by-side turns, it provides even crop spacing and consistent growing conditions, especially at the field edge and "Variable rate Control"

which allows us to fertilize and spray exactly where and exactly as needed. All machines need a connection to a computer that can control them, but they are usually connected via the ISOBUS controller, which is usually located on the tractor and the data needed to control the fertilizer and spray maps are imported to it. The machinery is controlled via the ISOBUS controller. For successful operation, we also need information about the exact location, which can be obtained from various location systems, one of the most well-known is the GPS system, with which we get an accuracy of 3 to 4 meters, which is enough to apply artificial fertilizers. Greater accuracy is required for spraying and sowing, which can be obtained through RTK and provides us with an accuracy of up to 1 cm. To determine how much of something to dose in a certain area, we first need data on the requirements and the condition of the field. The necessary data can be obtained with a drone or satellite, where with the help of multispectral sensors we can detect the condition of the plants and produce special vegetation indices, which show us the depressed and healthy conditions of the plot. Since we cannot determine the exact cause based on the image itself, it is necessary to go to the field and determine the causes and adjust further measures based on the findings.

Soil and environmental data and information can be accessed through a dedicated GIS web browser. The content of data and information changes dynamically. At this time, interpreted and upgraded public data of the Pedological Map of Slovenia 1:25,000, some pedological maps of a more precise scale, pedological profiles and some data from research projects on the subject of KIS soils are available. In addition, access to various information in raster format is enabled, which is important for guiding sustainable agricultural production, for protecting the environment and natural resources.

## Prediction of Crop Irrigation Using Remote Sensing

Proper growth and development of plants depends on an adequate amount of water. The low level of agricultural production is, among other things, a consequence of the low productivity of water use. When we decide to irrigate, it is important not to irrigate too much or too little and that the irrigation is carried out in the correct period of time.

The consequences of unprofessional irrigation have a negative impact on:

•the health status of plants, which increases the extent of plant diseases and requires greater consumption of plant protection funds,

•amount of crop,

•the quality and durability of the crop,

•the market value of the crop and thus the competitiveness of production,

•reduced uptake of nutrients into the plant and increased possibility of leaching nutrients from the root zone,

•the effectiveness and degradation of plant protection agents and increases the chances of their being washed out of the soil,

•the efficiency of water use and the economic and environmental sustainability of agricultural production, as it causes excessive consumption of water for irrigation.

## Remote Sensing of Pests

In recent years, the approach of so-called "remote detection of harmful organisms"-electronic traps- has also started to be used in the field of monitoring harmful organisms. With the help of Trapview electronic traps, it is possible to remotely monitor the appearance of pests from the Lepidoptera order, of course those for which there is a pheromone. The device consists of a solar panel, an outer casing and an interior containing electronics for image capture and data transmission and a sticky panel with a pheromone added by the user himself. The device transmits data (an image of a sticky board with

catches) via the GPRS protocol to the manufacturer's server, which enables the user to view the catches via a web or mobile application. The introduction of these new technologies in the prognostic service enables the rationalization of procedures, since the current use of pheromone lures requires field visual inspections and thus material costs increase. The device is equipped with a high-resolution video camera, the data is transmitted via the mobile network, so it is possible to monitor catches in the application on a mobile phone or computer. Images of captured butterflies can be monitored via the Trapview application, which also allows the user to view recent and historical images throughout the season.



*Figure 3. Trapview electronic trap for monitoring of corn borer*

# REDUCING THE USE OF PESTICIDES IN AGRICULTURAL PRODUCTION

The reduction in the use of phytopharmaceuticals in Slovenia is based on compliance with the requirements of the Act on Phytopharmaceuticals (ZFfS-1-Official Gazette of the RS, No. 83/12 and 35/23), Regulations on training on plant protection products (Official Gazette of the RS, No. 85/13), Rulebook on conditions for trade in plant protection products and on management and transmission of data on trade in plant protection products (Official Gazette of the Republic of Slovenia, no. 107/13 and 30/18), Rulebook on requirements regarding the correct operation of devices for applying plant protection products and on the conditions and method of carrying out their inspections (Official Gazette of the Republic of Slovenia, No. 36/19), the Rules on the Correct Use of Phytopharmaceuticals (Official Gazette of the Republic of Slovenia, Nos. 71/14, 28/18, 56/22 and 155/22), the Rules on integrated protection of plants against harmful organisms (Official Gazette of the Republic of Slovenia, No. 43/14), Order prohibiting the circulation and use of certain phytopharmaceuticals on the territory of the Republic of Slovenia (Official Gazette of the Republic of Slovenia, No. 31/11 and 83/12-ZFfS-1), Regulations (EC) no. 1107/2009 of the European Parliament and of the Council of 21 October 2009 on placing plant protection products on the market and repealing Council Directives 79/117/EEC and 91/414/EEC (2009/1107), Directive 2009/128/EC of the European Parliament and of the Council of 21 October 2009 on establishing a framework for Community measures to achieve the sustainable use of pesticides (Text applies to the EEA) Text applies to the EEA. (2009/128) and Commission Directive (EU) 2019/782 of 15 May 2019 amending Directive 2009/128/EC of the European Parliament and of the Council regarding the establishment of harmonized risk indicators (Text applies to the EEA) (2019/782).

Regarding the reduction of the use of plant protection product (PPP), various non-chemical methods of plant protection are primarily used for the direct control of harmful organisms in integrated plant protection, which limit the populations of harmful organisms below the harmfulness threshold and have priority over chemical suppression (use of PPP). These methods are also referred to as low-risk plant protection methods and include physical, biotechnical and biotic measures. Non-chemical plant protection methods also include the use of "low-risk PPP" based on microorganisms, plant extracts and pheromones, other low-risk substances and the use of basic substances.

Reducing the use of PPP on agricultural and non-agricultural areas is possible by using non-chemical methods of protection (mechanical control of harmful organisms, use of basic substances, biotic protection of plants...). In order to avoid as much as possible a greater risk to human health, the use of PPP is restricted or completely prohibited on non-agricultural areas and public areas where the safe use of PPP cannot be ensured, or where harmful organisms can be controlled by alternative methods. At the same time, it is also necessary to consider the possible exposure of people in public areas who could be exposed to risk when using PPP. On non-agricultural areas, such as roadsides, railways, non-chemical methods are used (e.g. weed control using steam...). In terms of reducing the use of PPP, the use of PPP on sports fields is limited to spot use and only if the use of PPP is necessary. This ensures the lowest possible exposure of people staying on the playgrounds after using PPP.

## Reduction of PPP Use Using Non-Chemical Plant Protection Methods

### Physical measures

Physical measures are measures that prevent or limit the access of harmful organisms to cultivated plants and measures for catching or destruction (suppression) of harmful organisms. These measures can be used to reduce the use of PPP whenever possible. Physical measures include:

•cleaning of seeds and other planting material (removal of impurities-weed seeds, removal of infected plants from seed crops or other sources of planting material-in nurseries, mother plantations),

•heat treatment of planting material (immersion of seeds or other planting material (grafts, cuttings...) in a water bath for a certain time at a certain temperature-method of destroying pathogenic bacteria, phytoplasmas or viruses in planting material, exposure of seeds to low temperatures...),

•soil disinfection with the help of water vapor (in horticulture, especially when growing in protected areas),

•cutting out infected plant parts (apple powdery mildew, apple cancer or pear blight...),

•soil cultivation (reduction of the population of harmful insects in the soil - weevils, corn borer..., plowing can influence the emergence and growth of weeds - especially perennial ones),

•various pest control measures (manual removal of pests, washing with water or air stream, use of ash, diatomaceous earth...),

•the use of colored sticky boards, light baits and food baits for catching harmful types of insects (light baits, sticky boards of different colors and food baits are mainly intended to monitor the appearance of pests, but to a lesser extent they also reduce their abundance),

•use of various traps (for catching rodents...) and sound repellents (for birds or rodents),

•preventing pests from accessing plants with obstacles (overlays, insect nets-insect nets, bird nets, high barriers at the edges of fields against insect attacks, fences and electric herders against wild animals),

•mechanical weed control (mechanical or manual weeding, harrowing or brushing, mowing, mulching...) and

•weed control with steam, hot foam, burning with flame (roads, railways...)

## Biotechnical measures

Biotechnical pest control measures are procedures that utilize some of the natural reactions of pests to certain chemical stimuli and include the use of attractants (e.g. pheromones), deterrents and food baits.

Pheromones are substances secreted by insects in small quantities and intended for mutual communication between individuals of the same species. In plant protection, pheromones are mainly used to monitor the populations of certain economic pests in plantations or crops (to monitor various types of beetles-apples, peach, etc.), moths, owls and other pests. With pheromone baits, we determine the presence and abundance of pests in time and space.

Some pest control methods have also been developed based on pheromones, one of which is the method of confusion or confusion. Sex pheromones are used to distract males from finding females to mate with and therefore females lay unfertilized eggs. The bewilderment method is used to control apple and peach curlers. The method is more effective if the pest population is not too large, if the plantation is isolated and if it is in a larger complex.

Pheromones are also used in so-called "mass hunting". Pheromones are used to attract insects to be caught in or on traps. Traps with pheromones must be in the plantation or distributed evenly and in sufficient numbers to the production facility, so that a sufficiently large number of insects can be trapped in them and thus their population and, consequently, the damage they cause can be reduced.

## Biotic measures

Biotic protection is a method of protection where one organism is used to reduce the population density of another organism. The goal of biotic protection is for other organisms to interact with pests or pathogens by destroying them or hindering their development. Plant pathogenic fungi also have their opponents (antagonists, pathogens), which either parasitize them or hinder their growth by

emitting substances (antibiotics) that harm them, so there is a constant competition between organisms for space and food.

Organisms that, with their way of life, benefit the grower in the control of harmful organisms are called beneficial organisms = natural enemies. In biotic protection, knowledge about the relationships between species is used and with selected beneficial organisms, the populations of harmful organisms are reduced and they are kept below the threshold of economic damage. Beneficial organisms are insects, mites, entomopathogenic nematodes, fungi, bacteria, viruses. They can be used to control insects, mites, fungi, bacteria and even some weeds.

In biotic plant protection, living beneficial organisms are used to control harmful organisms. Depending on the mode of action on harmful organisms, beneficial organisms are classified into four groups:

**1) Predators:** They are insects, mites... that feed on plant pests and destroy them. In order to successfully maintain a population of predators, there must be enough pests in the appropriate development stage and established environmental conditions that enable the development of predators. The most successful native beneficial predators among insects and arachnids are ladybugs, ladybugs, thrips, predatory rodents, predatory bedbugs and predatory mites. Predators regulate the abundance of plant pests outdoors and in sheltered areas.

**2) Parasitoids:** Are insects that are more host specialized than predators. They lay one or more eggs in the host (egg, larva, beetle or adult pest). The hatched larvae of the parasitoid feed on the host's tissue and its appearance changes but does not die immediately. An adult parasitoid emerges from the pest. An example of a parasitoid that is often used in protected areas is the greenhouse leafhopper (Encarsia formosa).

**3) Pathogens:** Are fungi, bacteria or viruses that infect their hosts, insects and other animal organisms. They penetrate inside them, causing them to weaken and possibly even die. The principle of action is parasitism. In insect pathology, they are also called entomopathogenic organisms.

**4) Antagonists:** Affect the survival or pathogenicity of harmful organisms, but do not use them as a food source. They inhibit the growth and reproduction of harmful organisms by competing with them for food and space (competition) or by disturbing them with substances they secrete (antibiosis).

The approaches in biotic protection are as follows:

•**Protective biotic protection:** It is based on measures with which we protect indigenous beneficial organisms and provide them with favorable conditions for settlement and reproduction,

•**Classical biotic protection:** It is a method of biotic protection, when we look for a non-native beneficial organism (most often in the area of origin of the pest) and introduce it to an area where a non-native pest has spread unplanned, which therefore has no effective natural enemies and

•**Mass propagation and targeted release of beneficial organisms:** The release of beneficial organisms to the place where the pest population needs to be reduced can be either by flood or by seasonal inoculation. Seasonal inoculative introduction of a beneficial species means the introduction of a laboratory or otherwise propagated indigenous or non-native beneficial species into the open air or into a protected area. Such an organism is introduced once or several times during the growing season, with the aim of automatic further reproduction.

Biotic protection has many advantages over chemical protection, because with biotic protection there are no residues of PPP in crops and biotic preparations do not have a grace period, they also do not damage plants, generally do not affect the phenomenon of resistance of harmful organisms, do not pollute the environment and are not dangerous to the people who use them.

The success of biotic protection depends to a large extent on the knowledge of the user, as a good knowledge of harmful organisms and the changes they cause on plants, as well as the thresholds of harmfulness, is necessary. Users must therefore be well trained to monitor the occurrence of harmful

and beneficial species of organisms. One of the negative features of biotic protection is that it works slowly. Users must also know the developmental cycle and threshold of usefulness of beneficial organisms. It is also very important to know how we transport and store preparations with beneficial organisms, when we introduce them depending on the size of the pest population, what the conditions are at the place of introduction (temperature, lighting, humidity) and what PPP was used before introduction.

When using beneficial organisms, PPP cannot be used simultaneously, because they are only some PPP compatible with beneficial organisms. Using the wrong insecticide will harm or kill beneficial organisms.

More detailed procedures for the introduction, cultivation and use of beneficial organisms, i.e. insects, mites and entomopathogenic nematodes are regulated in Slovenia by the Rulebook on biotic protection of plants (Ur. l. RS, no. 45/06), the introduction and use of microorganisms (fungi, bacteria and viruses) is governed by the Act on Phytopharmaceuticals.

In biotic protection, an essential limitation is that we may only use beneficial organisms that have been proven to be unable to cause harm in the environment by affecting non-target organisms. Types of beneficial organisms can be native or non-native, a native organism (autochthonous) has always been present in an ecosystem and therefore we do not expect negative impacts when using such an organism. A non-native organism (allochthonous, exotic) is an organism that is not present on the territory or was not present until it was inhabited by humans. Part of the mentioned rulebook are the lists of native and non-native beneficial organisms, the introduction and use of which are permitted in the territory of Slovenia. Only organisms listed on these lists may advise, recommend and advertise.

## Reducing the Use of PPP Using "PPP Based on Microorganisms, Plant Extracts, Pheromones, Other Low-Risk Substances and Basic Substances"

Under the term PPP we understand all substances that are intended for the protection of plants or plant products for protection against harmful organisms. In integrated plant protection, in order to reduce the use of chemical substances, PPP are preferentially used, which are less dangerous and less burdensome for human health, animals and the environment. This also includes the use of PPP made on the basis of microorganisms, plant extracts, pheromones and low-risk substances. The same legislative regulations apply to the registration and use of these preparations in Slovenia as for chemical PPP. The current list of registered PPPs based on microorganisms, plant extracts, pheromones and low-risk substances is available at the web address: http://spletni2.furs.gov.si/PPP/REGSR/PPPsezn.asp?L=1&S=4&top=1

## Pest Control with Entomopathogenic Microorganisms

Pest control with entomopathogenic microorganisms is a measure when entomopathogenic fungi, entomopathogenic bacteria or viruses are used to control harmful insect species and the control is based on insect pathology, then we are also talking about microbiotic protection. Fungi, bacteria or viruses must be ready for use, so that they can be stored and applied, while maintaining a high level of vitality in order to be effectively activated after application. Entomopathogenic fungi infect insects in various developmental stages (adult insects, larvae, beetles). Among the entomopathogenic fungi, fungi from the genera Beauveria and Metarhizium have shown the greatest utility in pest control, although many others are being used and tested. Among entomopathogenic bacteria, Bacillus thuringiensis (B.t.) has been widely used for pest control for decades. These bacteria form proteins in the form of crystals, which are converted into toxins in the digestive tract of insects and cause the death of the insect. Entomopathogenic viruses primarily infect insect larvae when they are ingested. Viruses with a narrow range of hosts are particularly suitable for biotic protection. In organic and

integrated apple production, the use of a preparation based on the *Cydia pomonella* granulosa virus to control the apple borer has already become established in Slovenia.

## Protection Against Diseases Based on Fungi and Bacteria

In the protection against diseases based on fungi and bacteria, organisms are used, such as fungi and bacteria that parasitize fungi or hinder their reproduction and development. In addition to parasitism, competition and antibiosis, some beneficial microorganisms also act to increase plant resistance to disease or promote plant growth, which makes it easier to withstand damage caused by harmful organisms. Similar to how we use a protective approach in biotic protection against pests, we can also use microorganisms that are already present in the growing area, or increase their abundance and diversity, in the control of pathogenic fungi or bacteria for plants. By adding organic matter (green manure, organic fertilizers, composted bark and other composts), loosening the soil and ensuring adequate humidity, we encourage the reproduction of saprophytic fungi and bacteria. When using microbiotic preparations to control plant diseases, the warnings regarding mixing with other fungicides must be followed in order not to destroy the active microorganism. The preparations are effective in a limited temperature range, with some of them it is also necessary to pre-prepare the spray slurry to accelerate the germination of spores of the beneficial fungus. There are no withdrawal periods for microbiotic preparations, or they are very short.

## Use of PPP Based on Plant Extracts, Pheromones and Low Risk Substances

Plant extracts consist of one or more substances found in a plant and obtained from plants or their parts by a process of pressing, grinding, crushing, distillation, extraction, fermentation or other process. Protecting plants from pests involves the use of various substances that are produced in the metabolic processes of plants and that play an important role in protecting the plant from harmful organisms. Among the more well-known and useful substances of plant origin in the world are preparations containing the active substance pyrethrin, which is a natural insecticide obtained in the form of powder or oil of the flea beetle Chrysanthemum cinerariifolium or Chrysanthemum coccineum. Among the more commercially available preparations with insecticidal activity, we also find an extract obtained from the Neem tree (*Azadirachta indica*)-neem oil. This contains a number of secondary metabolites, including salanin, which acts as a deterrent and deters insects from feeding and azadirachtin, which inhibits growth in insects and causes disturbances in reproduction and metamorphosis. In addition to its insecticidal effect, neem oil also has a nematocidal, bactericidal and fungicidal effect.

The PPP group includes all substances, with the exception of nutrients that affect the life processes and growth of plants (plant growth regulators, substances to promote resistance in plants) and substances that are used in the procedures of biotechnical methods of control of SO (pheromones, deterrents or repellents). Some of the listed substances are defined as low-risk substances based on special criteria. Information on low-risk substances is available in the European PPP database: https://ec.europa.eu/food/plant/pesticides/eu-pesticides-database/active-substances/?event=search.as.

## Use of Basic Substances

Basic substances that can be used for plant protection are those substances that are not problematic, do not cause hormonal imbalances and do not have neurotoxic or immunotoxic effects. They are approved for other purposes and are not normally used for plant protection and are not placed on the market as plant protection products-PPP, but are nevertheless useful for plant protection, either directly in preparations consisting of basic substances. Substances that meet the criteria for food can

be considered basic substances. The use of basic substances in the European Union (EU) is approved by the European Commission.

The list of permitted active substances that are approved as basic substances for plant protection can be found on the MKGP-UVHVVR website: https://www.gov.si/teme/osnovne-snovi-za-varstvo-rastlin/. Next to Slovenian names in the first column, Latin or English names are listed in the second column. Some of these substances can also be used by the user in organic production, which is indicated in the third column

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4. Regulations on integrated protection of plants against harmful organisms: http://www.pisrs.si/Pis.web/pregledPredpisa?id=PRAV11530.
5. Rules on the correct use of phytopharmaceuticals: http://www.pisrs.si/Pis.web/pregledPredpisa?id=PRAV11541.
6. Rulebook on the conditions for trade in plant protection products and on the management and transmission of data on the sale of plant protection products: http://www.pisrs.si/Pis.web/pregledPredpisa?id=PRAV11540.
7. Regulations on training on plant protection products: http://www.pisrs.si/Pis.web/pregledPredpisa?id=PRAV11537.

# DECREASING NEGATIVE IMPACTS ON THE ENVIRONMENT AND PEOPLE

## What Are Plant Protection Products

Plant protection products (PPP) are preparations used in agriculture to protect plants and crops from pathogens, weeds and pests. Before placing them on the market, it is necessary to evaluate their active ingredients, which contain substances that may have dangerous properties and to determine their acceptable use in order to ensure the protection of people and the environment. The process of evaluating active substances and preparations is called registration. We try to reduce the risk to human health and the environment as much as possible by controlling the traffic and use of plant protection products. In Slovenia, as well as other EU members, we mainly support other methods of plant protection before the use of plant protection products, even though we are aware that plant protection products are still important for today's agricultural production (1).

## Use of Plant Protection Products

The way plant protection products are used plays an important role in preventing potential negative impacts of PPP on the environment and human health. PPP must be used in a manner that does not contaminate groundwater and surface water and to prevent reliance of PPP on adjacent surfaces. This should also be done when preparing the spray slurry, removing the remains of the spray and packaging. During use, personal protective equipment is mandatory to protect the user's health (1).

## The Effect of The Use of Plant Protection Products on People

PPP can enter the body in different ways, such as by inhaling aerosols, dust and vapors containing pesticides, by oral exposure through consumption of food/water and by direct contact skin exposure. PPP are released into the soil and groundwater, which can end up in drinking water and pesticide sprays can drift and pollute the air. The effects of plant protection products on human health depend on the toxicity of the chemical and the length and extent of exposure. Farm workers and their families are most exposed in direct contact with PPP. Every person contains PPP in their fat cells. In humans, children are the most vulnerable group because they are still developing and their immune system is not yet as developed or weaker than that of an adult. In any case, with improper handling of PPP, these can bioaccumulate in the body (2).

PPP can be divided according to their dangerous properties for human health in case of acute exposure into:

•harmful to health-such PPP cause damage to various organs (liver, kidneys, ...) and organ systems (nerves, bones, ...). Damage mainly occurs after ingestion; skin contact or inhalation,

•irritant-this type of PPP cause suffocation due to irritation of the respiratory tract (lungs, trachea, nose), can cause coughing, watery eyes, irritation of the skin and mucous membranes, which can manifest as inflammation of the skin and mucous membranes.

•Caustic-this type of PPP causes ulcers and burns of the skin and mucous membranes (3).

## Reducing The Impact of PPP On Human Health

In order to reduce the negative impact of PPP on human health, it is necessary to follow the basic rules of safe use of PPP. The fact is that PPP are not dangerous when used correctly and thus reduce the negative impact on human health as well as on the environment. At the same time, the following steps must be taken into account:

•Before purchasing PPP, we always first check the stocks and at the same time remove all those PPP that have expired. We take such resources to the nearest hazardous waste collection center,

•PPP are always stored in appropriate rooms, which must be locked,

•We always buy registered PPP. When transporting, we ensure that PPP are transported separately from animals, food, agricultural products and feed and we ensure the safe transport of PPP to the place of use,

•Before use, carefully read the instructions for use,

•During the preparation and dosing of PPP, we always wear personal protective equipment, which we also use during spraying and later when cleaning devices for applying PPP. Always wash the gloves after use (4).




*Figures 1. Personal protection equipment*



*Figures 2. Personal protection equipment*




*Figures 3 in 4. An example of correct and incorrect storage of waste packaging of plant protection products*

•We use modern and technically impeccable spraying devices, which prevent point pollution and drifting of the spraying slurry (4).

•After use, empty PPP are properly stored until they are sent to the collection point (4).

## Impact of the Use of PPP on The Environment and Biodiversity

In the long term, the well-being of agricultural economies mainly depends on the ecosystem services of living organisms, water, air, soil quality and other natural resources. Good management must therefore include the protection of the environment if we want to ensure the preservation of all these resources, which are important for all living beings. PPP are indispensable in food production nowadays, but their improper use can have a very heavy impact on the environment. In addition to the positive effects of PPP against harmful organisms, their use can have many environmental impacts: they can contribute to the pollution of water sources, air and soil and due to their toxicity to non-target organisms, they affect important functions of ecosystems, such as natural pest control or pollination. It is important to be aware of the main causes that can lead to negative impacts on the environment. These causes are: improper disposal of waste PPP and packaging, inappropriate application of spray slurry, spreading of spray slurry outside the treatment area and spills [3].

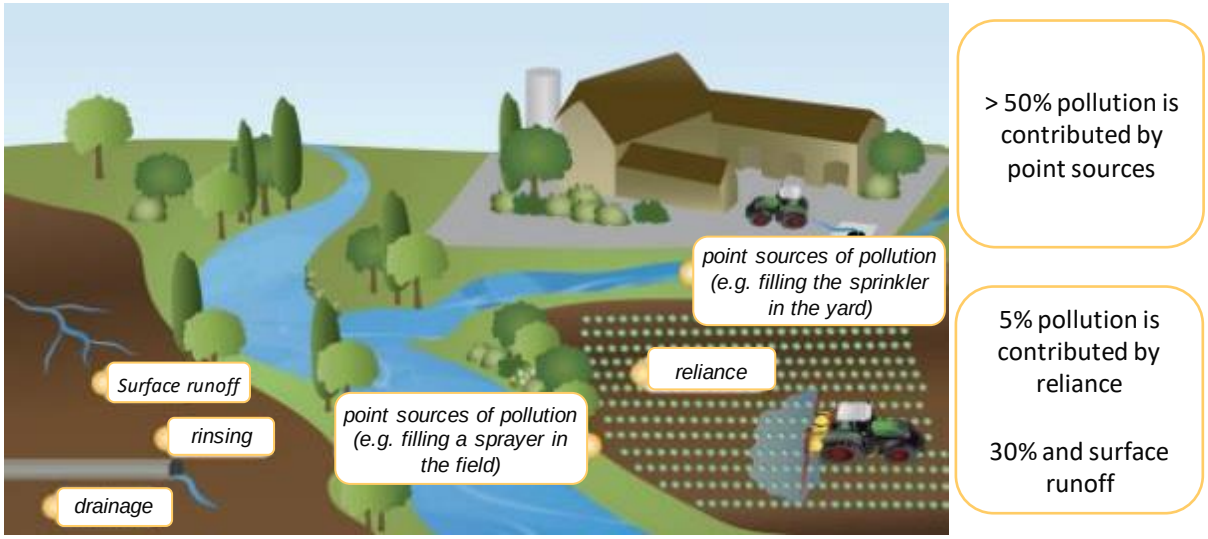



*Figure 5. Point and non-point sources of pollution (Source: Basic principles of good agricultural practice Plant protection and use of PPP)*

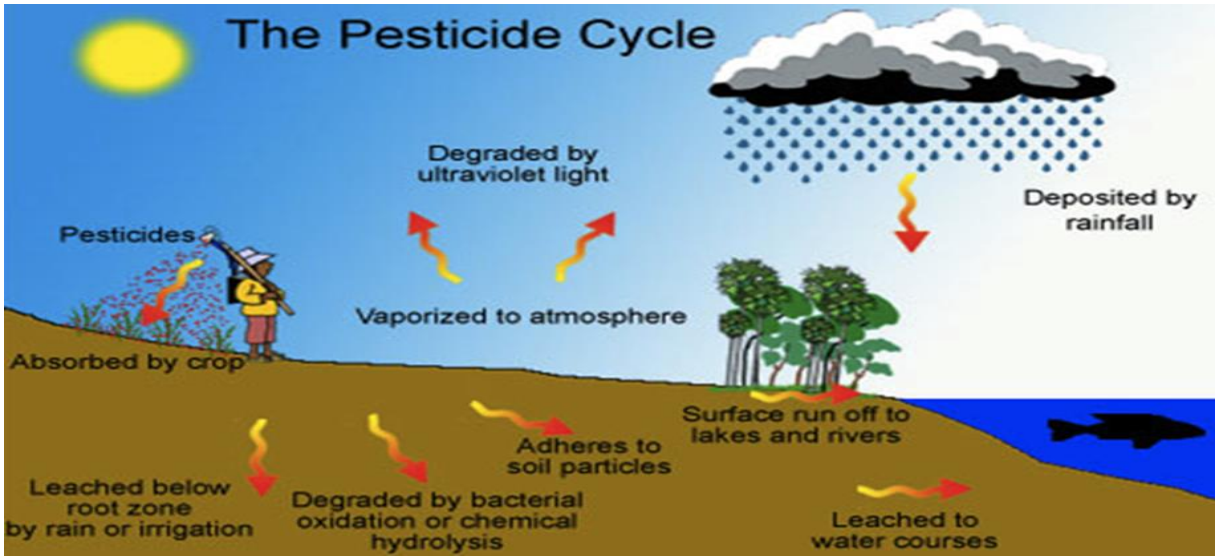



*Figure 6. Circulation of PPP in nature and their impact on people and the environment*

## Reducing the Impact of PPP on the Environment and Biodiversity

In order to reduce the negative impact of PPP on the environment and biodiversity, it is necessary to take measures into account: it is necessary to prevent reliance on neighboring agricultural and non-agricultural areas, on nearby water sources by properly planning the correct application of PPP, by using appropriate spraying machinery and by following the instructions for correct use of PPP.

Insofar as the application of PPP is carried out over-relying only on these, the amount of PPP that must be applied to the target organisms is reduced. As a result, the spraying efficiency is reduced.

It is also recommended to establish so-called green belts in the vicinity of agricultural areas, which are overgrown with dense plant cover, which helps us to reduce the reliance of PPP on e.g. nearby water sources, to neighboring agricultural areas and help prevent surface erosion of spray slurry.

Prescribed measures and more detailed methods of correct use of PPP to reduce risks to the environment due to their use must be defined in the national legislation of each country [3].

## Measures to Reduce Risk When Using PPP Products

When implementing measures to reduce risks in the use of PPP, it is necessary to adopt certain general measures that must be taken into account, regardless of whether a risk assessment for PPP has also been made regarding safe use and application. [3]

These measures are as follows:

•When using PPP, care must be taken to never spray over bodies of water (ditches, wells, melioration channels, drainage ditches, etc.).

•It is necessary to establish an untreated safety belt on agricultural land, for the protection of aquatic organisms. For example, in Slovenia, safety zones are at least 5 meters from 2$^{nd}$ order waters and 15 meters from 1$^{st}$ order waters (rivers, lakes, seas).

•The selection, application and use of PPP must be adjusted according to the hydrological and climatic conditions of the area and soil properties.

•There is a greater possibility of surface runoff and erosion on non-vegetated terrains, which can be prevented by establishing green belts, by plowing in layers or across the slope of the inclined terrain, by using minimal cultivation techniques, by mulching during the vegetation period, by covering the soil, by ensuring an adequate supply of organic matter.

•The use of PPP is not permitted on flooded and frozen soil.

•When implementing irrigation, it is necessary to plan irrigation very carefully and appropriately, taking into account the condition of the soil, the physical and chemical properties of the soil and weather factors.

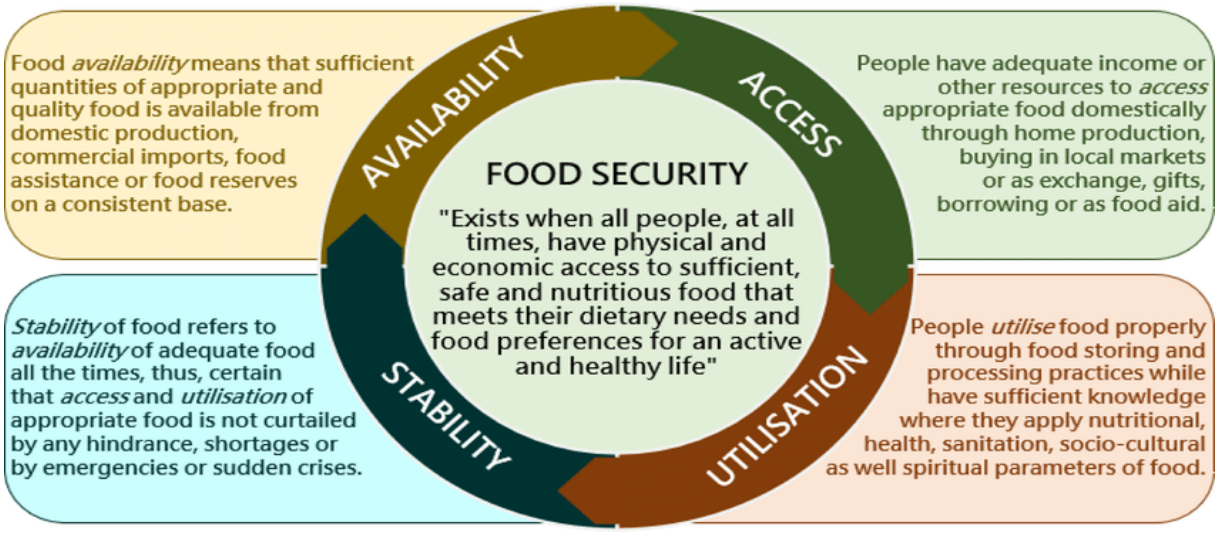
•Soil irrigation after PPP application increases leaching and surface runoff similar to rainfall [3].

It is very important that when using PPP we take into account all the measures we have listed and at the same time it is important that each user of these resources keeps accurate records of the use of PPP.

# INCREASE LOCAL AGRICULTURAL PRODUCTION AND FOOD SELF-SUFFICIENCY

## Introduction

Food security, as defined by the United Nations' Committee on World Food Security, means that all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their food preferences and dietary needs for an active and healthy life [1].



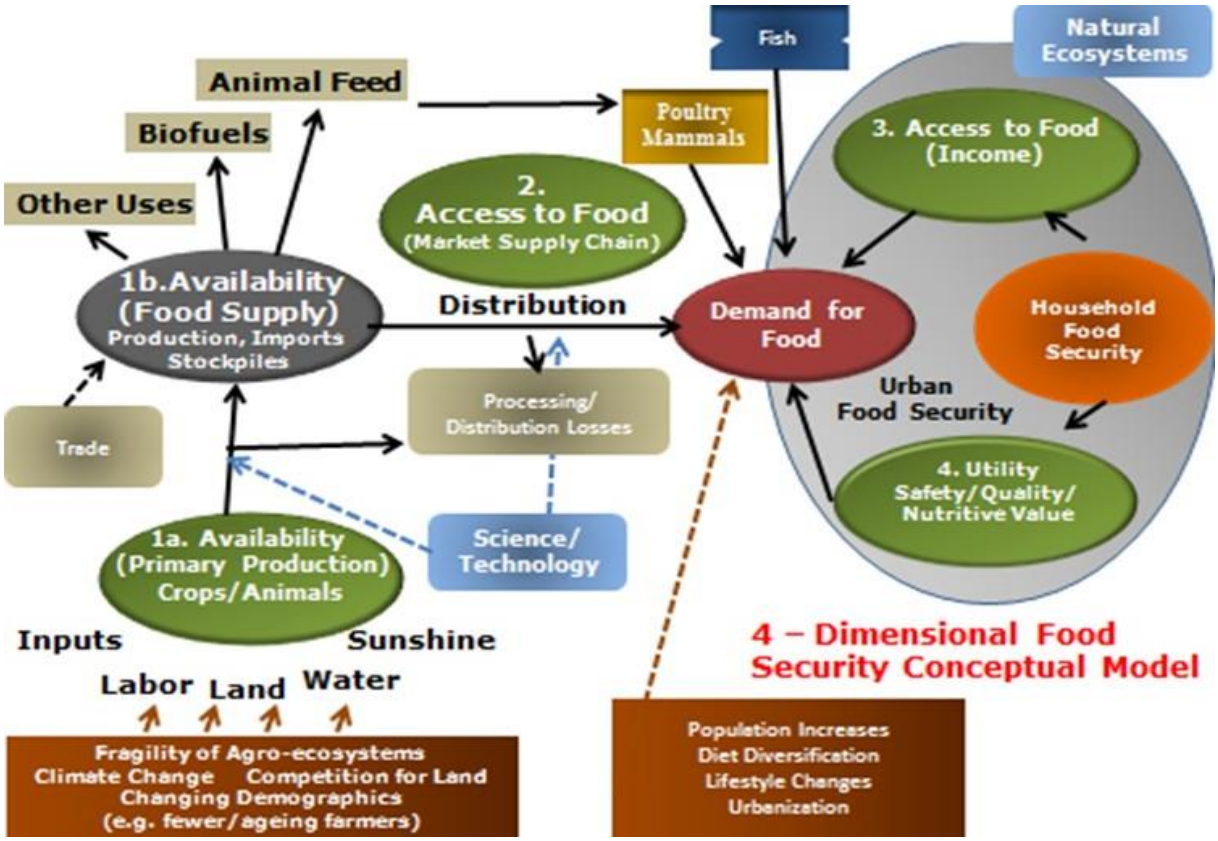

*Picture 1. Four dimension of food security (https://www.researchgate.net/figure/Four-dimensions-of-food-security-As-per-its-definition-food-security-has-four fig1 355187464)*

## Food Self Sufficiency

Food Self-Sufficiency (FSS) and price volatility have become a high priority political agenda for governments [2] Increasing crop diversity is an agroecological approach to improve FSS, so small producers can maintain the stability of their food systems, reducing the risks of stress, pest outbreaks or droughts [3]. A region can increase the stability of its food system by building its own FSS [5]. Food production is a starting point in the analysis of sovereignty and food security. Revenue generation through efficient field production provides a real productivity base [4]. The traditional agricultural production of production systems determines access to food and obtaining complementary income through the sale of products and by-products, this being considered as the result of the integration of life strategies [5].

## Challenges in Food Production While Ensuring Food Safety with Reduced Use of Phytopharmaceuticals

"It is expected that the world's population will be increased to one third, The FAO estimates that, if current income and consumption growth trends continue unabated, agricultural production will have to grow by 60 per cent to satisfy the expected increased demands for food and feed. A 60% increase in global food demand will occur by 2050 against 2006 levels due to population increases and changes to food patterns, while climate change will continually impact global food systems" [6]. "The number of people affected by hunger globally has been on the rise since 2014 despite food production doubling over the last 3 decades. Over the course of 2019 "two billion people, or 25.9% of the global population, experienced hunger or did not have regular access to nutritious and sufficient food" [7].




*Picture 2. 4-dimensional Food Security Conceptual Model [(https://www.researchgate.net/figure/The-Four-Dimensions-of-Food-Security fig1 283048378)]*

The fundamental task of agriculture is to provide adequate amounts of unblemished food, or to improve self-sufficiency with agricultural products, which is forced by climate change with increasingly frequent natural disasters, which make food production increasingly unpredictable and numerous crisis events related to the global economy. Ensuring sufficient quantities of safe food while taking into account the principle of sustainability, preservation of the natural environment, space and biodiversity is not an easy task, as agricultural production is constantly threatened by numerous plant diseases, pests and plant invasive species, which reduce the quality and quantity of crops and directly affect the quality of food and the economy of the production of agricultural plants. In order to achieve the set goal, it is also necessary to focus on caring for the environment and reducing the risks and impacts of the use of phytopharmaceuticals (PPP), which are an important element of plant health protection, on human health and the environment [8].

Controlling pests that damage crops and plants is necessary both to safeguard food security and to ensure viable income to farmers for their production. This needs to be done while minimizing the risks to people and the environment. Such an approach, using natural methods whenever possible and chemical pesticides as last resort, is called 'integrated pest management' (IPM). Today, the European Commission published a database presenting an overview of the IPM methods currently available, accompanied by a study assessing their effectiveness and prospects for their further uptake.

The database includes about 1300 examples of practices, techniques and technologies across eight IPM principles established at EU and international level, such as the use of crop rotation and balanced fertilization, monitoring of harmful organisms, targeted and reduced application and, more importantly, the preference for non-chemical pest control methods. The database also includes 273 "crop-specific guidelines" developed by Member States' national authorities and public bodies to implement the IPM requirements under the Sustainable Use of pesticides Directive (SUD). This overview of practices, established following two years of work, shows that there is a great variety in the uptake and implementation options for IPM across EU countries. All examples are presented in

national languages with a brief introduction in English. This toolbox is intended to inspire national authorities, farm advisors etc. to develop and implement IPM approaches after adapting them to local/regional farm and agroclimatic conditions. The database, hosted in the JRC's Data-Modelling platform of resource economics (DATAm), will be updated with additional examples on a regular basis. [9].

## General Overview of IPM Strategy

A cornerstone of the Directive is the promotion of IPM, for which general principles are laid down in Annex III to the Directive. Along with the promotion of organic farming, IPM is one of the tools for low-pesticide-input pest management and IPM must be implemented by all professional users.

•IPM involves an integrated approach to the prevention and/or suppression of organisms harmful to plants through the use of all available information, tools and methods.

•IPM aims to keep the use of pesticides and other forms of intervention only to levels that are economically and ecologically justified and which reduce or minimize risk to human health and the environment.

•Sustainable biological, physical and other non-chemical methods must be preferred to chemical methods if they provide satisfactory pest control.

## Definition of IPM

Integrated pest management means careful consideration of all available plant protection methods and subsequent integration of appropriate measures that discourage the development of populations of harmful organisms and keep the use of plant protection products and other forms of intervention to levels that are economically and ecologically justified and reduce or minimize risks to human health and the environment. 'Integrated pest management' emphasizes the growth of a healthy crop with the least possible disruption to agroecosystems and encourages natural pest control mechanisms.

## Principles of Pest Control

1. The prevention and/or suppression of harmful organisms should be achieved or supported among other options especially by:

- •crop rotation,
- •use of adequate cultivation techniques (e.g. stale seedbed technique, sowing dates and densities, under-sowing, conservation tillage, pruning and direct sowing),
- •use, where appropriate, of resistant/tolerant cultivars and standard/certified seed and planting material,
- •use of balanced fertilization, liming and irrigation/drainage practices,
- •preventing the spreading of harmful organisms by hygiene measures (e.g. by regular cleansing of machinery and equipment),
- •protection and enhancement of important beneficial organisms, e.g. by adequate plant protection measures or the utilization of ecological infrastructures inside and outside production sites.

2. Harmful organisms must be monitored by adequate methods and tools, where available. Such adequate tools should include observations in the field as well as scientifically sound warning, forecasting and early diagnosis systems, where feasible, as well as the use of advice from professionally qualified advisors.

3. Based on the results of the monitoring the professional user has to decide whether and when to apply plant protection measures. Robust and scientifically sound threshold values are essential components for decision making. For harmful organism's threshold levels defined for the region, specific areas, crops and particular climatic conditions must be taken into account before treatments, where feasible.

4. Sustainable biological, physical and other non-chemical methods must be preferred to chemical methods if they provide satisfactory pest control.

5. The pesticides applied shall be as specific as possible for the target and shall have the least side effects on human health, non-target organisms and the environment.

6. The professional user should keep the use of pesticides and other forms of intervention to levels that are necessary, e.g. by reduced doses, reduced application frequency or partial applications, considering that the level of risk in vegetation is acceptable and they do not increase the risk for development of resistance in populations of harmful organisms.

7. Where the risk of resistance against a plant protection measure is known and where the level of harmful organisms requires repeated application of pesticides to the crops, available anti-resistance strategies should be applied to maintain the effectiveness of the products. This may include the use of multiple pesticides with different modes of action.

8. Based on the records on the use of pesticides and on the monitoring of harmful organisms the professional user should check the success of the applied plant protection measures [10].

# The Benefits of Relying on Local Agriculture for The Future

## The importance of local food

A modern man should not be indifferent to what kind of food he eats. From a health point of view, it is recommended to eat seasonal vegetables and fruits from the local environment, as they are usually more optimally ripened and have a higher biological (nutritional) value. Reasons to buy local food are:

## Reduces the distance food travels

Much of the food on supermarket shelves has traveled long distances to reach your plate. By shortening the food chain, consumers can reduce food miles and reduce carbon emissions. Above all, you also reduce the amount of pollution that you indirectly cause through consumption. Buying local can really help reduce your greenhouse gas emissions and your overall impact.

## It's healthier

You are more likely to get better quality products if you shop locally. If the source is local, you are guaranteed full traceability back to the farm. No preservatives or other chemicals need to be added to local food to keep it fresh in transit. Fruits and vegetables begin to lose their nutrients within 24 hours of being picked, so locally grown food is most nutrient-dense when picked at the peak of ripeness.

## Less packaging is involved

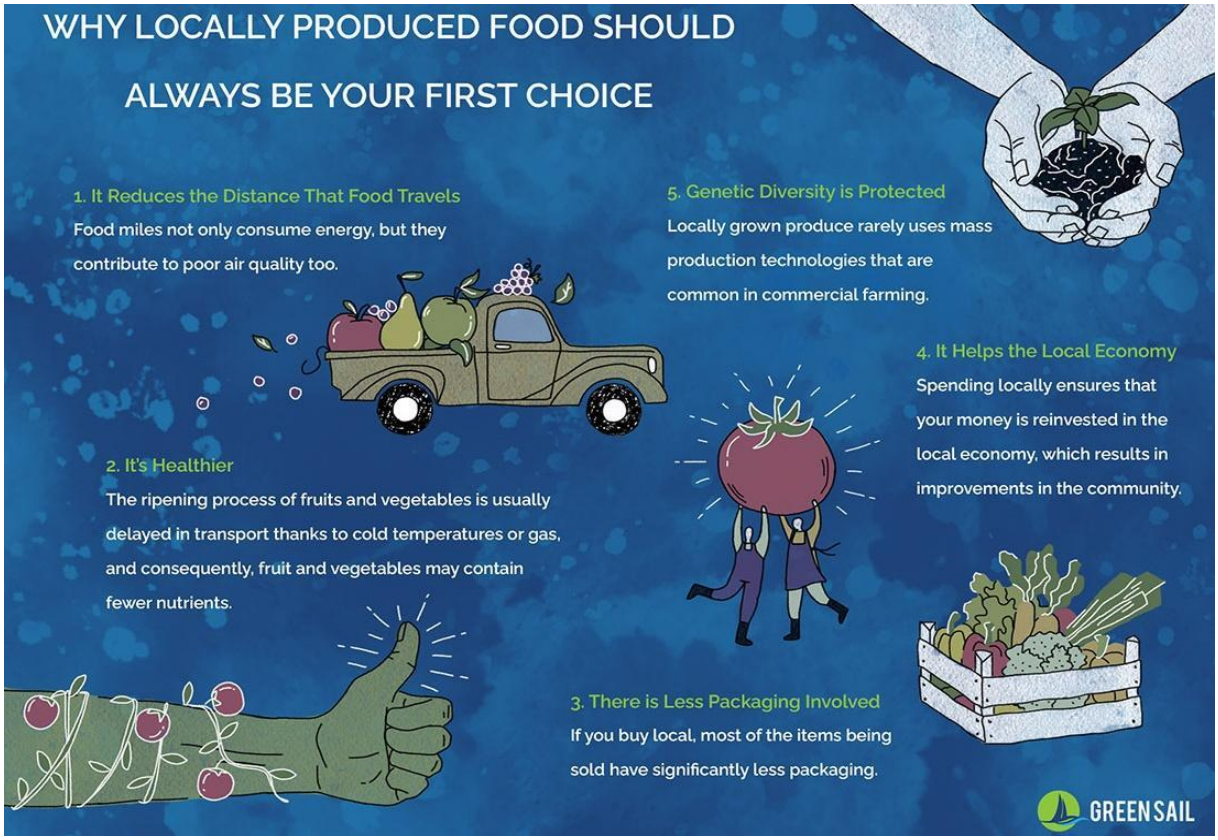
Shopping at local markets is an opportunity to reduce food and packaging waste. Much of the food produced is wasted from seed to plate and waste is generated at all stages of the supply chain, from production and harvesting to distribution and consumption (where the highest percentage of waste occurs at this stage).

## It helps the local economy

At the most basic level, when you buy local, more money stays in the community. If we take a closer look at how money flows, we can see the profound economic consequences of keeping money in cities or regions and how the fate of many communities in the country and the world increasingly depends on it. Because local farmers do not have the same transportation and distribution costs as large agribusinesses, they are able to keep more of the profit from their sales, which helps small agribusinesses become more successful.

## Genetic diversity is protected

Many types of cultivated products use modern commercial technologies from certain gene chains. In small-scale farming, farmers can use different types of crops with many different colors, which helps preserve the genetic diversity of the crops. Similarly, a variety of animals can be raised on a small farm, helping to increase biodiversity and offering more options to the consumer [11].



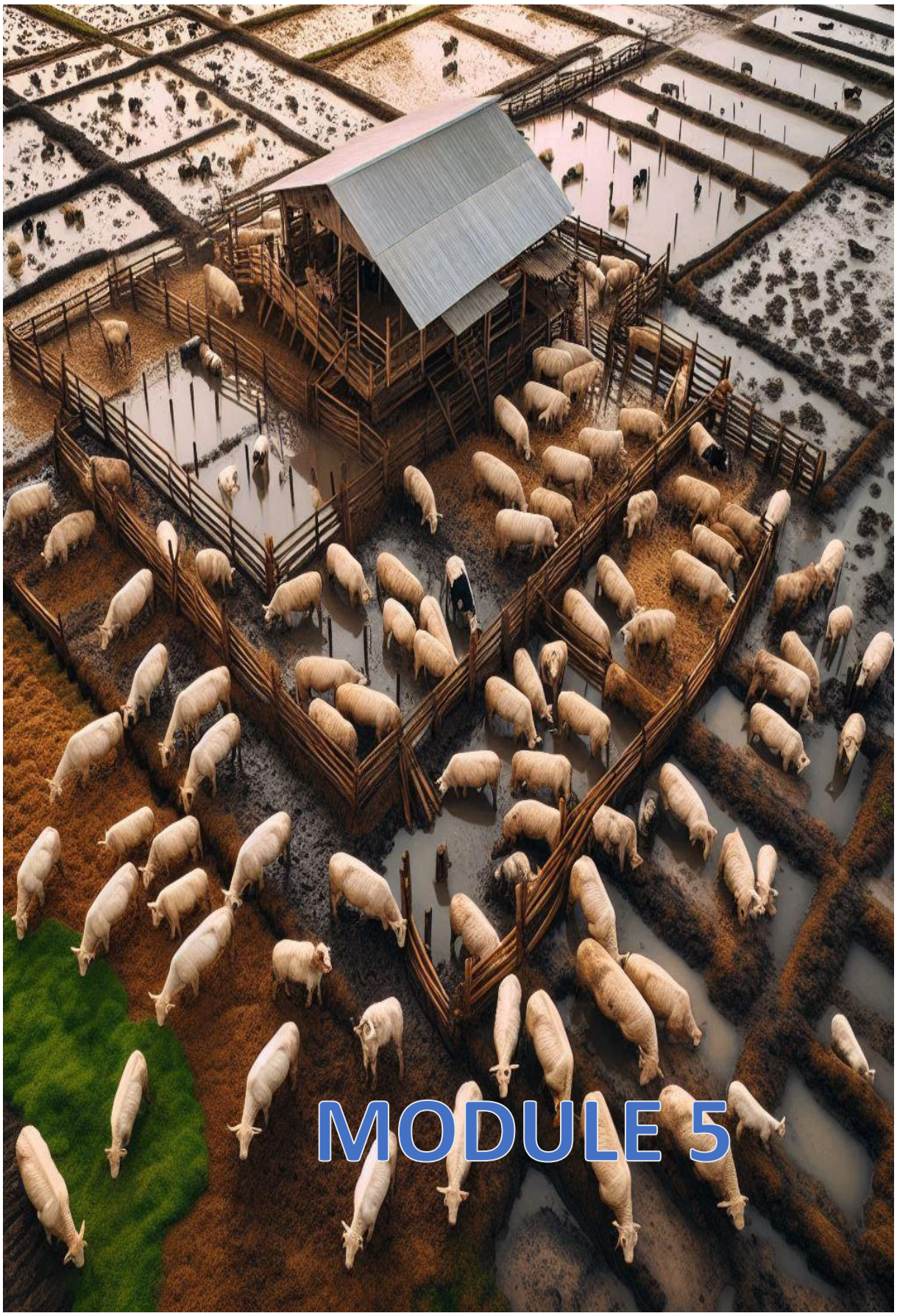

*Picture 3. why locally produced food should always be your first choice [https://www.green-sail.com/blog/why-locally-produced-food-should-always-be-your-first-choice]*

Local food production can help create jobs in rural areas, which strengthens the local economy. In addition, greater food security is ensured, especially for communities around the world suffering from hunger and poverty. Some research has found that when smallholder farmers become a priority in the global food sector, communities can thrive. Also, local food often tastes much better than food that comes from industrialized farms. The harvest season begins at the peak of maturity, not early, so that they eventually mature. As a result, local foods or produce are richer in nutrients. They don't have to travel as far-the longer the food sits, the more nutrients are released. A societal shift to seasonal eating would require us to start relying on local agriculture, which would also help with nutrient miles. So-called seasonal food calendars are known in many countries, such as South Africa, where they know EatOut, which offers infographics of seasonal produce. Thailand offers Union Fresh Seasonal Charts with color coding for seasonal foods. Even in the Netherlands, they have access to seasonal food guides

and there are plenty of options for fresh vegetables. By investing in local farms now, communities can invest in local farms in the future. Local food production thus in turn supports local families, preserves genetic diversity and local locations among plants, which means that future farms will be tougher and healthier. In the future, we will have to rely more on local agriculture if the industry is to feed a growing population and sustain the economy. Small farms increase food security for impoverished communities and have a smaller impact on the environment. These are causes that everyone can support as the population and demand continue to grow.

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MODULE 5

# Livestock Under Climate Change Conditions: Impacts, Mitigation and Adaptation

**Dušica Ostojić ANDRIĆ**

## Outline

•Direct Impact of Climate Change on Livestock Production

•Indirect Impact of Climate Change on Livestock Production

• Direct Effects of Livestock Production on GHG Emissions

• Indirect Effects of Livestock Production on GHG Emissions

• Mitigation Strategies for Greenhouse Gas Emission

• Adaptation Strategies of Animals to Climate Change

• Human Adaptation Strategies to Climate Change in Livestock Production

•Possibilities for Encouraging and Implementing Mitigation and Adaptation

## Introduction

Climate affects the number of livestock, their production, reproductive performance, morbidity and mortality and food supply in general. It is difficult to expand production while reducing climate impacts and Greenhouse Gas (GHG) emissions because of the relationship between the need for growing livestock production and the effects of continuous climate change. The degree of exposure, which is determined by the duration, frequency and magnitude of these changes as well as the available resources (location, housing and feeding condition, water supply etc.), affects how sensitive livestock are to climate change. Level of health care (e.g., vaccination rate) and race-specific differences also play a significant role. There are indications that the quantity and distribution of livestock may be impacted by climate change, especially in locally adapted breeds, which are mainly kept in extensive conditions. From all of the above, it is clear that the complexity of the presented problem requires a serious and thorough approach, which is primarily based on understanding climate change's effects on animal production, along with knowing the possibilities for their mitigation and adaptation.

# DIRECT IMPACT OF CLIMATE CHANGE ON LIVESTOCK PRODUCTION

Products and services related to livestock are crucial for people. Around one-quarter of the world's land that is not covered in ice is taken up by livestock and one-third of all arable land is used to grow crops for animal feed [1]. One-third of the world's population relies on animal husbandry as a source of income, contributing about 40% of the global agricultural GNP [2]. Globally, animal products make up one-third of the protein, one-fifth of the calories and a significant portion of the B12, iron and calcium that people consume. The demand for animal products grows together with the global population growth. But as the climate changes globally, livestock farming is feeling the effects more and more. These implications include rising temperatures, more varied precipitation patterns, growth in the occurrence of extreme events and rising carbon dioxide levels [3].

Kummu et al. [4] predict that one third of the world's crop production and more than 30% of animal production may be displaced outside stable climate conditions by 2081-2100 if warming is not limited to 1.5-2℃. In principle, there are direct and indirect impacts of climate change [5]. Climate change and $CO_2$'s effects on livestock metabolism, immune function and temperature regulation are referred to as direct impacts. Indirect impacts arise from climate impacts on livestock feed, water accessibility and pest/pathogen communities.

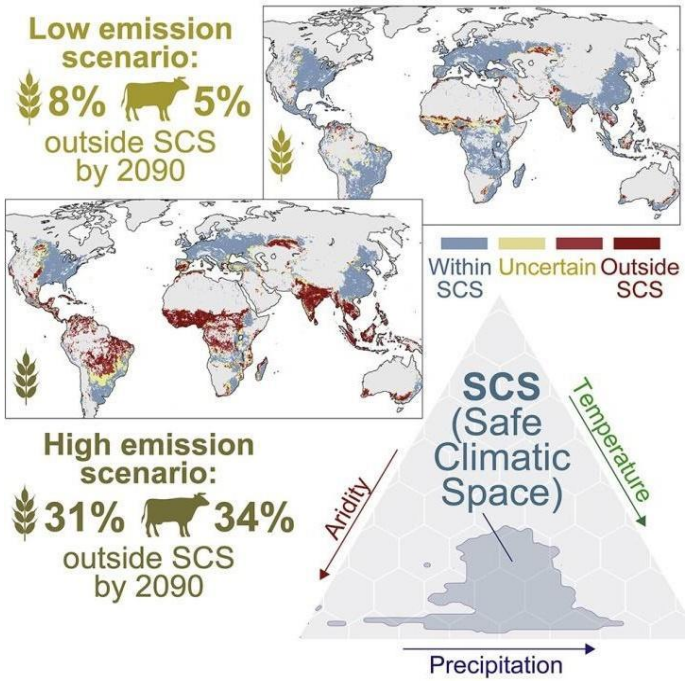



*Figure 1. Scenario of high and low GHG emissions and their impact on livestock production [4].*

## Heat Stress

The production performance of animals is highly dependent on the environmental conditions in which they are raised. The optimum ratio of temperature, humidity and airflow is called the thermal comfort zone and is species-specific. In this zone, the animal is able to achieve optimal production performance with minimal energy spending [5]. When the temperature rises above this range, heat stress occurs and the animal's organism expends additional energy to regulate body temperature, which negatively affects productivity. If the animal provides an appropriate phenotypic response to the effect of the thermal stressor, we say that it has adapted, i.e. acclimatized [3]. Heat stress caused by high temperature is a bigger problem and has a greater effect than stress caused by low temperature [6]. Against the backdrop of climate change, the global increase in temperature means that greater importance is attached to thermal stress caused by the effects of high temperatures. Therefore, heat stress is generally considered to be the dominant topic in consideration of thermal stress.

When animals are unable to emit enough heat to maintain homeothermy, heat stress develops [7]. After "overheating" there is accelerated respiration and tachycardia, along with an increase in body temperature. As a result, there may be alterations in mortality and immune system operation, as well as decreased food intake, milk production and reproductive effectiveness. A summary of the various physiological and biochemical changes associated with heat stress that occur at different systemic levels in the body of dairy cows are shown in Figure 2.

When considering climate change issues, it is important to emphasize the adaptability of animals. Compensation and adaptation mechanisms that are activated during heat stress play an important role. Although their initiation can lead to a decrease in animal productivity, achieving homeothermy and homeostasis as conditions for survival is the primary goal. During heat stress, the humoral system plays a crucial role in regulating homeostasis via the hypothalamic-pituitary-adrenal axis. The main result of this interaction is the reduction in the level of growth hormone and thyroxine, which reduces the activity of basal metabolism. Given the effects of climate change, there are ways to resist them at the cellular level, i.e. genes. Based on the so-called heat shock proteins, which play a crucial role in adapting to heat stress, corresponding genes responsible for acclimatization at the cellular level were also identified. In the genome of animals living in warmer climates, such genes are more common, which in the future can be used with advanced biotechnological methods to modify the genotype with a view to adaptation to climate change [8].

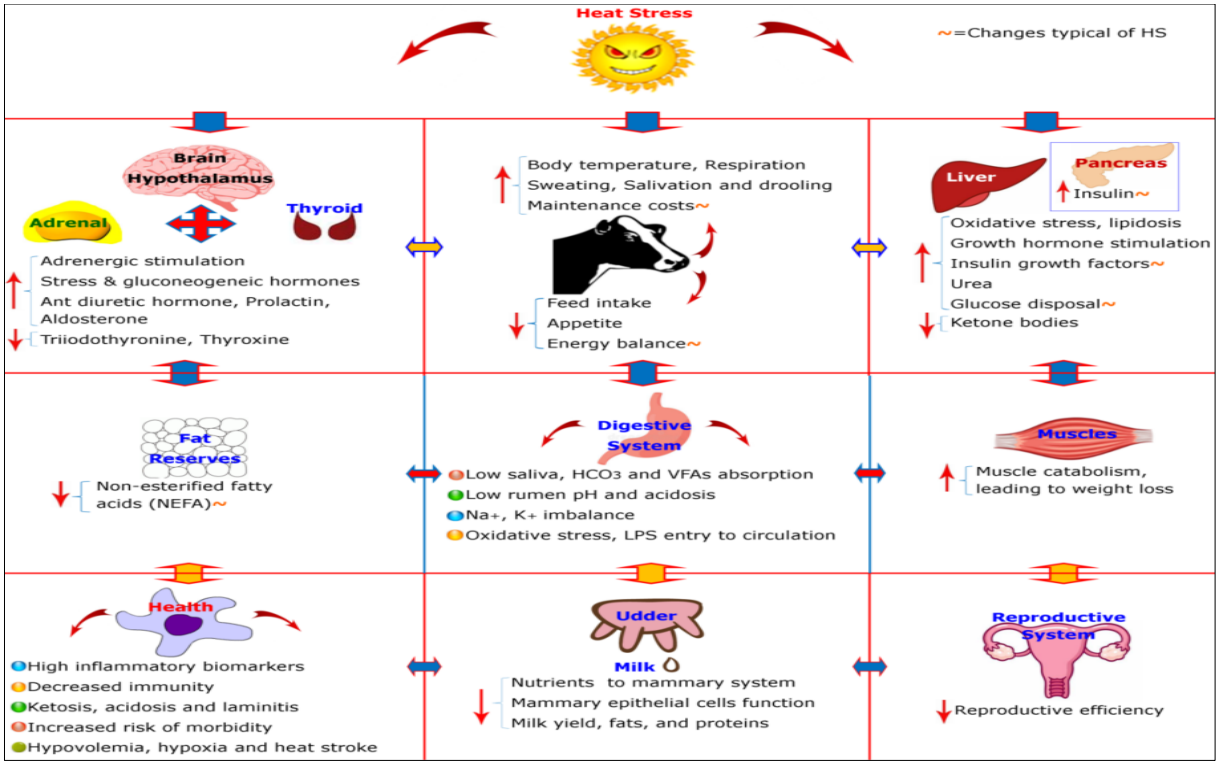



*Figure 2. An overview of the physiological and biochemical alterations brought on by heat stress in different body systems of dairy cows. Changes that are typical for animals in extreme heat are denoted by the symbol "~". Lipopolysaccharides (LPS) and volatile fatty acids (VFAs) [7].*

## Feed Intake

One of the responses to a hot environment is decreased food intake. Increased heat stress in ruminants was linked to reduced hunger, intestinal velocity and ruminating [9]. As the ambient temperature rises over 25-26°C, and especially beyond 30°C, feed intake falls in dairy cows [10].

Compared to other ruminants, goats are less vulnerable to heat stress. When the outside temperature is more than 10°C over their thermal comfort zone, however, their voluntary food intake declines [11].

When the temperature rises from 20 to 35°C, pigs under heat stress have higher body temperatures and their feed intake falls by about 11% [12]. Such effects persist even after the cessation of exposure of animals to heat stress. Therefore, it has been proposed that early morning feeding might aid prevent reduced food intake [13].

Poultry was also found to have reduced feed intake at high temperatures. A temperature increases of approximately 10°C in poultry from hatching to 6 weeks of age resulted in a reduction in feed consumption of almost 10% [14]. Consequently, this was reflected in the reduction in feed conversion efficiency and daily gain [15]. The given relationships are shown in Figure 3.

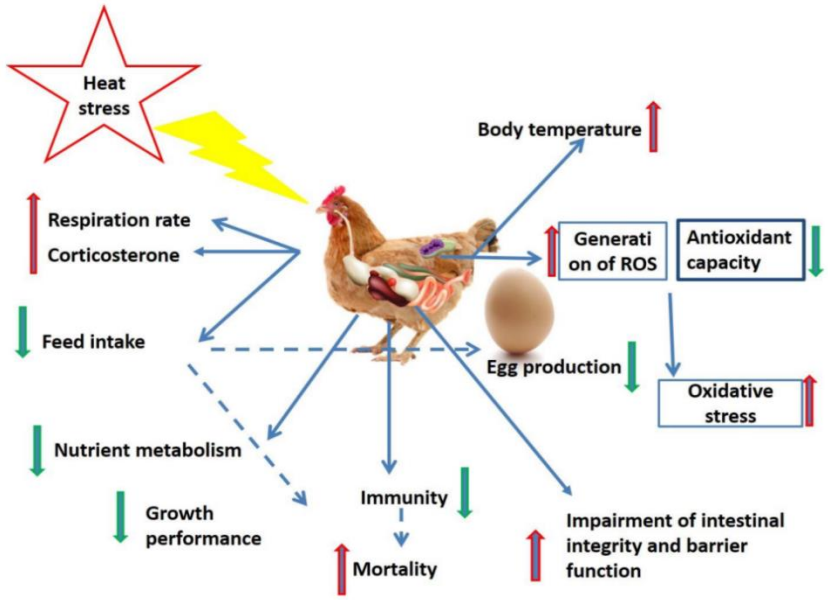



*Figure 3. Effects of heat stress in poultry [15].*

## Production

Generally, in all livestock species, reduced feed intake due to heat stress leads to reduced production of milk, meat and eggs, which in turn leads to financial losses. Dairy cows under heat stress reduce their intake of dry matter, which explains approximately 35% of the reduction in milk production [16]. In addition, more productive breeds show greater sensitivity to heat stress than breeds of lower production since they emit more metabolic heat due to their larger size. Consequently, with the increase in metabolic heat production caused by heat stress, there is a decrease in milk production. Moderate heat stress during lactation causes feed intake reductions, metabolic alterations and compromised mammary gland formation in dairy cows, which results in 25-40% fewer milk production [17].

In addition to heat, the yield and composition of milk is also affected by the humidity of the environment, that is, their interaction expressed through the heat-humidity index (THI). It was found that lactating cows begin to suffer from heat stress when the values of this index are above 72 and that the content of milk proteins and milk fat decreases with its increase. Lactose and protein content can be about 49% lower as a result of heat stress [18]. Similar changes in the composition of milk were also found in dairy breeds of goats and buffaloes, but in a small number of studies. Thus, in goats under the influence of elevated temperature, a decrease of 12%, 3-10% and 4% was observed in growth, milk and meat production, respectively [11, 19, 20].

Probably due to altered placental hormone synthesis and decreased intake of dry matter [22], heat stress during the final 50 days of gestation in dairy cows impairs mammary development and decreases colostrum and milk yield [21].

Studies have shown that heat stress adversely affects meat production [23]. In ruminants under the influence of heat stress, there is decrease in growth, carcass weight and fat tissue thickness, followed by lower meat quality [24]. There are indications that heat stress through lower food intake and reduced availability of glycogen in muscles can be reflected in the appearance of dark meat [25]. However, studies have shown that small ruminants (goats and sheep) compared to large ones, show greater adaptation to a warm and humid environment [26]. Cattle reared in feedlots are a significantly more vulnerable category because captivity limits their ability for adequate cooling (shade, water, wind) as well as due to exposure to rough radiating surfaces and feeding by high-energy nutrients [3].

Pigs, similarly to ruminants, decrease in growth, carcass weight, intramuscular fat content and meat quality when exposed to high temperature. It was found that the daily gain in pigs can decrease by 10% under the influence of high temperatures [27]. The physiological response and consequences of heat stress in pigs are schematically shown in Figure 4. Traditionally, these changes were believed to be due to reduced feed intake, but recent studies have shown that heat stress itself also reduces metabolic rate and alters post-absorptive metabolism, without regardless of reduced food intake [28].

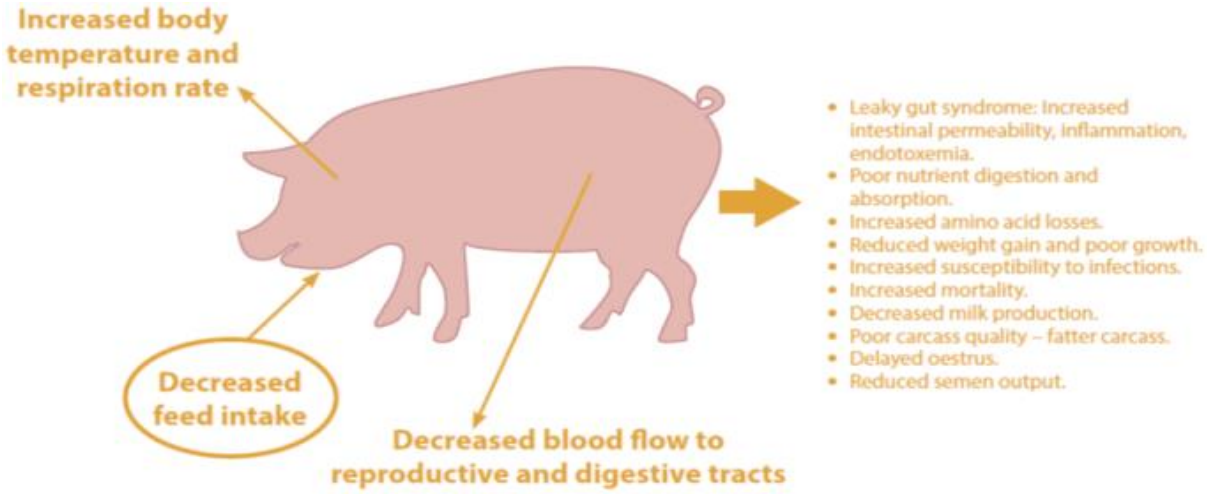



*Figure 4. The physiological response and consequences of heat stress in pigs (adapted from Artuso-Ponte, 2018 in All About Feed). https://www.chemunique.co.za/swine/preventing-heat-stress-in-pigs/*

Poultry that are confronted with heat stress use more energy to retain thermal homeostasis at the cost of growth. In broilers under heat stress, a decrease in growth, feed conversion rate, breast muscle mass and protein content in meat was found [14, 15]. The traits that demonstrated the highest level of vulnerability to heat stress in laying hens were eggshell strength, daily feed intake, egg mass and egg production [15, 29].

## Reproduction

Both sexes are influenced by heat stress on reproduction. Heat stress shortens the estrus cycle and decreases fertility in females while raising of anestrous occurrence and prenatal mortality. Males that experience heat stress have poorer sperm quality, smaller testicles and less fecund semen overall. Both sexes showed significant seasonal changes in reproductive efficiency [30, 31].

Although poultry reproduction is also affected by heat stress, there appear to be some differences compared to the performance found in mammals. Male broilers are more sensitive to heat-induced infertility than females [30]. In laying hens, environmental stress can delay the ovulation process, reduce yolk quality and affect egg production [31].

Reduced reproductive performance of dairy and fattening breeds during the summer can be particularly costly for the producer. Gestational and lactating dairy cows are particularly prone to increased metabolic heat due to their high-energy diets, high feed intake and metabolic activity required for digestion and milk production (Figure 5). These factors can reduce the conception rate by

10-20% but also cause losses during pregnancy [32]. The correlation between THI and pregnancy loss rate is shown in Figure 6 [33].

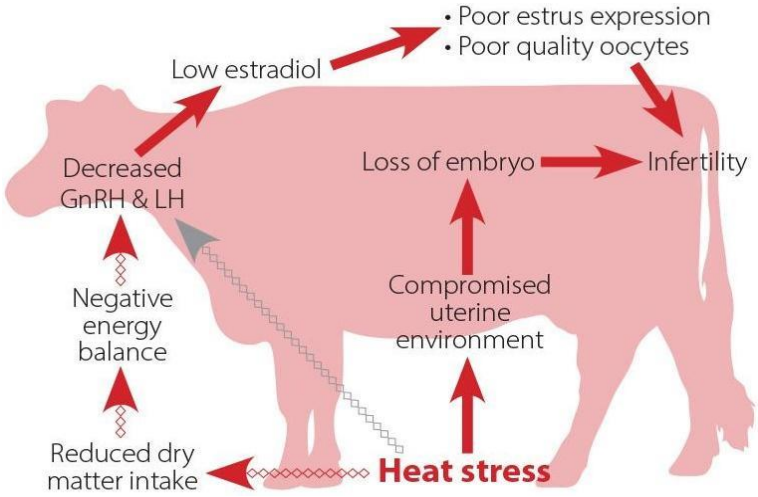



*Figure 5. Effect of heat stress on reproductive disorders in cows (https://www.techmixglobal.com/repro-heat-stress/)*

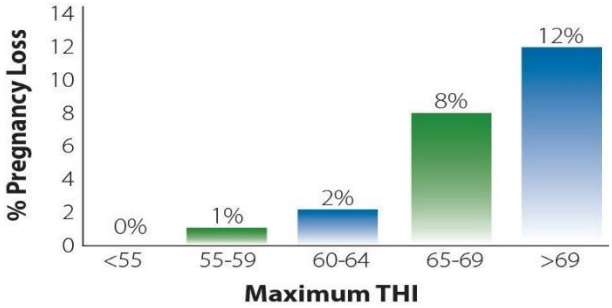



*Figure 6. Relationship between THI and pregnancy loss rate [33].*

Short-term and long-term exposure to heat stress significantly impairs sheep fertility and reduces semen production and ram quality, resulting in fewer lambs per ewe (Figure 7). Also, a decrease in the body weight of lambs at birth and a weaker development of the mammary glands of sheep as a result of heat stress during pregnancy can reduce the survival and weight of lambs at weaning [34].

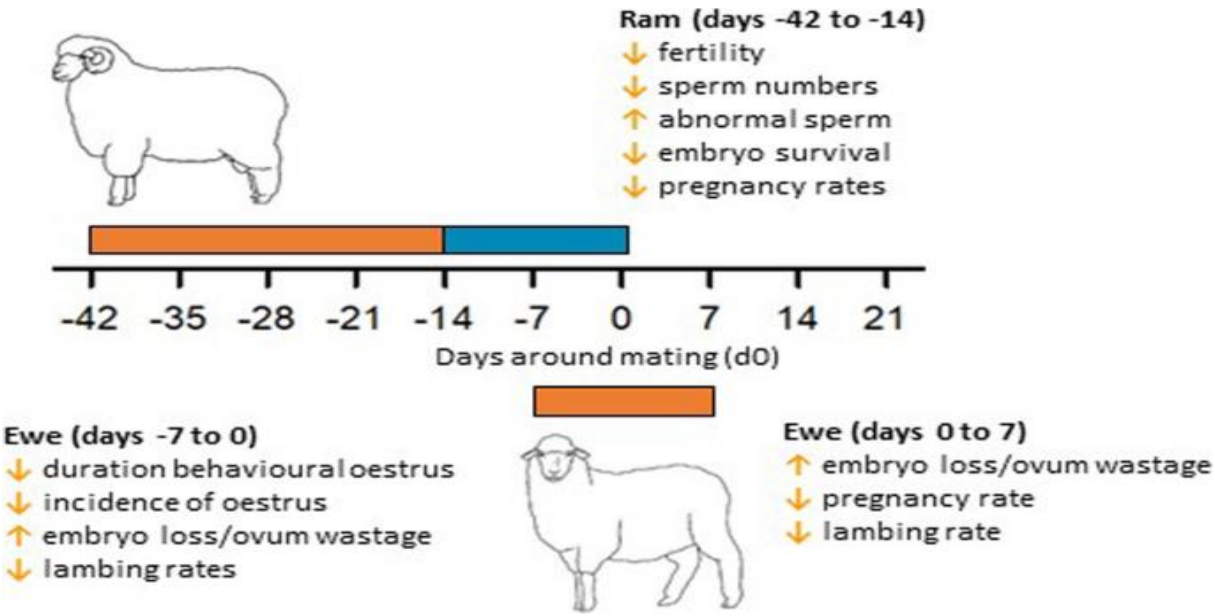



*Figure 7. Impact of heat stress before and throughout the mating season on rams' and ewes' fertility. Temporal normothermic (blue) and hyperthermic (orange) temperatures before mating [34].*

## Health

Climate change, especially global warming, affects animal health directly and indirectly [3]. In this chapter, diseases caused by the action of both influences will be dealt with, since they certainly relate to animal health. Direct impacts include vector-borne diseases, as well as those caused by water (e.g., flooding), soil, temperature and moisture, or transmitted by rodents. Climate change can lead to the conversion of land use and disruption of biological diversity resulting in various adaptive changes in animals. In addition, the indirect effects of climate change on animal health are considered to be those that lead to the modification of microbial communities, changes in the host's immune and general response to pathogens, starvation and food poisoning.

The intensity of the impact of climate change on the health of livestock depends on several factors, such as genotype, specific and non-specific disease resistance of animals, rearing areas, as well as on the characteristics of pathogens [3]. The immune system plays a critical role in ensuring adequate health, but heat stress can significantly disrupt its defense function [35]. High temperatures and changes in the precipitation regime favor the development and spread of pathogens and consequently can alter their distribution and lead to the emergence of new diseases [36]. As a result of the immunosuppressive effect of heat stress, livestock becomes more susceptible to disease, leading to an increase in morbidity and mortality rates in herds [3].

Heat stress can affect livestock health in other ways as well. Thus, under the influence of several hours of heat stress, pigs can develop symptoms of gastro-intestinal disorders [37]. Exposure to high ambient temperatures in broilers and laying hens leads to unfavorable changes in the gut microbiome [38].

It is important to note that, especially in developing countries, the impact of climate change on livestock disease occurrence is more difficult to assess compared to other impacts [3].

## Mortality

Increased mortality of farm animals as a result of heat stress can have a significant negative economic effect. Excessive heat strain elevates the mortality rate, according to studies in pigs and dairy cows [39]. It has also been found that hot and humid weather poses a greater threat to the lives of cows and pigs than dry and warm weather and temperatures above 37.7℃ with humidity levels of over 50% are hazardous [40].

Compared to mammals, poultry has a higher and more fluctuating body temperature and are also more susceptible to heat stress. An ambient temperature of up to 27℃ or a body temperature of up to 41℃ may be considered suitable for rearing chickens. However, lethal outcomes for chickens occur when the body temperature increases by 4℃ [41].

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# INDIRECT IMPACT OF CLIMATE CHANGE ON LIVESTOCK PRODUCTION

Various scenarios of climate change predict a temperature increase of 1.1℃ to 6.4℃ by the end of this century [1]. Along with global warming, changes in the precipitation regime and increasingly frequent extreme climatic events represent a potential danger for the provision of food and water in farm animals breeding. In addition to the direct impacts discussed in the previous chapter, the indirect effects of climate change on soil fertility and degradation, availability of water, fodder yield, quality and availability and the spread of pathogens must also be taken into account.

## Forage Quality

Adequate nutrition is essential for animal health, desirable growth, production and reproduction. Increases in atmospheric $CO_2$ and temperature, as part of climate change, change the quantity and quality of forage, with the intensity of these changes depending on the animal husbandry system, location and species [2]. In addition to the above, significant influencing factors are precipitation patterns, extreme climatic events, variations in production and water supply.

The direct impact of climate change on livestock nutrition (food intake and digestive processes) has already been discussed. Indirectly, climate change can affect livestock nutrition through changes in the physical and chemical characteristics of plants that are part of livestock feed. In this way, climate changes also affect the quality of feed for livestock (cereals and roughage). Depending on the degree of warming and the severity of the drought, plants respond to heat stress in different ways physically and chemically. Acidic and neutral detergent fibers, crude protein, nitrogen, water-soluble carbohydrates and minerals (Ca, P, Mg, K) are typical nutritional parameters taken into account when forage quality is discussed [3].

Variations in nitrogen and water-soluble carbohydrate concentrations are influenced by dry conditions and high temperatures [4]. Extreme weather conditions cause tissue to age prematurely, which can dramatically lower the quality of the forage. Specifically, plants mature faster and the water content in their tissues is reduced more quickly even under mild heat stress. Lignification and an increase in the stem-to-leaf ratio negatively affect the digestibility and quality of forage. Lee et al. [5] warn that an increase in temperature reduces the nutritional value of animal feed, which can result in higher methane production. However, in certain circumstances (higher $CO_2$ values), the effect of high temperatures can be reversed, that is, digestibility can increase, which indicates the complexity of the interaction between climatic factors [6-7]. Figure 1 shows the average influence of elevated $CO_2$ on the main indicators of forage quality in different groups of plants [7].

The literature that investigates the impact of climate change on crop production is very large, but a special aspect is the effects of climate change that are reflected exclusively on the provision of feed consumed by livestock.

Forage can be defined as "edible parts of plants that can provide food for grazing animals or that can be harvested for food" [8]. Legumes and grasses make up the two main types of forage plants. Based on leaf anatomy, plants can be divided into cold season (C3) and warm season (C4) groups [9]. $CO_2$ has been found to affect crop growth. While yields of C4 crops (maize and sorghum) may not directly respond to elevated $CO_2$ but may indirectly benefit from drought, yields of C3 crops (soybean and wheat) improve under increased $CO_2$ concentrations. Rainfall, temperature and extreme weather conditions like drought are other climatic variables that influence the availability of feed. For rice, soybeans, sorghum and corn, more rain is advantageous [10-11]. Temperature rises favor C4 species more, however, these benefits vary by location, plant species and production technologies [12].

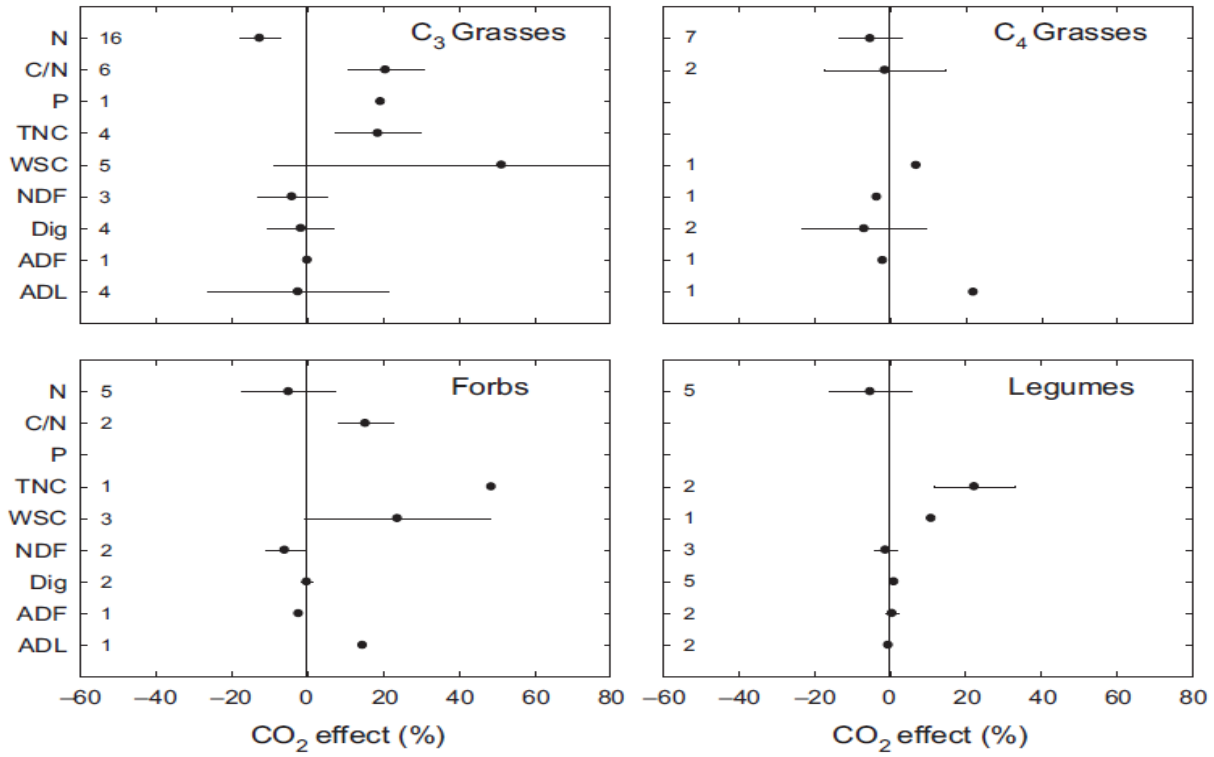



*Figure 1. The average effect of increasing $CO_2$ on the key forage quality indicators [7].*

Drought causes a significant reduction in yields, especially in warm regions. Recent research in Europe has shown that drought stress is a major driver of maize and winter wheat losses, particularly during poor yield years [13]. It is difficult to separate the effects of these climate conditions on vegetation growth because they are frequently combined. For instance, whereas greater temperatures at higher latitudes may boost crop adaptability and lengthen the growing season, higher temperatures at lower latitudes may be linked to water stress.

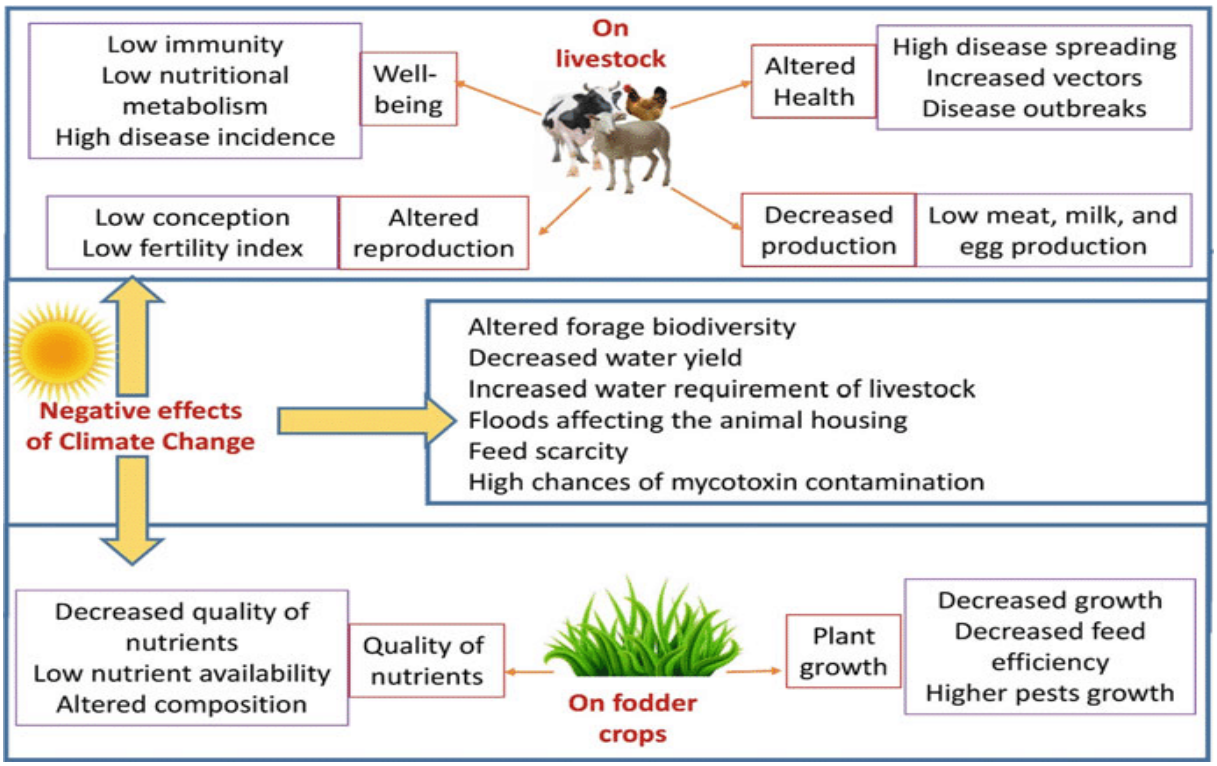



*Figure 2. Negative impacts of climate change on livestock [17].*

Besides the fact that higher temperatures and drier conditions favorizing C4 species, they can also cause increased toxicity in some plants. Also, an elevated concentration of $CO_2$ in some plants can reduce the concentration of proteins and minerals, while in some it can cause greater toxicity. The danger of elevated $CO_2$ values is also in the favoring of C3 plants and the spread of trees at the expense of grasses [14].

The distribution of biomes and the composition of grasslands and pastures are significantly altered by the rise in average temperature. Shorter intervals of pasture growth may result from changes in rainfall patterns and more frequent droughts. According to several research, fluctuations in temperature, $CO_2$ concentration and nitrogen deposition lower pasture productivity [15].

In addition, pasture systems are especially vulnerable to climate change due to limited adaptation possibilities. In particular in arid and semi-arid grazing systems, increased temperatures, as well as less rainfall, are anticipated to decrease pasture yields and exacerbate soil degradation [16, 17].

## Water

Water is in short supply everywhere and the severity of water shortages varies according to its availability and demand. Agriculture, with a share of 69% is the greatest single consumer of water on the planet [17]. Water is used in the livestock industry for animal consumption, the manufacturing of feed and the processing of products. About 22% of the world's total evapotranspiration from agricultural land and 41% of the overall water use are driven by animal husbandry [18]. With increasing human population and growing demand for livestock products, water scarcity is likely to become an increasingly important limiting factor for agricultural production.

Water availability and livestock water use are projected to alter as a result of climate change [19]. An increase in temperature will probably enlarge water consumption per head and per hectare, as well as irrigation water consumption [20].

Another issue, brought on by increasing sea levels is water desalination [21]. In the upcoming years, competition for water between livestock, crops and non-agricultural uses will intensify, necessitating highly effective production technologies to handle water shortages [19].

In addition to the quantity, there is also concern about the quality of raw water, which according to predictions may also be reduced [14]. This can be caused by rising temperatures and sea levels or higher loads of sediment, nutrients and pollutants from heavy rainfall. Poor water quality can reduce water and feed consumption in animals and endanger their health.

## Seasonal Variations and Extreme Climate Events

The seasonal pattern and availability of resources and crops may alter due to climate change, having additional effects on the livestock. It is to be expected that animals will experience more heat stress as heatwave frequency and duration rise. According to Knee et al. [22], there are significant seasonal variations in the amount of glycogen in beef muscles. They have found that better beef quality is associated with rearing on nutrient-rich springtime pastures compared with rearing on poorer, summertime pastures. Furthermore, grazing and livestock management may face new difficulties due to changes in the seasonal patterns of forage supply. The production of animal feed is threatened by the rising threat of extreme drought, so adaptive measures are required to deal with such extreme events. Additionally, alterations in snowmelt timing modify the patterns of water availability throughout the year, which also has an impact on feed supply [23].

Recent research has shown that heat waves and droughts in the continental climate region of the Pannonian Plain, which extends into Hungary, Serbia, Bulgaria and Romania, have a particularly serious impact on natural grasslands. Stričević et al. [24] performed a predictive analysis of climate change at five localities in Serbia, for two selected scenarios of greenhouse gas emissions-RCP4.5 and RCP8.5.

The obtained results indicated that in the coming period, the vegetation of natural grasslands will be exposed to changes in climatic conditions, frequent droughts and frequent occurrences of extremely high temperatures (Table 1, Figure 3).

*Table 1. Simulated number of drought days on selected localities in Serbia [24]*

| Scenario | Period | Rimski Sancevi | Valjevo | Kragujevac | Negotin | Leskovac |
|---|---|---|---|---|---|---|
| RCP 4.5 | 1986-2005 | 101 | 95 | 100 | 106 | 101 |
| | 2016-2035 | 101 | 97 | 101 | 107 | 102 |
| | 2046-2065 | 103 | 99 | 103 | 109 | 105 |
| | 2080-2100 | 103 | 99 | 103 | 108 | 105 |
| RCP 8.5 | 1986-2005 | 100 | 94 | 100 | 106 | 102 |
| | 2016-2035 | 101 | 96 | 101 | 106 | 101 |
| | 2046-2065 | 102 | 99 | 103 | 108 | 104 |
| | 2080-2100 | 106 | 103 | 107 | 111 | 109 |

This can lead to endangering the survival of grass plant species, especially species of northern temperate climate, which are the main components and bearers of the yield of sown lawns for the production of coarse fodder in the meadows and arable fields of Serbia. On the other hand, drought tolerance will develop by natural diversity and the spread of species resistant to high temperatures and water deprivation, such as weeds and lower quality species.

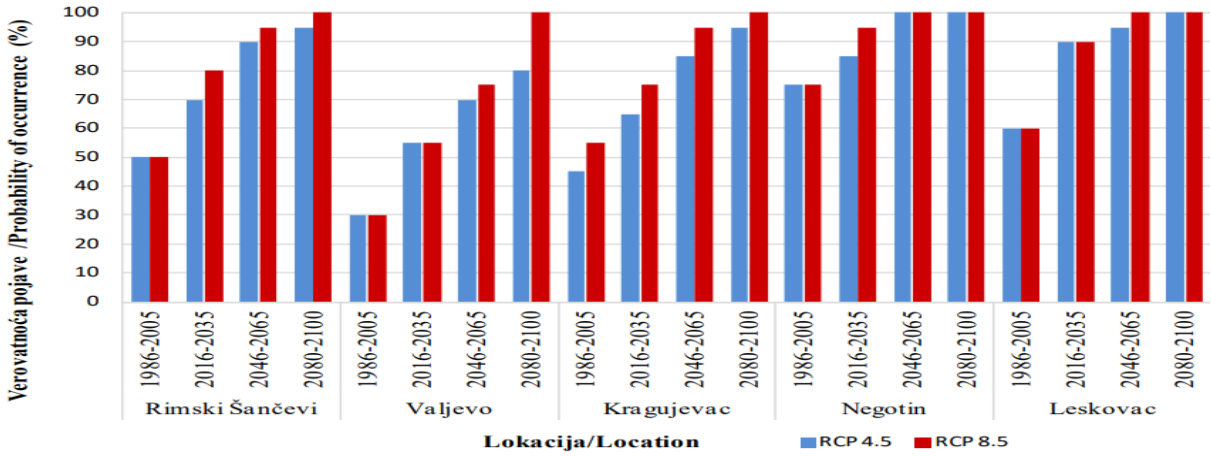



*Figure 3. Probability of occurrence (%) of max. daily temperature (> 30 °C) for more than 30 days [24].*

It is important to mention here the effect that seasonal variations and extreme climatic events can have on increasing the morbidity and mortality of livestock. In particular, prolonged droughts cause a shortage of water and pasture, which reduces the immunity of livestock against infectious diseases. Additionally, pursuit of resources, triggers the movement of grazing animals into places with a higher danger of infectious diseases, like wildlife reserves. In this case, closer animal-to-animal interaction between domestic and wild animals increases the chance of disease transmission [25]. Also, livestock may be exposed to the risk of new pathogens due to increased contact with wild animals in the grazing areas established by deforestation and changes in land use [26].

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## DIRECT EFFECTS OF LIVESTOCK PRODUCTION ON GHG EMISSIONS

According to estimates, livestock production is a significant source of greenhouse gas emissions, contributing 14.5% in total anthropogenic emissions, i.e. 8.1 gigatons of $CO_2$ equivalent per year [1]. $CO_2$ equivalent ($CO_2$-eq) is a unit of measurement for carbon dioxide, usually expressed in metric tons, and is used to standardise the measurement of all greenhouse gases (GHGs) that contribute to global warming. These gasses retain heat in the Earth's atmosphere, leading to rising temperatures and other climate changes.

The carbon footprint is used as a measure of the amount of $CO_2$ and other GHG emissions released into the atmosphere during human activities (energy use, transportation, food production, etc.). It provides a way to quantify the total amount of GHG emissions produced by a particular activity, product, or person. To calculate the carbon footprint, all GHG emissions are converted into $CO_2$-eq based on their global warming potential (GWP). GWP indicates how much heat a gas traps in the atmosphere compared to $CO_2$ over a given period of time (usually 100 years). Thus, depending on the source, methane has a GWP value 28-36 times that of $CO_2$ over 100 years, so that the emission of 1 tonne of methane is equivalent to the emission of 28-36 tonnes of $CO_2$ equivalent. The GWP value of nitrous oxide is 265 times that of $CO_2$ over 100 years, so the emission of 1 tonne of nitrous oxide is equivalent to the emission of 265 tonnes of $CO_2$-eq. By using the $CO_2$-eq measure, it is possible to compare emissions of different greenhouse gases and monitor progress in reducing total greenhouse gas emissions over time.

Methane ($CH_4$), nitrous oxide ($N_2O$) and carbon dioxide ($CO_2$) are the three primary greenhouse gasses released by livestock. Carbon dioxide is released primarily from the combustion of fossil fuels in power machinery and from the burning of biomass through microbial decomposition. Carbon dioxide emissions can also result from the conversion of arable land into permanent grassland (through land use change) or from adjustments in agricultural land management. Methane is produced during the decomposition of organic material under anaerobic conditions (during enteric fermentation of ruminants, storage of manure, or organic waste from the processing industry). Nitrogen oxides are released during the microbial transformation of nitrogen in the soil or in manure.

The FAO Global Environmental Assessment Model in Livestock (GLEAM) [2] was used to analyze the relative abundance of the mentioned gasses, and the IPCC (2014) 100-year warming potential (298 for $N_2O$ and 34 for $CH_4$) was used to convert their levels into $CO_2$-eq.

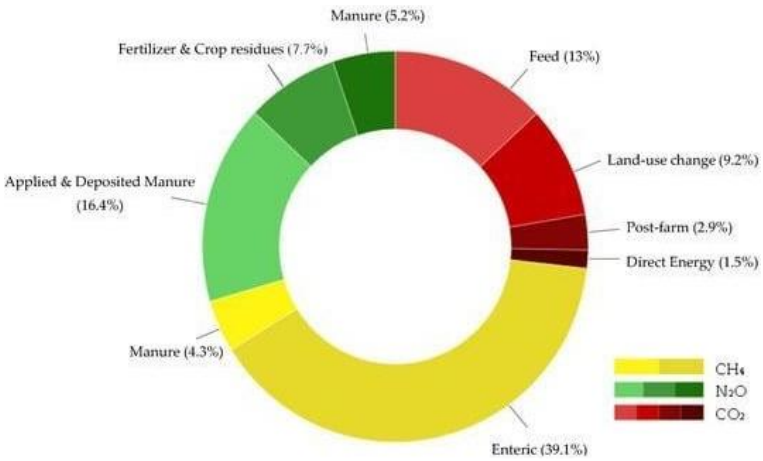



*Figure 1. GHG emissions from different sources in livestock [1; 2].*

According to this model, methane ($CH_4$), nitrous oxide ($N_2O$) and carbon dioxide ($CO_2$) account for 50%, 24% and 26% of emissions respectively in the animal products supply chain (Figure 1). With a participation of about 62% of the total emission of all types of livestock, cattle are the main source of GHG. At the same time, dairy and beef cattle produce similar amounts of emissions. Emissions from

other species (including pigs, poultry, buffalo and small ruminants) range from 7 to 11% individually. Figure 2 shows the estimated share of emissions by livestock species.

The values of $CO_2$ equivalent emissions in cattle production estimated using the GLEAM model [2] are 3.0 for beef and 1.6 gigatons for milk. Pork production emits 0.82 gigatons of $CO_2$-eq, chicken meat and eggs 0.79 gigatons of $CO_2$-eq, buffalo meat and milk 0.7 gigatons of $CO_2$-eq and 0.5 gigatons of $CO_2$-eq from small ruminant meat and milk production. Other poultry and non-edible products account for the rest of the emissions.

Comparing emissions between different types of animal products based on protein production is perhaps a more relevant way to express these relationships. In this case, buffalo meat is characterized by the highest emissions intensity, averaging 404 kg of $CO_2$ -eq per kg of protein produced. In second place is beef production with an average of 295 kg $CO_2$-eq per kg protein. This is followed by meat and milk from small ruminants and buffalo milk, with emissions of 201, 148 and 140 kg $CO_2$ -eq per kg protein, respectively. In this calculation, the group with the lowest emission intensity (less than 100 kg $CO_2$ -eq per kg protein) includes the production of cow milk, poultry meat and eggs, and pork [2]. It is important to emphasize that the estimated emission intensity varies significantly depending on the region, i.e. agroecological conditions, applied production technology and overall management.

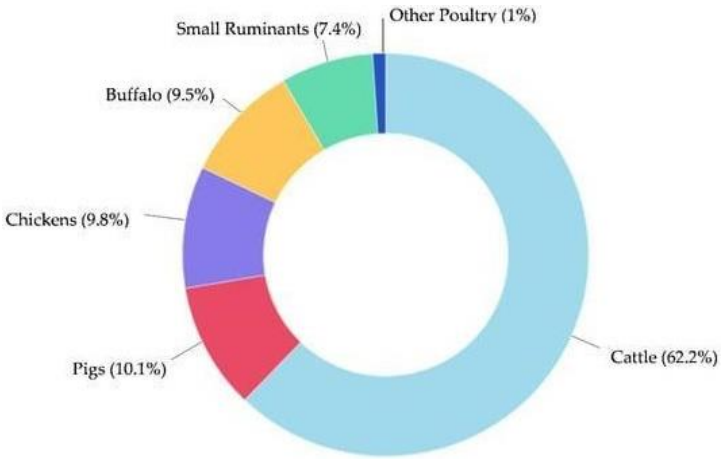



*Figure 2. GHG emissions by livestock species [2].*

Direct emissions are those resulting from animal husbandry, including the release of harmful gasses through enteric fermentation and manure. The group of direct emissions can also include emissions that occur through accompanying energy consumption. Indirect emissions mainly come from animal feed production and related land use changes. The ratio of the sizes of direct and indirect emissions has not yet been fully clarified, i.e. It is still not possible to specify which of these two types of emissions has the greater share [3; 4].

## Enteric Fermentation

In the digestive system of ruminants (figure 3), the process of enteric fermentation takes place, which involves the decomposition of organic matter, mainly of fibrous-cellulosic type, under the influence of the microflora present [5]. This is essentially a unique and useful process that enables the conversion of hard-to-degrade substances (cellulose, lignin) into nutritionally valuable substances that are ultimately used for human nutrition. However, during enteric fermentation, there is also the formation of harmful gas-methane, which animals release into the environment (by exhaling, belching, defecating). In this way, ruminants are the group of domestic animals that contribute the most to the emission of methane into the atmosphere [6].

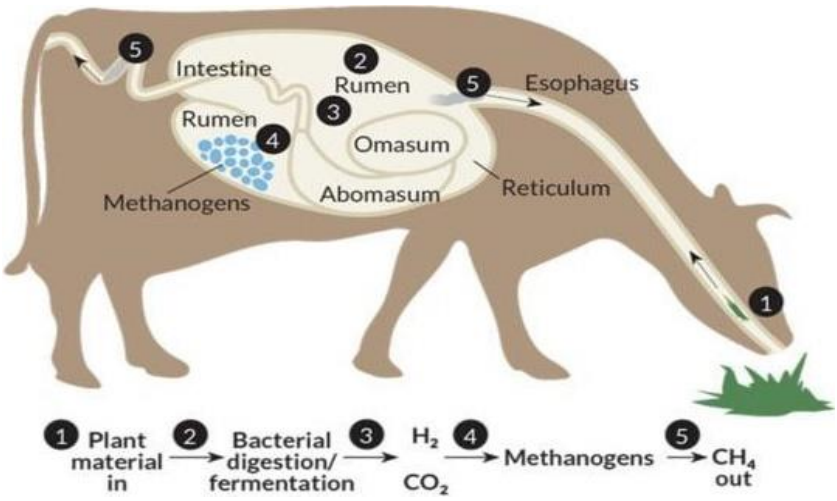



*Figure 3. Enteric fermentation and methanogenesis in ruminants [5].*

Methane produced by enteric fermentation accounts for 39.1% of total GHG emissions (Figure 1), and has a 28 times higher atmospheric warming potential than $CO_2$ [7]. In non-ruminants, methane production also takes place, but in incomparably smaller amounts. However, the amount of methane produced by ruminants is not constant, but is influenced by various factors (Figure 4).

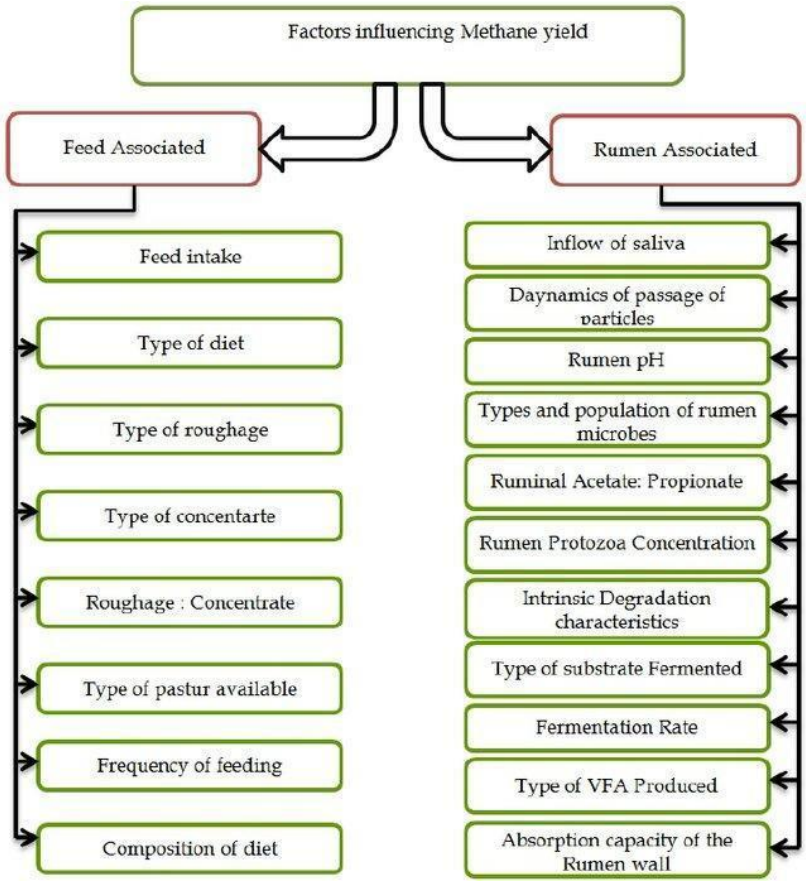



*Figure 4. Factors affecting methanogenesis in ruminants [8].*

The feed intake has the greatest influence on the emission, i.e. The amount of nutrients consumed as well as their quality. Thus, with the increase in feed digestibility, methane synthesis decreases and animal productivity increases. If animals consume more abundant meals, this is reflected in increased methane emissions. In addition, the health status of animals and the presence of feed additives can also have an impact on emissions.

It can be concluded that the ruminant species, the production system as well as the regional characteristics synergistically influence the speed at which food energy will be converted into methane [1].

Given the contribution of ruminants to $CH_4$ emissions and the negative impact of methanogenesis on productivity, it is necessary to find effective ways to reduce this process. So far, several strategies have been defined, generally related to dietary and management modulations, manipulations of rumen activity, and advanced strategies at the molecular and biochemical levels. This will be discussed in detail in a subsequent chapter.

## Manure Management

The ongoing intensification and specialization of livestock production is leading to an increase in the amount of manure which is a source of the greenhouse gases (GHGs) methane ($CH_4$) and nitrous oxide ($N_2O$). It is estimated that manure is responsible for nearly 10% of total greenhouse gas emissions [2]. Net emissions of these gases result from a variety of microbial activities in the manure [9]. Cattle and pigs represent the largest source of methane emissions from manure as it is showed in figure 5 [4; 10]. In contrast to enteric fermentation, which mainly releases methane, manure is also a substrate for the release of nitrogen oxides in addition to methane.

Figure 1 shows that the average contribution of methane and nitrogen oxide emissions from manure to total GHG emissions is 4.3% and 5.2%, respectively. The absolute and relative values of emissions of these gases from manure depend on environmental conditions (air temperature, humidity), the duration of storage and handling of the manure, and the type of animal feed. For example, the formation of methane is favorably influenced by anaerobic conditions, while both aerobic and anaerobic conditions are required for the formation of nitrogen oxides from ammonia [4].

It has been found that the greatest amounts of nitrogen oxides are released when manure is deposited in a solid state or spread on the ground [3]. This corresponds to an estimated 16.4% share of nitrogen oxide emissions for deposited/applied manure, as shown in Figure 1. Conversely, when manure is stored in a liquid state (lagoons), gas emissions increase in favor of methane [10].

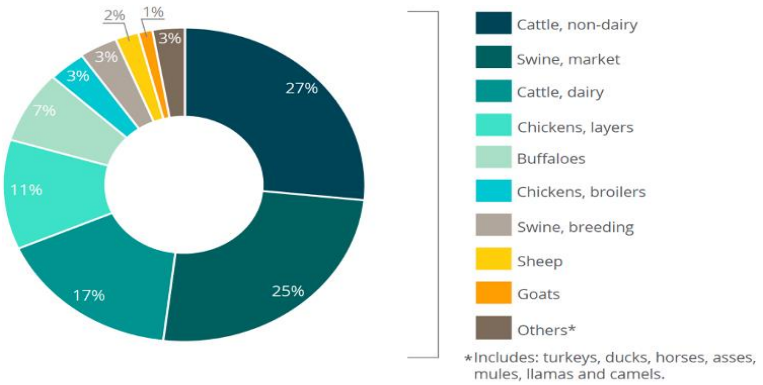



*Figure 5. Contribution of the different livestock sectors to emissions from manure [4].*

## Energy Consumption

Many production processes in animal husbandry require the use of energy, such as the production of fertilizers, the use of machinery, and the transportation of feed and livestock. On farms themselves, energy is required for heating/cooling, feeding, ventilation, lighting, milking, and manure management. Electricity is generally used for lighting, feeding, and milking systems, while fossil fuels associated with direct energy consumption are used for manure management and heating. The production of feed for livestock, as well as the production of animal products, also involves energy

consumption. It can be concluded that energy consumption in animal husbandry is concentrated in the production of feed, housing, and manure management.

The source of energy in animal husbandry is mainly fossil fuels, and its consumption represents another source of $CO_2$ emissions. It is estimated that the total energy consumption in the production cycle of animal products contributes about 25% of the total emissions in the livestock sector [1].

Throughout the production process, it is assumed that the production of animal feed (concentrates, canned feed, or pasture) represents the largest energy consumption [11]. Problematically, there are some analytical inconsistencies here, as energy consumption associated with feed production occurs off-farm and is generally not attributed to the livestock sector in official agricultural statistics.

Feed production, storage, and transportation are intensive processes that consume large amounts of energy associated with fuel, fertilizers, and pesticides. In addition, the production of animal products is generally energy inefficient, since a large part of the energy of the meal is spent on the maintenance of body structure (tissue regeneration) and physiological processes (heat losses), and less on the production of structures used in human nutrition [12]. Of all the parameters that influence energy consumption in livestock production, the most important are the species and type of animals, geographical location, agroecological conditions, and production system.

In relation to the breed and type (purpose) of livestock, Paris et al [13] found that energy consumption ranges from 2.1 to 5.3 MJ/kg per ECM in cow milk production, 59.2 MJ/kg for cow-calf system production, 15.9 MJ/kg to 22.7 MJ/kg in pork production, 9.6 MJ/kg to 19.1 MJ/kg in broiler production, 20.5 to 3.5 MJ/kg in egg production (Figure 6).

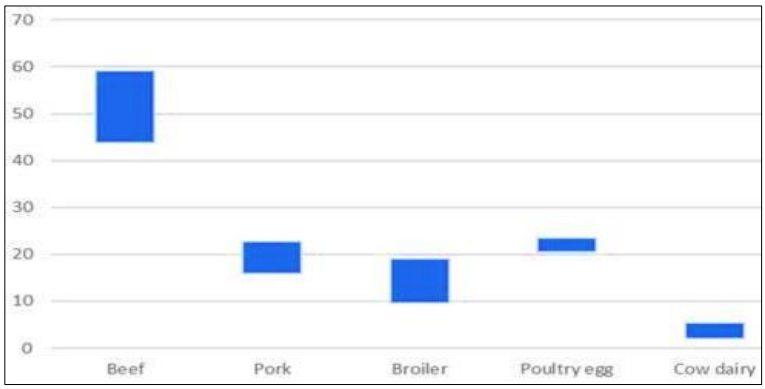



*Figure 6. Energy consumption in the production of animal products in relation to the type of livestock (MJ/kg) [13]*

In a meta-study by Paris et al [13], feed production dominated as an indirect energy input (75% of consumption) in all livestock systems (EU-27) except beef production (Table 1). Housing and feeding (mainly in the form of electricity) and manure management (mainly using diesel) account for the majority of direct energy consumption in beef production. In dairy farming, milking, milk cooling, and water heating accounted for most of the direct energy use. Here, there are differences in energy sources depending on the geographic location of the study, as some locations primarily use electricity for a particular purpose, while others use fossil fuels directly. Electricity use for water pumping, lighting, and other activities proved to be relatively low. According to the included studies, cattle farming was the most energy-intensive production system (per kilogram of meat), followed by pig and poultry farming.

In the coming years, the increasing intensification of agriculture will require a conversion of production methods in the livestock sector in order to contribute to environmental sustainability, i.e., to reduce the emission of harmful gasses. This would mean the conversion of livestock production to alternative and more sustainable production technologies based on ecological principles and greater use of renewable energy sources.

*Table 1. Intervals of energy inputs (low-high) for indirect (feeds) and direct consumption in different production systems (MJ/kg) [13].*

| Production System | Animal Feed | | Direct Energy Use | |
|---|---|---|---|---|
| | Low | High | Low | High |
| **Cow milk** | 1.11 | 4.40 | 0.54 | 1.76 |
| **Beef** | 17.34 | 27.23 | 9.36 | 31.97 |
| **Pork** | 11.60 | 16.41 | 2.60 | 11.10 |
| **Broiler** | 6.50 | 14.82 | 0.50 | 6.60 |
| **Egg** | 10.30 | 13.20 | 0.60 | 10.30 |

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# INDIRECT EFFECTS OF LIVESTOCK PRODUCTION ON GHG EMISSIONS

The production of animal feed has a significant impact on greenhouse gas emissions and is a major contributor to the overall carbon footprint of livestock production. These emissions include all three major greenhouse gases: $CO_2$, $N_2O$ and $CH_4$. Fertilizer and pesticide production for growing, processing and transporting feed, fuel use in production and associated land use changes are responsible for emitting the largest amounts of $CO_2$. $N_2O$ emissions come primarily from fertilizer use and manure application and, to a lesser extent, from the cultivation of forage legumes (e.g., alfalfa, clover, soybeans, peas, rice). The amount of $CH_4$ emissions from animal feed production is much lower than $CO_2$ and $N_2O$ emissions [1]. In addition, the production of animal feed is often associated with land use change due to the clearing of forests or other natural habitats, which may further exacerbate the climate change problem.

It is estimated that about 50% of emissions are from $N_2O$, which is generated from fertilizing forage crops and $CH_4$, which is generated from manure spreading on pastures. A quarter of the total emissions are related to changes in land use [1].

## Feed Production

The production of feed, its processing and its transport generates greenhouse gas emissions, which are estimated to account for about 45% of total emissions from livestock production [1]. Feed production in poultry (meat and eggs) and pig farming contributes 60-80% of GHG emissions and 35-45% for cattle (milk and meat) [2].

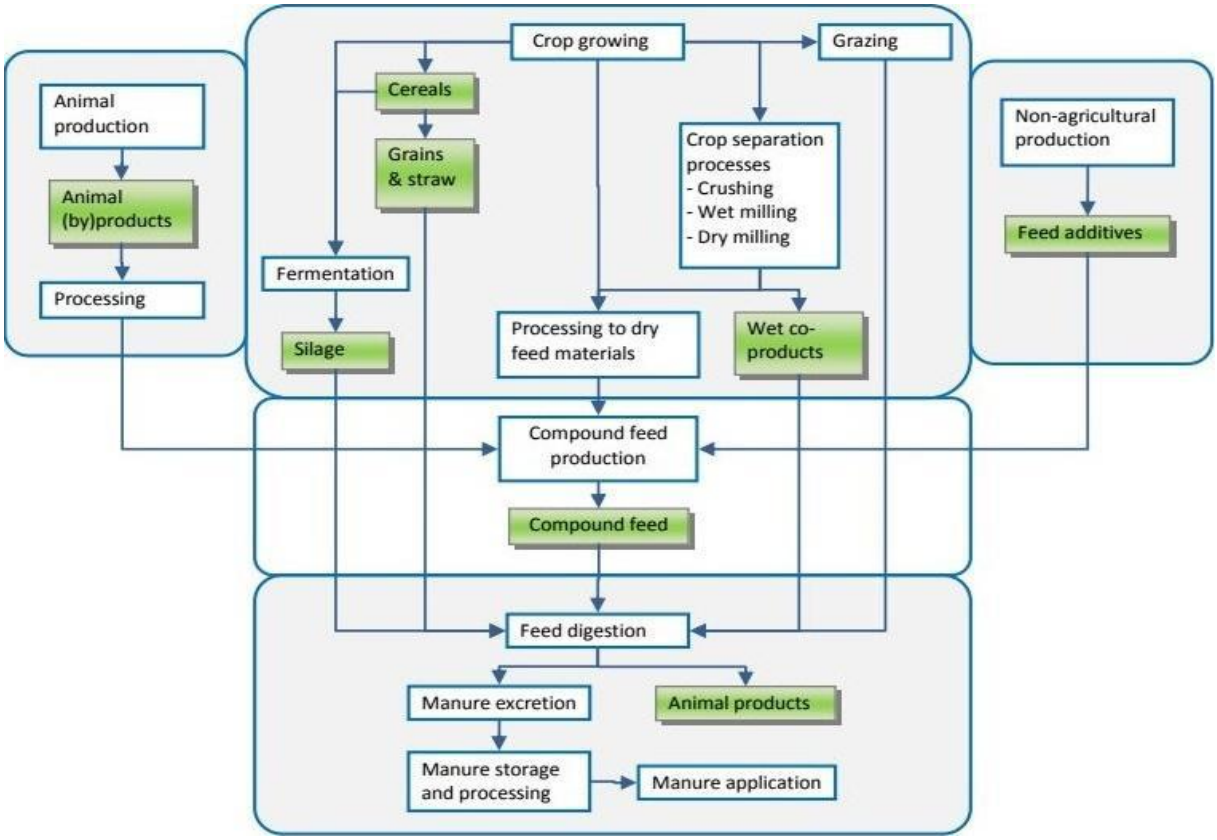



*Figure 1. Diagram of the entire process of production and utilization of animal feed (green fields represent animal feed) [5]*

The assessment of greenhouse gas emissions from livestock production has shown that the cultivation, processing and transportation of feed, as well as the efficiency of its utilization in the animal organism, are the most important factors influencing the amount of emitted gases [3].

The production of feed is a complex process consisting of a whole series of interconnected (horizontal and vertical) technological processes. At each stage of feed production, a certain amount of harmful gases is emitted. The peculiarities of agroecological conditions and feeding and rearing technologies contribute significantly to the differences in emission levels generated by feed production at regional and local levels. Therefore, the models used to evaluate this type of emissions are very complex, as it is necessary to include a large number of factors that are important for the analysis, as well as a large amount of information describing each of them [4].

Figure 1. shows a schematic representation of the whole production and processing process in the production of livestock feed. The variety of animal feeds is quite large. Some nutrients are consumed directly where they are grown, which is the case, for example, with grassland for grazing ruminants. In this case, there is no storage or transportation of nutrients and no corresponding emissions from these processes. In contrast, canned feeds, such as silage and hay, must be stored and in some cases processed, which affects the value of emissions from the production of these feeds.

Feed mixtures are multicomponent structures composed mainly of cereals and various additives and their production requires industrial processing. Even though most of the nutrients for feeding farm animals are based on agricultural products, modern animal husbandry often uses by-products of animal origin as well as synthetic substances such as vitamins, minerals, amino acids, enzymes, etc. The production of each of the above components consumes certain inputs and energy that affect greenhouse gas emissions. Storage and transportation are additional emission sources that occur between almost every phase in the structure shown in Figure 1.

In all links of the production chain, we can distinguish between inputs, activities and side effects, all of which have their own emission characteristics. Therefore, the total emission of a given link is the result of the inputs and activities used. Correct calculation and input data are required to calculate emissions.

In general, it can be said that in most cases, the total emission results from the emissions generated by the following feed production processes:

- cultivation of crops,
- transportation,
- storage,
- fertilization (use of manure, artificial fertilizers and crop residues),
- use of machinery,
- use of pesticides,
- industrial processing,
- use of fossil fuels and electricity,
- other,

For a better understanding of the technology of feed production and the corresponding GHG emissions, the sequence and interrelationships of the individual production processes are shown in Figure 2.

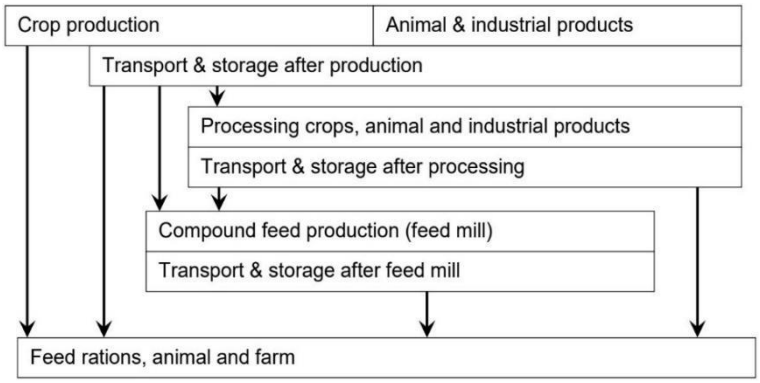



*Figure 2. Relations between procedures in animal feed production [4]*

Crop production includes both cultivation of crops itself and its connection with other links in the overall production chain: seed and young plant material production, fertilizer production and application, manure transport and placement, pesticide production and use, cultivation equipment production and maintenance, fossil energy use for cultivation activities, soil $N_2O$ and $CH_4$ emissions associated with N application and peat soil drainage, etc., Use and energy losses during storage prior to further use in industrial processing and the production of livestock mixtures [4].

A number of inputs such as fertilizers, pesticides and fuels are used to grow crops. Some of these inputs cause greenhouse gas emissions during the consumption phase, such as nitrogen, which causes nitrogen oxide emissions and fuels, which cause carbon dioxide emissions. Others, such as pesticides and phosphate or potash fertilizers, are not considered to cause GHG emissions during the consumption phase. The use of various machines for plowing, fertilizing, etc. requires energy consumption during use in agricultural production and causes associated GHG emissions. Table 1 shows the estimation of GHG emissions during the production of various forages such as grass, corn and alfalfa.

*Table 1. Estimated GHG emissions in the production of grasses, corn and alfalfa (in grams of $CO_2$-eq per kilogram of product) [4].*

| Product | Grass, Fresh | Grass Silage | Grass Dried | Maize Silage | Maize Dried | Lucerne, Fresh | Lucerne, Silage | Lucerne, Dried |
|---|---|---|---|---|---|---|---|---|
| DM content (g/kg) | 163 | 474 | 918 | 301 | 909 | 200 | 403 | 910 |
| GHG emissions (g $CO_2$-equivalents/kg) | | | | | | | | |
| Cultivation | 87 | 240 | 201 | 49 | 49 | 68 | 149 | 68 |
| Transport to process | | | 35 | | 35 | | | 35 |
| Allocation factor | | | 3.39 | | 3.39 | | | 3.39 |
| From cultivation (including allocation) | | | 682 | | 166 | | | 231 |
| Processing (drying) | 0 | 0 | 1168 | 0 | 1157 | 0 | 0 | 1168 |
| Total of cultivation, processing and transport (sum of above) | | | 1885 | | 1358 | | | 1434 |
| Transport to feed mill | | | | | | | | |
| Feed mill | | | | | | | | |
| End of feed mill | | | | | | | | |
| Transport to farm | 0 | 0 | 10 | 0 | 10 | 10 | 10 | 10 |

As mentioned earlier, the carbon footprint of animal feed can vary depending on a number of factors, including the type of feed, the production methods used and the geographic location of feed production. However, there are some types of feed that have a larger carbon footprint than others. One of the main factors contributing to the carbon footprint of feed production is the use of nitrogen-Based fertilizers [1, 4, 7]. These fertilizers are typically used in the production of crops such as corn, soybeans and wheat to increase the yields of these crops.

Nitrogen fertilizer production is very energy-intensive and can release nitrous oxide, a potent greenhouse gas whose warming potential is about 300 times greater than that of carbon dioxide [4, 7]. In addition, the production and transportation of nitrogen fertilizers themselves also contribute to greenhouse gas emissions. Consequently, food crops that require large amounts of nitrogen fertilizer tend to have a larger carbon footprint [8].

Greenhouse gas emissions per ton of nitric acid vary from 2.8 t $CO_2$ eq/t nitric acid in Europe, North America and the rest of the world to 3.6 t $CO_2$ eq/t nitric acid in China and India. It is important to note that in the application of synthetic fertilizers, three types of nutrients are distinguished: N, P and K, with zero GHG emissions from the application of phosphorus and potassium [4].

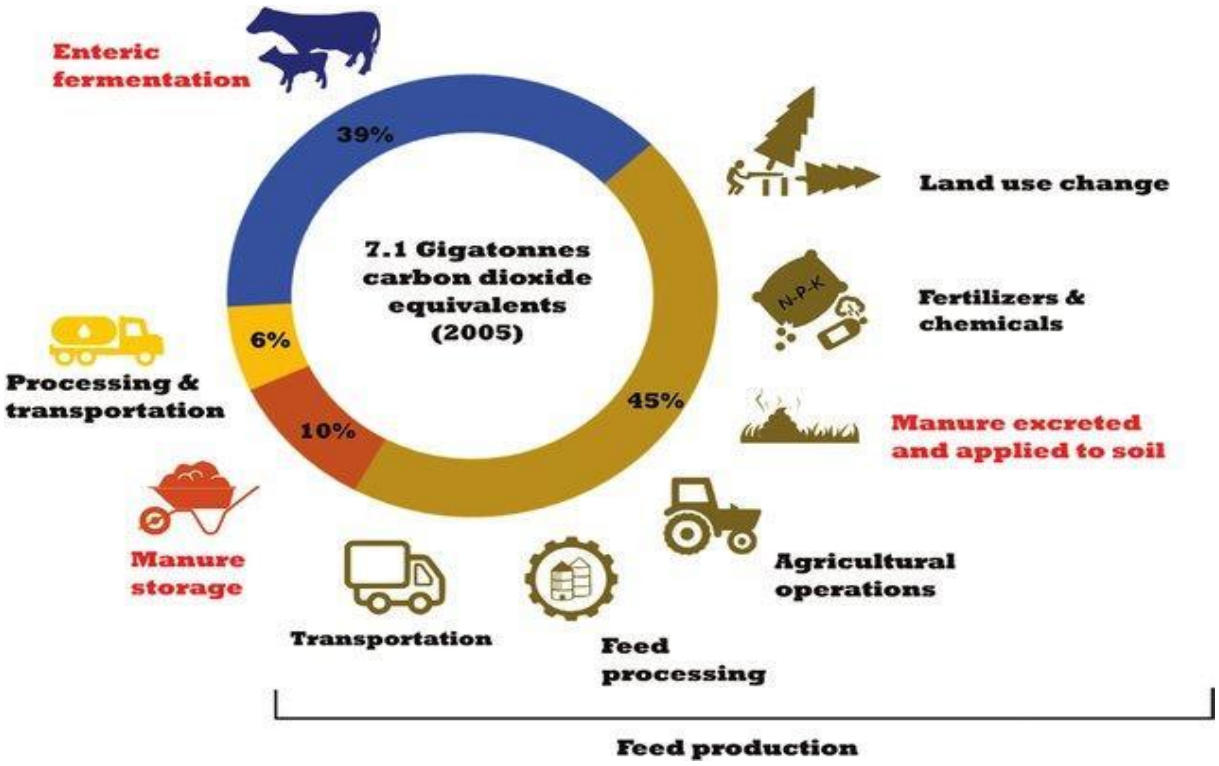



*Figure 3. Contributions of emissions from different processes in the production of animal feed and direct emissions (words in red) [1, 8].*

Soil organic matter can be maintained only by a constant supply of fresh organic matter from crop residues, green manures and animal manures.

Manure is an important source of organic matter, especially on cropland. However, the application of manure as fertilizer for forage crops and its deposition on pastures causes a significant amount of nitrogen oxide emissions, accounting for about half of these emissions [9]. When animals are kept on pastures, their excreta (urine and feces) are disposed into the soil. Therefore, GHG emissions from grazing should be counted as part of total GHG emissions from animal products.

When manure is applied in large quantities, the high N content can have negative effects. This manifests itself in high levels of nitrate leaching and ammonia emissions and thus eutrophication and acidification. When manure is applied to grassland or cropland, it (partially) replaces the use of synthetic fertilizers (N, P and K), and theoretically emissions from the production of synthetic fertilizers can be avoided [4].

Although feed production often leads to increased nitrogen concentrations in agricultural soils, good manure management can reduce the need for artificial fertilizers.

Feed is often transported long distances to the animals that will consume it. This transportation results in greenhouse gas emissions, particularly $CO_2$ and nitrogen oxides emitted by trucks and other vehicles. Emissions resulting from the transport of feed and its components vary widely, but the recommendation of Welling et al [4] is an implementation of a unique standardized calculation method independent of the components that make up the feed. Blonk et al [5] also report variations in the contribution of GHG emissions from transportation to total GHG emissions in beef production. These authors found that for beef production in the cow-calf system in Ireland, the contribution of transport to total GHG emissions was less than 4%. Pork production contributed four times more to total emissions (16%).

Emissions from fossil fuels and electricity in feed production occur at almost all stages of production but are still mainly associated with transportation and operation of machinery [4, 8]. Fossil fuels are generally used to transport feed and the inputs used in its production (to power trucks, ships and other

transport vehicles). Greenhouse gas emissions are primarily caused by the combustion of these fuels, directly releasing $CO_2$. This can be particularly significant for inputs and feeds that are produced in one part of the world and then transported long distances to feed mills, warehouses, or farms. In addition to these combustion emissions, greenhouse gas emissions (including methane and $N_2O$ emissions) are generated during the production and transportation of these fuels, the production of capital equipment and the production and operation of the distribution network [4]. The contribution of associated emissions can range from 5% to nearly 40% of emissions from combustion alone [5]. Electricity is generated from fossil fuels and other energy sources such as nuclear power and hydropower. The combination of energy sources for electricity generation is different for each power system. The efficiency of converting fossil energy into electricity varies depending on the type of technology used [4].

Industrial feed processing can have a significant impact on greenhouse gas (GHG) emissions, both directly and indirectly. Direct impacts mainly relate to the consumption of electricity and fossil fuels associated with the use of industrial machinery and mechanization in the technological processes of processing and production and to the transportation of feedstock and nutrients. In addition, GHG emissions generated at other stages of feed production may be closely related to emissions generated during industrial processing (e.g., production of additives, supplements, enzymes, etc.). As an example, the production of one kilogram of the synthetic amino acid threonine leads to the emission of 16978 grams of $CO_2$-eq [4]. In this context, it is important to mention the influence that the use of industrially processed feeds can have on the properties of manure. Namely, the more nutrient-rich composition of such feeds is also reflected in the properties of manure, which can lead to increased emissions of $CH_4$ and nitrogen oxides ($N_2O$). It can be concluded that within the animal feed production sector, the industrial processing stage is an important area in efforts to reduce the carbon footprint.

In summary, feed production has a significant impact on greenhouse gas emissions and efforts to mitigate climate change must address this issue. Strategies to reduce the carbon footprint of feed production can include increasing the efficiency of fertilizer use, promoting sustainable land use practices and shortening transportation distances of feed crops and other inputs. Ultimately, a holistic approach that encompasses the entire livestock supply chain is needed to reduce greenhouse gas emissions and mitigate the effects of climate change.

## Land Use Change

Agricultural land occupies almost 40% of the total land area of which about 60% is for feeding livestock [10]. Due to the projected population growth, the demand and consumption of livestock products is expected to increase. This would inevitably lead to an increased demand for arable land needed to grow crops used to feed livestock. This is a process whose scenario is already known from a historical point of view, since the intensification of all agriculture, including animal husbandry, has been taking place since the beginning of the 20$^{th}$ century. The negative side of this process is certainly the change in land use, which mainly refers to the conversion of forests and grasslands into arable land for feed production. This may lead to an increased release of carbon dioxide into the atmosphere, while on the other hand, the process of carbon dioxide absorption and storage becomes disabled. In summary, in this way, the balance of the carbon cycle in nature is disturbed, which in modern conditions of accelerated industrialization has disastrous effects on the environment, especially in terms of climate change.

Namely, through the process of photosynthesis, plants absorb carbon dioxide from the atmosphere and store it in above-and below-ground biomass. It is important to emphasize that forest land has a better ability to absorb carbon compared to cropland and pasture, making it the main reservoir along with the ocean (Figure 4).

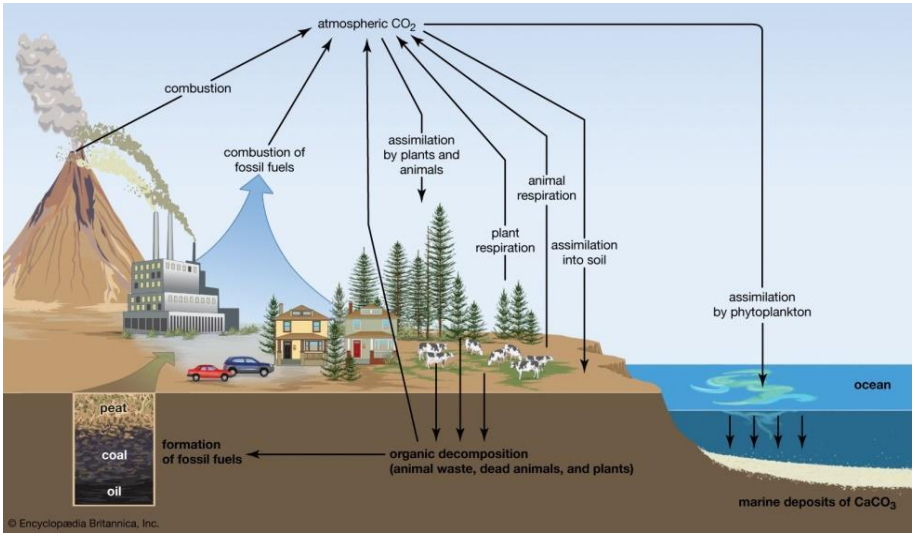



*Figure 4. Carbon cycle [11]*

Conversion of forest land to cropland and pasture results in a large amount of stored carbon being released into the atmosphere. According to the literature, several methods have been developed to estimate GHG emissions caused by land use change, but there is still no consensus among scientists on their reliability. Table 2 shows a comparison of emission values obtained by different selected assessment methods [7].

*Table 2. GHG emissions due to land use change (gray fields)-comparison of different assessment methodologies [4]*

| | **Wheat France** | **Soy Bean Brazil** | **Rape Seed Germany** | **Palm Fruit Malaysia** |
|---|---|---|---|---|
| N input organic manure (kg/ha) | 29 | 41 | 62 | 27 |
| N input synthetic fertilizer (kg/ha) | 119 | 3 | 200 | 130 |
| yield main product (kg/ha) | 6565 | 2442 | 3610 | 21300 |
| yield co product (kg/ha) | 3764 | 0 | 0 | 0 |
| Allocation emissions to main product (-) | 0.78 | 1 | 1 | 1 |
| GHG main product (g/kg) | 337 | 477 | 1032 | 604 |
| Land Use Change emissions | | | | |
| Feed Print (based on 1180 kg/ha) (g/kg) | 141 | 483 | 327 | 55 |
| Audsley et al. (2010) (1430 kg/ha)* (g/kg) | 171 | 585 | 396 | 67 |
| FAO (2010) (g/kg) | 0 | 7690 | 0 | - |
| Leip et al. (2010) (g/kg) | 35 | 1099-1207 | 153 | - |

Even though land use change in modern times has already contributed significantly and negatively to climate change, research shows that improvements are still possible [1, 8]. According to the Intergovernmental Panel on Climate Change (IPCC) [12], timely and continuous implementation of improved agricultural practices and forestry measures is important for mitigating climate change, as they can contribute significantly to the removal of carbon dioxide from the atmosphere. First and foremost, this includes improved management of cropland and pasture-for example, more efficient use of fertilizers to prevent leaching of unused nitrates, tillage practices that minimize soil erosion, restoration of organic soils and restoration of degraded soils.

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# MITIGATION STRATEGIES FOR GREENHOUSE GAS EMISSION

In previous chapters, it was already mentioned that livestock production is a significant source of greenhouse gas emissions, participating 14.5% of total anthropogenic emissions [1]. Greenhouse gases (GHGs) retain heat in the Earth's atmosphere, leading to rising temperatures and other climate changes. Therefore, mitigating greenhouse gas (GHG) emissions from livestock is crucial to combat climate change and reducing the associated risks, environmental degradation, protecting ecosystems and biodiversity, improving public health and economic stability and promoting a more sustainable and equitable future for all. While adaptation efforts are also crucial, mitigation remains the most effective way to address the root causes of these challenges, as the livestock sector is a significant contributor to global emissions. Regarding this, the EU strategy entitled "carbon farming" is gaining more and more importance in recent years. It focuses on managing both land and livestock through the management of soil carbon stocks, materials and vegetation, greenhouse gas (GHG) flows at the farm level, with the aim of mitigating climate change. "Carbon farming" includes practices and changes in land use that produce one or more of the following outcomes: 1) carbon capture (sequestration) and subsequent storage in biomass above/underground and in agricultural land, 2) avoiding future $CO_2$ and other GHG emissions, and/or, 3) reduction of existing $CO_2$ and other GHG emissions.

Since livestock GHG emissions vary significantly between production systems and regions, Gerber et al. [1], believe that the potential for mitigation lies in the gap between management practices resulting in the lowest and highest emission rates. By implementing practices currently used by the top 25% of producers with the lowest emission intensity, emissions from the livestock sector could be reduced by 18%. Furthermore, if techniques employed by the top 10% of producers were adopted, emissions could be reduced by 30%.

The animal production industry is responsible for anthropogenic greenhouse gas emissions, but at the same time, it has significant potential for mitigation. Contemporary scientific literature provides a wealth of data on possible measures to mitigate climate change from the aspect of animal husbandry. In order to briefly present the main of them, a summarize of mitigation strategies by Grossi et al. [2], is given in Table 1.

*Table 1. Mitigation potential of the main strategies in livestock production (without consideration of land resources) [2].*

| Strategies | Category | Potential Mitigating Effect* | |
|---|---|---|---|
| | | Methane | Nitrous Oxide |
| Enteric fermentation | Forage quality | Low to medium | † |
| | Feed processing | Low | Low |
| | Concentrate inclusion | Low to medium | † |
| | Dietary lipids | Medium | † |
| | Electrons receptors | High | † |
| | Ionophores | Low | † |
| | Methanogenic inhibitors | Low | † |
| Manure | Solid-liquid separation | High | Low |
| | Anaerobic digestion | High | High |
| | Decreased storage time | High | High |
| | Frequent manure removal | High | High |
| | Phase feeding | ‡ | Low |
| | Reduced dietary protein | ‡ | Medium |
| | Nitrification inhibitors | ‡ | Medium to high |
| | No grazing on wet soil | Low | Medium |
| | Increased productivity | High | High |
| Animal management | Genetic selection | High | ‡ |
| | Animal health | Low to medium | Low to medium |
| | Increase reproductive eff. | Low to medium | Low to medium |
| | Reduced animal mortality | Low to medium | Low to medium |
| | Housing systems | Medium to high | Medium to high |

**High=≥30% mitigating effect, Medium=10-30% mitigating effect, Low=≤10% mitigating effect. †Inconsistent/variable results. ‡Uncertainty due to limited research or lack of data.*

## Land Resource Management

Land resource management can be key to mitigating the environmental impact of livestock. Mitigation strategies that rely primarily on improvements in land management are thought to be far more effective than those that primarily focus on reducing emissions from livestock [3]. The same authors suggest that switching to more efficient and less demanding livestock systems can significantly reduce emissions. For example, it is known that raising cattle in feedlots results in lower emissions compared to pasture systems. However, by applying adequate measures in the management of pastures and livestock production, it could contribute up to 7% of the global mitigation potential from the impact of agriculture by 2030 [4].

Strategies that could be implemented include practices based on the principles of regenerative agriculture and carbon farming. The mentioned practices basically rely on carbon sequestration.

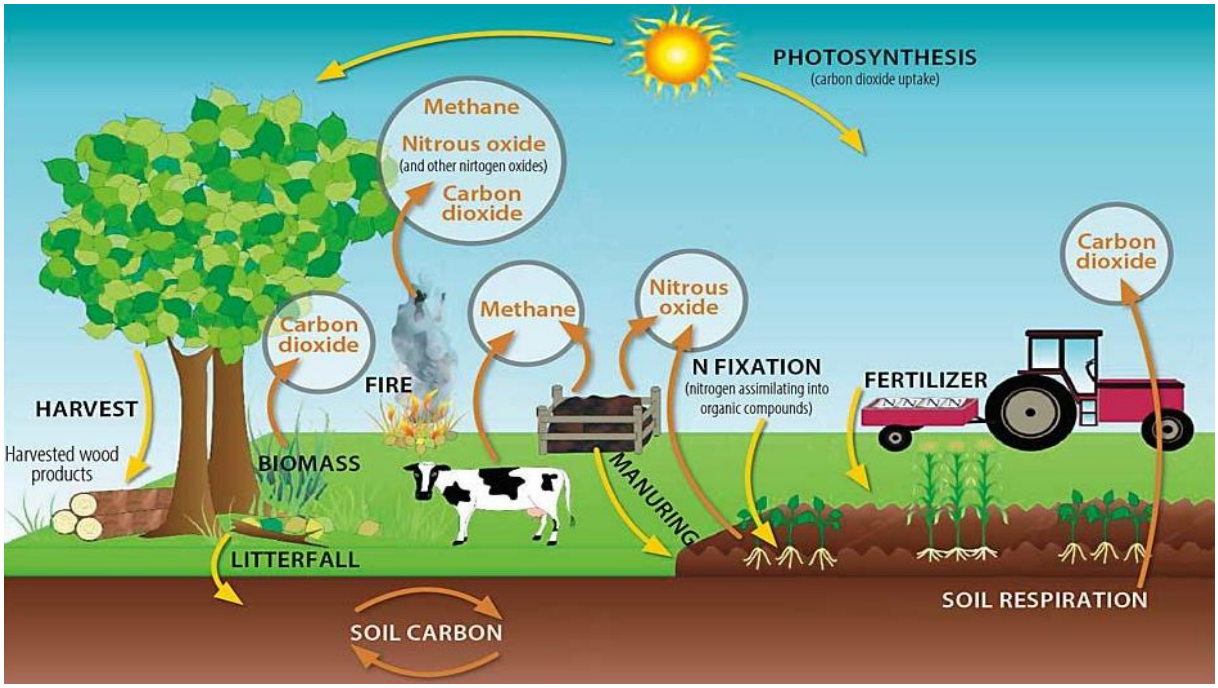



*Figure 1. The main greenhouse gas emission sources/removals and processes in managed farmland [5].*

Carbon sequestration is the process of capturing carbon dioxide from the atmosphere and storing it in the land. It has been estimated that soil under crops and pastures can store up to 8.6 gigatons of carbon dioxide per year [5]. Therefore, improvements in the management and utilization of agricultural areas (pastures, fields, etc.) that result in effective carbon sequestration in the soil can mitigate the impact of livestock systems on the environment. By applying different agricultural practices-commonly called "regenerative agriculture" and "carbon farming"-it is possible to create new or increase existing carbon sinks:

•Practices to increase productivity: fertilization, irrigation, use of productive perennial grass species, presence of legumes

•Production of crops with higher yields, which can reduce the need for additional land use and help protect existing forests and grasslands. This can also lead to increased carbon sequestration, as more carbon is stored in plant biomass and soil.

•Converting arable land into grasslands and improving the floristic composition of grasslands contributes to carbon sequestration by improving soil health and promoting the growth of plants with deep roots that can store more carbon in the soil. This can additionally have a positive effect on reducing erosion and improving water quality.

•Conservation-reduced tillage (shallow ploughing), which reduces soil degradation during crop production and prevents excessive release of carbon into the atmosphere.

•Application of practices used in organic and sustainable agriculture, such as covering crops, applying compost, etc. which are in principle close to the principles of regenerative agriculture

•Reduction of deforestation due to their significant role in the process of carbon sequestration and ensuring the ecological balance

•The application of "silvopasture" as a form of agroforestry is the practice of grazing domestic animals on areas with integrated trees within the framework of cultivated fodder plants. In addition to the benefits of trees on grassland fertility and soil carbon sequestration, feeding tannin-rich leaves can reduce methane emissions in ruminant guts [6].

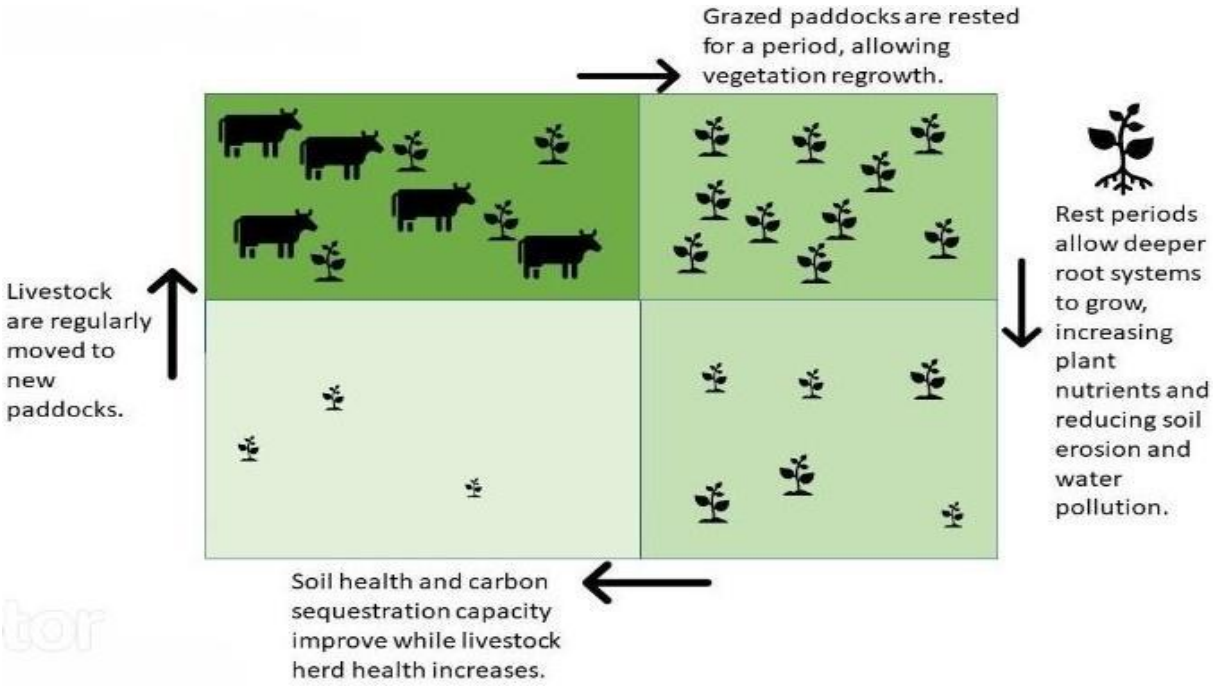



*Figure 2. Advantages of rotational grazing system [7].*

•Improving the management of grazing lands has the potential to capture approximately 0.15 gigatonnes of carbon dioxide equivalent per year on a global scale [8]. The application of the rotational grazing system, reflects favorably not only on the preservation of pasture quality, but through higher productivity and better root growth, a greater accumulation of organic matter (carbon) is ensured. In addition, sequestration on such pastures can be increased by applying measures of regenerative agriculture, by adding compost, for example. Here, however, it is important to point out that the sequestration effect achieved in this way is not permanent but is measured over years or decades. It is certain, therefore, that at some point the gas emission will exceed its deposition in the soil and this grazing system will again become a source of emission

•Sustainable management of agricultural residues can bring double benefits-increasing the carbon sink through the decomposition of plant residues on the soil and reducing the emission of greenhouse gases through the use of the remaining biomass for the production of bioenergy instead of fossil fuel [9].

## Enteric Fermentation Management

Reducing methane emissions from ruminants is a significant challenge in the ruminant production sector. Various strategies have been suggested to address this issue, which can generally be divided into four categories:

1) dietary manipulation,

2) feed additives,

3) vaccines and,

4) genetic selection,

These options have different levels of effectiveness in reducing methane emissions, as shown in Table 1. The focus is on improving rumen fermentation efficiency and increasing animal productivity to reduce methane emissions.

## Dietary manipulation

The quality and digestibility of forage have a significant impact on enteric methane production. Along with the maturation of plants, there is an increase in the content of lignin, which reduces their digestibility. Harvesting forage, particularly grass, at an earlier stage of maturity for ensiling can increase the soluble carbohydrate content and reduce lignification. Practices aimed at improving forage quality have shown a potential reduction in enteric methane of about 5% per unit of fat protein corrected milk, according to Knapp et al. [10]. Physical processing of forage-chopping, grinding and steaming, also improves their digestibility and alleviates methane production in the intestines of ruminants [11]. However, the potential of such emission reduction is not significant, i.e. is less than 2% per unit 4% m.m. corrected milk [10].

Increasing the proportion of concentrate in ruminant rations to improve diet digestibility is another effective strategy for mitigating methane emissions. According to Knapp et al. [10], this approach can significantly reduce methane emissions-as much as 15% per unit of 4% m.m. of corrected milk with a proportion of concentrate of 35-40%. However, simultaneously with the increase in the proportion of concentrated nutrients (fermentable carbohydrates) in meals, the risk of developing metabolic diseases such as rumen acidosis also increases [1].

Therefore, it is important to carefully consider the ratio of bulk and concentrated nutrients when implementing this strategy.

Addition of fat or fatty acids to ruminant diets can reduce enteric methane emissions by reducing the proportion of energy from fermentable carbohydrates and altering the microbial population in the rumen [12]. Some by-products such as cottonseed, brewer's grains and cold-pressed canola meal have been proven effective in reducing enteric fermentation [13]. Dietary lipid supplementation at a level of 5% to 8% of dry matter intake is an effective strategy for mitigating methane emissions, as reported by Grainger and Beauchemin [14]. In this way, the emission of enteric methane can be reduced by about 15% per unit of 4% m.f. corrected milk [10].

However, the mitigation potential of high-oil by-products is still understudied. In some cases, methane production may increase due to increased fiber intake [11]. Inclusion of lipids higher than 10% can disrupt rumen function by altering the microbial population, which reduces fiber digestibility. This potentially leads to increased excretion of organic matter and nutrients, as well as methane emissions from manure. Addition of lipids can also adversely affect rumen fermentation, milk fat synthesis and fatty acid composition. Meals with a higher content of oil and oilseeds reduce feed intake and fiber digestibility, so they are generally not recommended in the diet of younger and fattening ruminants. On the other hand, their use can be stimulating in lactating animals [15, 16]. When considering the use of oil for emission reduction, it's important to take into account that the production of oilseeds is associated with a significant increase in upstream GHG emissions per kg of dry matter [16].

## Feed additives

The most commonly used food additives with the ability to modify rumen biochemical processes in the direction of methanogenesis suppression are phytobiotics, probiotics, organic acids and ionophores [17, 18]. Although a significant number of previous studies have shown the effectiveness of their use, for wider application, more extensive research is needed to rule out side effects such as possible toxicity and associated health risks.

The inclusion of secondary metabolites from medicinal and aromatic plants (MAPs) in the diet of ruminants leads to a significant modulation of the rumen microbiome, favoring the growth of beneficial microorganisms and inhibiting methanogenic microbes [19]. These so-called phytobiotics alter rumen fermentation patterns by stimulating the synthesis of propionate and other volatile fatty acids, while limiting the hydrogen required for methanogenesis. This metabolic redirection further contributes to the reduction of methane emissions. Finally, certain metabolites act antimicrobially, which is another direct way of inhibiting methanogenesis [20].

The most significant secondary metabolites present in plants that are important for reducing methane emissions are: essential oils, saponins, tannins, polyphenols and flavonoids.

Essential oils can affect fermentative processes in the rumen resulting in reduced $CH_4$ production in vitro. Some studies have given promising results with a reduction of methane emissions up to 90% [21]. Essential oils are thought to remodel the gut microbiome in a way that reduces methanogenic microorganisms [22]. The suppressive effects of certain extracts and essential oils can be attributed to their toxic nature, which leads to a decrease in the population of microorganisms in the rumen, microbial fermentation and methanogenesis [23]. The mechanism of this action is still not completely clear, so for the adequate use of essential oils in the suppression of methanogenesis, it is necessary to conduct more extensive research in in vivo conditions.

Other bioactive compounds in plants-saponins, tannins, polyphenols, flavonoids, etc., mainly act as a mechanism of inhibition of methanogenic microbes in the gastrointestinal system of ruminants. Thus, saponins inhibit proteolytic ciliated protozoa and, through defaunation, indirectly contribute to the reduction of $CH_4$ emissions. Tannins exert their action by inhibiting hydrogen-synthesizing microorganisms, as well as by suppressing methanogens [17]. It is considered that the potential of flavonoids in mitigating $CH_4$ emissions is also significant, but more extensive research in in vivo conditions is necessary.

Starting from saponins as defaunations of protozoa and tannins as methano-inhibitors and suppressors of $H_2$ production during fibrolysis, some research has addressed the effects of these plant compounds on methanogenesis in ruminants. A study by Antonius et al. [23], showed that supplementation of *M.oleifera*, *C.longa* Linn., and *P.timoriana* in ruminant diets effectively increased total gas production, digestibility of dry matter and organic matter and reduced $CH_4$ gas emissions and protozoan populations during rumen fermentation.

Other bioactive compounds from plants, such as polyphenols and flavonoids, may also be useful in an anti-methanogenesis strategy in the rumen. In vitro study by Jo et al. [26], showed that adding extracts (containing polyphenols and flavonoids) from oriental MAPs (*Vitis vinifera* L. and *Rhus succedanea* L.) to ruminant diets can reduce methane production and the presence of methanogenic archaea.

A study by Rossi et al. [27], showed that a combination of essential oils, bioflavonoids and tannins reduced methane production by 8 to 22% *in vitro*. Optimum product concentrations for 24 hours were 0.0025-0.005% DM in liquid form. In an in vivo study, this mixture was observed to improve milk production, feed digestibility and feed conversion rate. These findings suggest that natural products such as essential oils, bioflavonoids and tannins have the potential to reduce methane production while improving dairy cow performance. Further validation in in vivo trials could lead to a reduced environmental impact of lactating cows.

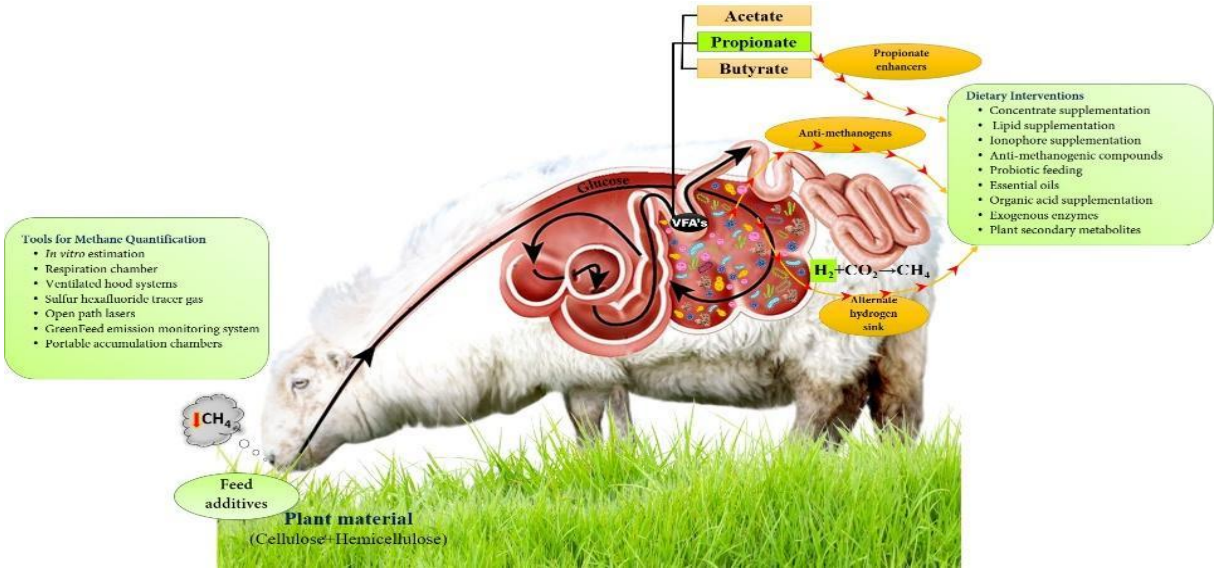



*Figure 3. Dietary manipulation methods and their mode of action on emission reduction [25].*

Seaweeds contain compounds (polysaccharides, proteins, peptides, lipids, phlorotannins, saponins and alkaloids) that reduce $CH_4$ production by suppressing archaea and protozoa. Experiments in which cattle were fed algae showed a noticeable reduction in methane emissions while simultaneously improving production performance. Among the compounds found in algae, bromoform ($CHBr_3$) exhibited the highest level of effectiveness in inhibiting methanogenesis [23].

Organic acids are commonly incorporated into domestic animal diets for multiple reasons. They enhance the acidity of the feed, preventing spoilage such as in silage. This improved pH level stimulates digestion and nutrient absorption, while also maintaining a healthy balance of microorganisms in the digestive system [23]. Formic acid, when used at lower doses, reduces overall gas production, but higher doses can have the opposite effect [28]. Both formic acid and fumaric acid exhibit significant inhibitory effects on gas production.

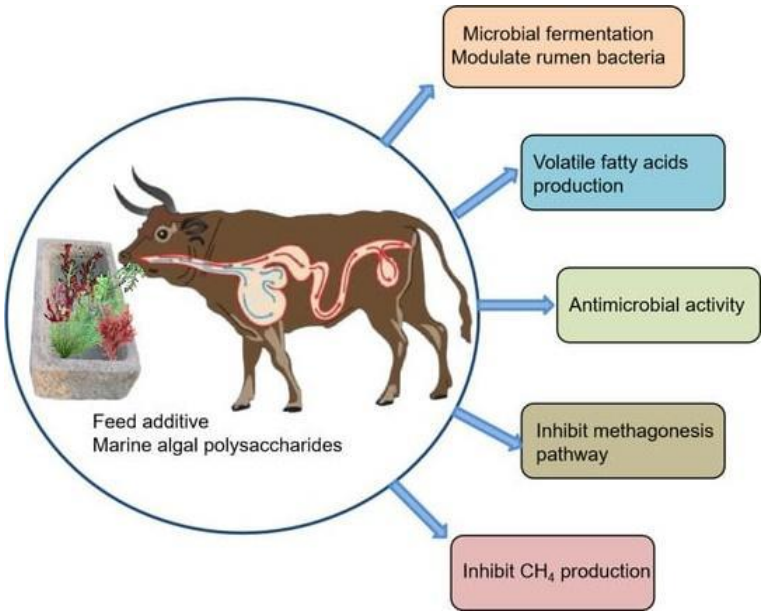



*Figure 4. Marine Algal Polysaccharides as Methane-Reducing Feed Additives [20].*

Ionophores are commonly used as additives in livestock feed to improve utilization efficiency and body weight. These compounds act as $CH_4$-inhibiting factors promoting the growth and proportion of Gram-positive bacteria in the rumen increasing propionic acid. Studies have shown that the use of ionophores, especially monensin, can lead to significant reductions in $CH_4$ production in livestock.

Holstein cows treated with monensin showed a 24.3% decrease in $CH_4$ production [29] while in Angus steers there was a 30% decrease in enteric $CH_4$ production [30]. The $CH_4$-reducing effect of monensin is attributed to changes in the production of volatile fatty acids in the rumen. It is important to note that excessive ionophore supplementation can be toxic to ruminants and that their residual levels in animal products should be monitored.

Probiotics are additives based on bacterial and/or yeast cultures. Introduced into the body, they achieve many benefits (on health, reproduction, production) and are increasingly being considered as a tool in the fight against methane emissions through the manipulation of the gastro-intestinal microbiome. The mechanism of their suppressive effect on methanogenesis is based on the fact that they direct fermentative processes towards the production of propionate. This reduces the concentration of hydrogen as a key precursor for methane synthesis.

In a recent in vitro experiment, Chen et al. [31], found that certain strains of propionic acid bacteria (*Propionibacterium jensenii* LMGT2826, *Propionibacterium thoenii* LMGT2827 and *Propionibacterium thoenii* T159) reduced $CH_4$ emissions by 18%, 8% and 20% compared to the control.

## Vaccines

The goal of such vaccines is to trigger the animal's immune response and the creation of antibodies with a suppressive effect on methanogen activity.

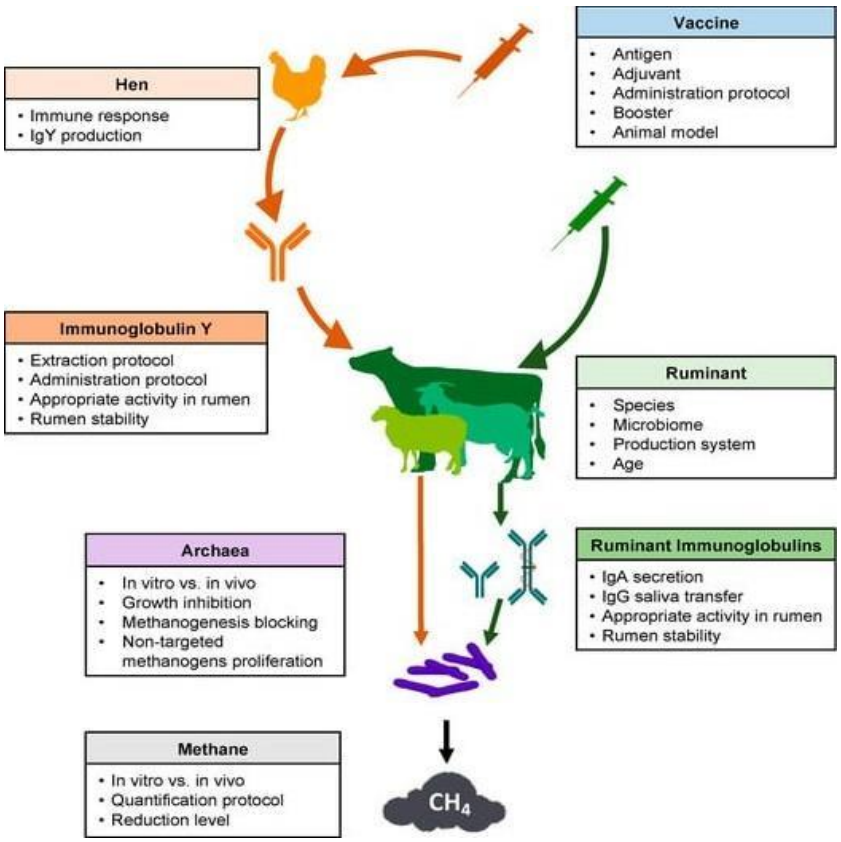



*Figure 5. Key Considerations for Methane-Reducing Vaccines in Ruminants [32].*

After the synthesis of antibodies in the animal's blood and saliva, they continuously pass through the saliva into the rumen, where they exert their effect. After vaccination, the mechanism of antibody synthesis once initiated should provide a suppressive effect on methanogenesis for a long period. The use of vaccines to reduce $CH_4$ production in ruminants has been suggested as a promising strategy, but its effectiveness is difficult to evaluate due to the lack of comprehensive studies. The variety of methods used in different studies also makes comparison of results challenging. Further research is needed to determine the feasibility, practical implementation and sustainability of this strategy,

including considerations such as antigenic capacity, Igs in saliva and how to accurately measure $CH_4$ production [32]. According to the researchers' current estimates, the first vaccines are not expected to be administered before 2030.

## Genetic selection

The use of genetic selection as a strategy for methane emission reduction could be briefly defined as the selection and favoring of individuals with a desirable genetic code in terms of reduced methane production and emission. This strategy might not give quick results, but in the long run it can be very effective because it allows for cumulative and lasting changes. The problem in its application primarily lies in the fact that it is necessary to generate databases on methane emissions in animals, while currently only a few countries actively record them. Additionally, comprehensive genomic reference databases as well as precise genetic indicators for $CH_4$ emission traits need to be developed [16]. In previous research, a higher heritability of methane emission traits was found in sheep (0.24-0.55) compared to dairy cows (0.11-0.33).

When choosing traits that would be emission indicators, the most suitable are: infrared (IR) spectrum of milk, rumination time, feed efficiency and rumen microbiome composition [33]. Recent research on a large sample of over 200,000 cows has confirmed that the wavelengths of the IR spectrum of milk are heritable [34]. This indicates that it would be possible to use genetic covariance between informative spectral wavelengths and methane emissions. Accordingly, milk volatile fatty acids have also been proposed as potential indicators for methane production. Another trait that has attracted significant interest as a potential indicator for emission reduction is the rumen microbiome. Difford et al. [35], conducted a study on 750 Holstein cows using 16S rRNA ribotyping and found that certain bacteria and archaea were associated with methane production and that there was significant heritability. Another study using nanopore technology to assess the whole metagenomes of 334 dairy cows revealed genetic correlations between methane concentrations and different genera of protists, archaea, anaerobic fungi and bacteria. The mentioned studies emphasize the potentially important role of the rumen microbiome in understanding and mitigating methane emissions. Ten years of research by Rowe et al. [36], confirmed a significant correlation between genetic material and $CH_4$ yield in sheep. Genetic selection, i.e. favoring genotypes with lower methane emissions, resulted is economically advantageous: ewes with a lower $CH_4$ yield (12% difference), weaned heavier, meatier lambs with a higher wool yield.

In considering genetic selection as a strategy to reduce $CH_4$ emissions, it is important to consider its effect on productivity. It was found that with increasing productivity, emission intensity decreases, but this effect is more pronounced in low-productive individuals [18]. However, the selection of low-emission animals should also take into account the possible impact on feed utilization efficiency, especially in terms of NDF digestion, which is important in feed production. Factors such as digestion rate, feed rate, rumen microbiome and rumen fermentation can influence both feed utilization efficiency and $CH_4$ emissions [16].

Unilateral selection to reduce methane emissions is unacceptable from the point of view of animal husbandry. Therefore, the question of its relationship with other traits that are of selection importance arises. Based on current knowledge, it is unlikely that selection for reduced methane emissions in ruminants would have significant effects on other traits such as reproduction and health. However, there is evidence of a relationship between methane production and milk production, as well as dry matter intake (DMI). Additional analyzes on larger datasets are necessary to further explore and confirm relationships with other traits [37].

In general, the use of genetic selection as a tool for mitigating strategies, although promising, does not allow for quick application and results, so it is currently more important to focus on other strategies with faster effects along with intensive work on generating conditions for its application.

## Manure Management

Manure contributes to GHG emissions because its decomposition releases methane and nitrous oxide. The emission level largely depends on the environmental conditions, its management and composition [38]. Methane and nitrogen oxide emissions are influenced by organic matter and nitrogen content in excreta.

Methane is produced when organic matter in anaerobic conditions is incompletely decomposed under the influence of bacteria. This most often happens when liquid manure is stored or treated in lagoons. Methane production can be additionally enhanced by long storage as well as warm and humid environmental conditions.

Nitrogen oxide is mostly produced from solid manure, its storage or deposition on pastures in a combination of aerobic and anaerobic conditions.

GHG emissions are generally higher with solid manure systems. Numerous studies have shown that the application of various practices can contribute to the reduction of emissions from manure. Some of the most important practices are as follows:

Dietary manipulation is a practice that has found its application in emission reduction not only directly- by modulating enteric fermentation, but also indirectly it can preferably affect the composition of manure [39]. It is essentially the effect of a protein-balanced diet on denitrification and $N_2O$ emission, which reduces nitrogen excretion through excreta. Also, diets enriched with tannin from natural sources may increase the proportion of nitrogen excreted in organic compounds via faces, rather than in the urine as urea, which in turn reduces the potential for $NH_3$ and $N_2O$ emissions [40].

Manipulation of the storage temperature is based on preventing the development of methanogenesis, which is favored by higher temperatures. Therefore, manure cooling can be a cost-effective way to mitigate emissions, especially in colder regions. The effect will depend on the frequency of manure removal from the barn and the temperature difference between the environments. In some holding systems that allow active cooling of the manure in the manure chute, cooling the manure at 42℃ was found to reduce $CH_4$ emissions by 16% compared to the non-cooling situation [41].

Composting of solid manure is a process of aerobic decomposition of its organic matter under the influence of microorganisms to carbon dioxide and water. This process can be enhanced by turning the manure and aerating it. Methane emissions can be reduced by aeration, but it can also raise the emission level of $CH_4$, $N_2O$ and $NH_3$ [42]. However, with enhanced composting (overturning and aeration), lower emissions of $CH_4$ and $N_2O$ are achieved compared to ordinary passive composting.

Covering solid manure during storage with straw or plastic film generally leads to a reduction of $N_2O$ and $CH_4$ emissions and can also have a positive effect on $NH_3$ emissions [42].

Covering liquid manure during storage is primarily aimed at preventing $NH_3$ emissions. The danger of $N_2O$ emissions during the storage of liquid manure are small, except in cases of formation of scum on the surface. The scum increases the potential for nitrification and denitrification, which results in $N_2O$ emissions, because with the drying of the scum, there is an intrusion of $O_2$ [43]. Similarly, scram formation increases the potential for methane oxidation as well. Lids and straw are used to cover the liquid manure, although the straw itself is a form of protection. Although all covering methods result in lower overall GHG emissions, the best results are achieved by combining covers and straw.

Manure separation is a process of mechanical separation of its liquid and solid fraction. To achieve the desired effect of emission reduction, additional measures are necessary for each of the fractions in the process of their storage. This includes the cover options mentioned above, while anaerobic digestion is also recommended for solid manure.

Anaerobic digestion is a technological procedure by which easily degradable organic matter in manure and other organic substrates is transformed into biogas (mainly $CO_2$ and $CH_4$). In this way, a double

benefit for the environment is obtained-the use of energy from biogas instead of fossil fuels and the reduction of $CH_4$ emissions during the storage of digested manure, which is further used as fertilizer. It is estimated that the total effect of this method in reducing GHG emissions exceeds 30%.

Manure aeration can result in a significant reduction of total GHG emissions, ranging from 43% to 99% for beef and pig manure respectively [44, 45]. However, $N_2O$ emissions can increase by as much as 144% [44], which is why in the application of this procedure it is necessary to implement measures to preserve $N_2$ in order to achieve the full effect of GHG mitigation.

The treatment with additives is aimed at changing the chemical properties of the manure, most often the pH value, in order to prevent or reduce GHG emissions. In this sense, acidification with sulfuric acid of a certain concentration is most often used in order to lower the pH value of the substrate. Reduction effects range from 67%-87% for $CH_4$ emissions in cattle to as high as 94%-99% in pigs [43].

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# ADAPTATION STRATEGIES OF ANIMALS TO CLIMATE CHANGE

Adaptation to climate change in livestock encompasses measures stemming from the animals themselves, as well as those instigated by humans. Livestock naturally adapt through various mechanisms to cope with climate conditions, while human adaptation involves implementing practices that aid animals in adapting to climate change and enhancing livestock performance. In the context of livestock, adaptation actions can be classified into two primary groups: animal and human adaptation responses/strategies [1].

The effects of climate change on livestock production are diverse and thermal stress is considered the greatest challenge for farm animals [2]. It's important to note that animals are seldom subjected to just one stressor. In addition to heat stress, they may experience concurrent issues such as insufficient feeding, water scarcity and poor nutrition. The combined impact of multiple stressors may be more than just the sum of their individual effects [3].

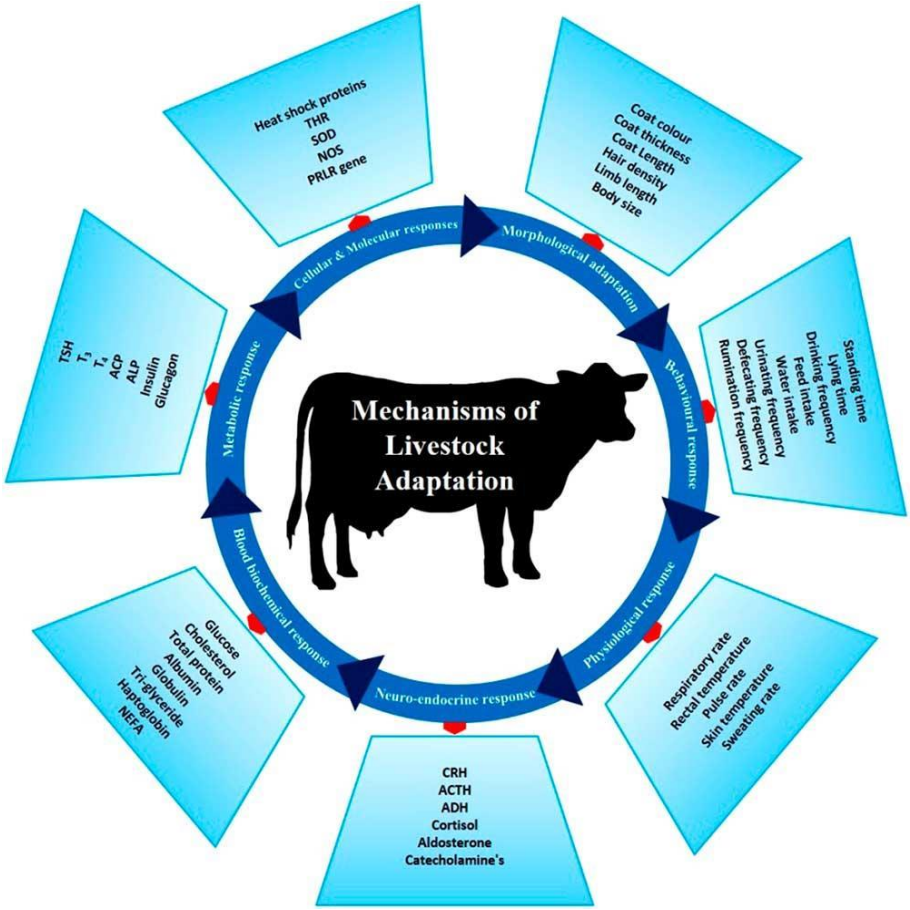



*Figure 1. Adaptive strategies of farm animals coping with climate change [6].*

*THR=thyroid hormone receptor, SOD=super oxide dismutase, NOS=nitrous oxide synthase, PRLR=prolactin receptor, CRH=corticotropin-releasing hormone, ACTH=adrenocorticotropic hormone, ADH=antidiuretic hormone, NEFA=non-esterified fatty acids, TSH=thyroid-stimulating hormone, $T_3$=triiodothyronine, $T_4$=thyroxine, ACP=acid phosphatase, ALP=alkaline phosphatase.*

However, the animals have inherent capabilities to withstand climate-related risks through the process of adaptation. In the animal's response to environmental stressors, two phases are distinguished: the initial response to environmental change and the later process triggered by the endocrine system. The resulting changes are aimed at reducing the impact of stress on the animal, allowing it to function more efficiently in a challenging environment. If stressful conditions persist across generations, these changes become genetically fixed adaptations [4].

This chapter aims to gather and synthesize information on significance of farm animals adaptation pathways and the different strategies to help them cope with adverse environmental conditions. In the face of climate change, the resilience and adaptability of farm animals stand as a testament to the intricacies of evolution and survival. To regain their homeostasis, animals need to adapt to the current climate conditions. Accordingly, their responses to specific stressors could be behavioral, physiological, biochemical, immunological, anatomical, or a combination of these factors (Figure 1.). These responses can vary depending on their prior exposure to stressors, the duration and severity of the stress, their physiological state and environmental constraints [5,6]. Although there are significant differences in heat tolerance between species, there is also variation between races within a species. Polygastric animals generally show a higher level of thermal tolerance compared to monogastrics, but there is overlap in environmental ranges for species and breeds. The ability to regulate body temperature depends on complex interactions between anatomical and physiological factors. Characteristics such as skin and coat properties, sweating and breathing capacity, tissue isolation, surface area to body weight or relative lung size, as well as endocrine profiles and metabolic heat production are known to influence heat load, but appropriate physiological, behavioral or genetic the mechanisms are not yet elucidated [7, 8].

## Physiological Strategies

Physiological strategies are the internal responses of farm animals to climate change that allow them to cope with the changing environmental conditions. Physiological strategies encompass the animal's physiological responses, including alterations of bodily functions, metabolic and endocrine, to maintain homeostasis and ensure their survival in a changing climate [9]. Animals have evolved several physiological strategies to cope with climate change [10]. For example, they have mechanisms in place to regulate body temperature, such as panting and sweating.

Elevating the respiration rate by panting is a key physiological mechanism through which heat-stressed animals dissipate extra heat by evaporating more moisture to the surroundings [11]. An increased pulse rate allows heat-stressed animals to enhance circulation and redistribute blood flow to the skin, which allows for more successful release of heat to the external environment [12]. Additionally, the elevated rectal temperature in heat-stressed animals contributes to additional dissipation of excess heat to maintain homeostasis [13]. Providing specific regulation of kidney function to maintain appropriate hydration levels (excess water) under high temperatures is also considered one of the important physiological responses.

Pigs do not have sweat glands and they also have relatively small lungs in relation to their body size, which reduces their cooling by panting. This makes them especially sensitive to the effect of heat stress, so the mechanism of heat release through the skin is of great importance for them.

Goats are well known for their remarkable ability to reduce their metabolic rate and enter a state of torpor during periods of extreme heat or cold, which helps them conserve energy and survive harsh conditions [14].

Within the physiological responses to heat stress, it's crucial to highlight the endocrine response. Specifically, the adrenal and thyroid glands, which are part of the endocrine system, are pivotal in helping animals adapt to heat stress [15].

The effect of high ambient temperature as a stress stimulus activates the hypothalamic-pituitary-adrenocortical axis (HPA) and the sympathoadrenal medullary axis (SAM) [15]. This results in the release of hormones responsible for the adaptation of animals to heat stress: glucocorticoids, catecholamines, antidiuretic hormone (ADH), thyroid hormones, mineralocorticoids, growth hormone (GH) and prolactin (PRL) [16]. The role of these hormones in ensuring thermal homeostasis is different. For example, increased cortisol production helps animals meet additional energy needs for their adaptive processes by using the gluconeogenesis pathway in the liver [17]. A significant decrease in the concentration of triiodothyronine ($T_3$) and thyroxine ($T_4$) was observed in the plasma and milk of

lactating cows, which is considered another adaptive mechanism to reduce additional heat load caused by increased metabolic activity [18]. In addition, compromised pituitary-thyroid axis activity was observed in heifers, with approximately 40%, 45.4%, and 25.9% reductions in TSH, $T_4$, and $T_3$ levels during heat stress, indicating their ability to produce less metabolic heat in an attempt to adapt to exposure to heat stress [19].

## Biochemical Strategies

Farm animals have developed certain biochemical strategies to adapt to climate change. These strategies involve the production and regulation of specific biochemical compounds that help animals cope with the challenges posed by changing climates. Two main adaptive strategies could be distinguished as biochemical: blood biochemical response (1) and cellular and molecular response (2):

## Blood biochemical response

When animals experience heat stress, specific biochemical changes occur to aid in adaptation and the maintenance of homeostasis. Studies have identified significant alterations in various blood biochemical parameters, including packed cell volume (PCV), hemoglobin (Hb), glucose, albumin, total protein, total cholesterol and non-esterified fatty acids (NEFA).

-Prolonged exposure to heat stress leads to a decrease in erythrocyte and hemoglobin levels [20]. This is because exposure to high ambient temperatures leads to increased oxygen consumption, resulting in elevated blood oxygen partial pressure, which in turn reduces erythropoiesis.

-The decline in PCV can be attributed to the excess water in the circulatory system, which is necessary for dissipating heat through hemodilution [21].

-Under the influence of heat stress, the level of albumin in the plasma increases, possibly due to its antioxidant effect on the heightened free radicals during heat stress [22]. One example of a biochemical adaptation in livestock, specifically cattle, is the regulation of renal function to maintain hydration levels under high temperatures. These adaptations involve changes in blood composition, such as an increase in plasma albumin levels to improve antioxidant capacity and protect against oxidative damage caused by heat stress.

-Furthermore, the level of glucose typically decreases as a result of reduced gluconeogenesis [23], while the decrease in NEFA levels in plasma is linked to its high consumption as an energy source in the liver and peripheral tissues [24]. According to Baumgard and Rhoads [25], the reduction in NEFA levels can be associated with the utilization of glucose to reduce metabolic heat during heat stress.

## Cellular and molecular response

The cellular response to heat stress is a vital part of animals' ability to tolerate high temperatures. When exposed to elevated temperatures, gene networks within and between cells activate mechanisms that lead to cellular adaptation. One crucial aspect of this adaptation is the production of heat shock proteins (HSPs), which safeguard cells from heat-induced damage and maintain cellular stability [26]. HSPs are essential for preventing protein denaturation and aggregation during heat stress conditions.

In response to heat stress, cells decrease DNA synthesis, transcription and translation processes, modify protein activity and boost HSP production [27]. Additionally, there is an increase in the oxidation of glucose and amino acids, a reduction in fatty acid metabolism, activation of the endocrine system in reaction to stress and stimulation of the immune system [4]. Genes linked to HSP synthesis, along with other genes related to heat tolerance, can serve as potential indicators for the adaptation of cattle and other farm animals to climate change stressors [28]. Identifying these genes, which

contribute to cellular heat tolerance, can be used in breeding programs through the use of markers or for creating new heat-tolerant animal breeds.

## Immunological Strategies

Climate change leads to a decline in animal welfare and health through the proliferation of vector-borne diseases and its detrimental effect on the animals' immune system, causing immune suppression and heightened susceptibility to infections [10].

Heat stress can disrupt the balance of immune cells, decrease antibody production and impair the function of immune organs, such as the thymus and spleen, leading to increased susceptibility to infections [29].

Different kinds of farm animals, exhibit varied responses to heat stress in terms of their immune function and ability to combat pathogens. However, there are some physiological limitations in this, primarily conditioned by genetics and the specifics of the breeding environment.

Unlike domestic animals raised in moderate climates and experiencing occasional heat shocks, their wild counterparts and breeds raised in warm and dry regions have developed certain immune system characteristics over time, making them more resistant to heat stress conditions. For example, one of the species most negatively affected by heat stress is cattle and particularly dairy cows [30]. In contrast to cattle, the dromedary camel can be considered a model of different immune reactivity to heat stress, thus helping to better understand thermotolerance mechanisms developed in livestock adapted to hot climates. Hussen's study [31] showed enhanced phagocytosis and reactive oxygen species (ROS) production activities of heat-challenged camel neutrophils and monocytes toward S. aureus, which is in contrast to the reported inhibitory effect of heat stress on antimicrobial functions of bovine neutrophils. Within breeds of cattle, Bos indicus (Zebu) cattle, have shown better adaptation to heat stress due to their heat tolerance and ability to maintain immune function under high temperatures [32].

The higher expression of immune response genes such as toll-like receptor (TLR) TLR2/4 and interleukins (IL) IL2/6 was also reported in heat-stressed Tharparkar cattle, suggesting active immune functions in these breeds to counter the effects of heat stress [33].

Similar results of increased TLR1, TLR4 and TLR5 expression were reported in indigenous Osmanabadi goats exposed to environmental stressors, such as heat stress, nutritional stress and combined heat and nutritional stress [34]. The enhanced TLR expression clearly indicates the active immune system of this breed even during heat stress conditions, firmly establishing their adaptive capability.

Heat stress in sheep can compromise their immune response, making them more susceptible to parasitic infections and respiratory diseases. However, some sheep breeds, such as the African Damara breed, have evolved in hot climates and exhibit better resilience to heat stress, maintaining their immune function and resistance to pathogens [35]. The research conducted by Astuti et al. [36] demonstrated that the Hungarian Cigaya, as an indigenous breed, exhibits superior thermotolerance and immune capabilities under heat stress when compared to the Hungarian Merino and the White Dorper, a tropical breed. The review by Daramola and Adeloye [37] indicates that goats typically have a higher count of lymphocytes than neutrophils in their circulation, suggesting a well-developed immune system in this species and thus, animals adapted to thermal stress are likely to experience better overall health due to their physiological adaptations and cellular and molecular responses.

FAO [38] provides a catalog of breeds, predominantly from developing nations, known for their resistance or tolerance to trypanosomiasis, tick infestation, tick-borne illnesses, internal parasites, dermatophilosis, or foot rot, encompassing 59 cattle breeds, 33 sheep breeds, 6 goat breeds, 5 horse breeds and 4 buffalo breeds.

While solid scientific evidence is currently lacking, it is assumed that tropical breeds of domestic animals not only exhibit better tolerance to heat stress but also possess a more adapted immune system for pathogens typical of regions with higher ambient temperatures. This potential advantage can be leveraged in domestic animal breeding programs as a promising technique for enhancing heat tolerance.

## Anatomical & Morphological Strategies

One significant response of farm animals to thermal stress is the anatomical changes that allow animals to cope with and survive in changing environmental conditions [39]. This phenomenon, often overlooked, sheds light on the plasticity and adaptability of species in the face of climate change.

The primary anatomical changes may involve alterations in body size, appendages, coat color and type and the respiratory system [40]. Furthermore, animals may develop specific morphological characteristics such as larger salivary glands, an expanded surface area of the absorptive mucosa and the capacity to significantly increase the volume of the foregut when consuming high-fibre meals [41].

## Coat colour, type and density

The hair coat's physical structure serves as the primary barrier between the body and the environment. Various hair characteristics directly influence heat exchange with the surroundings. Hair structure provides protection against direct solar radiation and facilitates convection and heat loss through evaporation. Key characteristics include coat reflectance, hair length and hair density per unit area [8].

In tropical regions, animals with light-colored coats reflect over half of the direct solar radiation, unlike dark-colored animals [8]. Adaptations in these regions involve having light-colored hair coats, such as white, light red, or red, which aid in reflecting solar radiation and minimizing heat absorption. Cattle in hot and arid environments benefit from their light-colored hair coats as a protective mechanism against solar radiation, reflecting rather than absorbing the radiation. Da Silva et al. [42] determined that coat color affects the thermoregulatory behavior of dairy cows. Light-coated cows showed greater resistance to heat stress compared to dark-coated cows, which affects their shade-seeking and heat-avoidance behavior. Furthermore, cattle in hot environments tend to have smooth, light, short and thin hairs, as well as fewer hair follicles per unit area, facilitating maximum heat dissipation during stressful conditions. Thus, the combination of a light-colored hair coat and specific hair characteristics enables cattle in hot and arid environments to better cope with high temperatures [2].

Sheep have developed thick wool coats that act as insulation during cold weather and help regulate body temperature in extreme heat [43]. Undesirable hair coat traits in sheep, such as dark and long hair or dense coats, can cause overheating. Conversely, lower coat thickness and less dense coats with short and thick hairs facilitate the dissipation of excessive body heat and contribute to homeostasis and better performance. This indicates an advantage for hair sheep over wool sheep. Indigenous sheep breeds in arid and semi-arid regions possess morphological characteristics such as carpet-type wool, which provides better protection against direct radiation. This type of wool also allows efficient heat dissipation during evaporation [44]. Some sheep breeds possess a fat tail considered a morphological adaptation that allows better heat dissipation [45].

## Body size

Body size directly affects energy requisite for maintenance, growth and production so changes in functional traits like body size have significant repercussions for the thermal biology and energetics of animals. Therefore, under conditions of climate change, one of the adaptive responses may be to reduce body size. For example, in hotter climates, animals may decrease in size as smaller bodies have a higher surface area to volume ratio, allowing for better heat dissipation [46]. Elayadeth-Meethal et al. [47] examined the adaptive tolerance to heat stress in dwarf cattle breeds (DCB, Bos taurus indicus)

and compared their thermoregulatory responses with those of standard size cattle breeds (SCB, crossbred, Bos taurus indicus × Bos taurus taurus). It was found that While SCB can acclimate to higher temperatures in the short term, they reach their tolerance limit under prevailing tropical conditions, whereas DCB are well adapted to the warmer climate. Increased hemoglobin concentration and reduced cellular size of DCB additionally contribute to enhanced thermal tolerance.

## Appendages

The size and characteristics of an animal's extremities, like tails, beaks and legs, are crucial for regulating its body temperature through heat exchange. The larger surface areas for sweating or panting, along with increased blood flow to peripheral tissues, exemplify the anatomical evolution of farm animals to regulate their body temperature effectively and minimize the risk of overheating. This leads to variations in animal morphology across different geographic areas, with animals in warmer regions having larger extremities relative to overall body size. This phenomenon, known as 'Allen's rule,' has not been receiving sufficient attention in relation to its response to climatic warming [48]. According to this rule, larger extremities relative to body size provide a greater surface area for effective dissipation of body heat. As a result, larger extremities can be advantageous in warmer climates but may not be as useful in cooler climates.

In birds, body parts like bills contain numerous blood vessels and lack feather coverage, making them crucial for heat release. This also applies to the unfathered or unfurred legs of birds and mammals, which aid in regulating body temperature. In mammals, ears and tails also play a role in releasing heat. The good examples are Brahman cattle and Nubian goat. The utilization of these body parts for temperature regulation is believed to underlie the patterns observed in Allen's rule, as these surfaces offer an efficient means of adjusting heat dissipation.

## Respiratory system

Additionally, the respiratory system of farm animals can undergo modifications as a response to climate change [10]. For instance, animals may develop larger lung capacities or altered breathing patterns to enhance their ability to regulate body temperature and cope with heat stress.

## Morphological Adaptations in Diverse Farm Animal Species

When it comes to climate change, particularly heat and drought, goats demonstrate the greatest adaptation abilities among all domestic animals. They can dissipate heat through their horns and thrive on minimal vegetation. Goats with droopy, long ears and loose skin, such as Boer and Nubian breed, tend to fare better in challenging, arid conditions.

Sheep are less tolerant of heat compared to goats, even though wool offers some defense against high temperatures. Sheep with hair instead of wool handle heat even better. For instance, breeds like the fat-tailed Red Maasai and the Sahel-type thrive in conditions with limited water and sparse vegetation. The South African Dorper and the Karakul sheep of Central Asia's deserts excel in drought conditions, surviving severe water shortages by storing fat in their tails, which serves a similar function to a camel's hump.

Continental cattle breeds, particularly highly productive dairy breeds, are susceptible to the impact of high temperatures, unlike their tropical counterparts from Asia and Africa (Zebu, Brahman, Gir, etc.). Therefore, to enhance their ability to survive in changing climate conditions, it is advisable to introduce genes such as the slick gene for short hair, elongated body shape and other genes from the genotype of tropical cattle.

In poultry, the absence of feathers on the neck in the Naked Neck chicken provides a distinct advantage in coping with heat stress. Additionally, chickens with larger wattles and combs also fare better in such conditions.

Thick fat under the skin, a lack of insulating fur, small lungs, inability to sweat and pant define pigs as the most sensitive species to heat stress. Duroc exhibits a moderate level of heat stress resistance, but certain breeds originating from the warmer regions of southern China, such as Luchuan pigs, Diannan small-ear pigs, Bamaxiang pigs and Wuzhishan pigs, possess heat-resilience traits that could aid in genetic adaptation solutions.



*Figure 2. Morphological characteristics of climate-resilient farm animal species*

Analyzing the anatomical adaptations of farm animals in response to climate change is essential for devising effective strategies to sustain livestock production in the face of global warming. Through the study and understanding of these adaptations, researchers and livestock managers can work towards implementing measures to enhance the well-being and productivity of farm animals in a changing climate.

## Behavioral Strategies

In addition to physiological, biochemical, immunological and anatomical adaptations, farm animals also employ behavioral strategies to cope with climate change [10]. These strategies involve alterations in their daily activities and movements to mitigate the impact of heat stress and maintain thermal homeostasis [43]:

•Seeking shaded and cooler areas, bathing or splashing water to reduce exposure to direct sunlight and cool down [9,10]. For instance, it has been observed that cattle generally prefer tree shade over man-made shaded structures due to the high evaporative cooling provided by tree leaves [49]. Poultry cools down by spreading their wings, while pigs, being the most sensitive, cool down in the mud and by lying on cooler surfaces.

•As the heat load increases, cows tend to reduce their resting time and increase their time spent standing [50]. This way, they increase their body surface area, facilitating evaporative heat loss and potentially averting radiative and convective heat from the ground [51]. However, the use of sprinklers

and fans on farms has been shown to effectively decrease the heat load, thereby increasing the cows' resting time.

•Changes in diet and foraging behavior include reduced food intake to lessen the metabolic load of the organism. In grazing cows, a shift to night grazing is observed at extremely high daytime temperatures.

•As the heat load increases, the frequency of defecation and urination decreases, primarily depending on the availability of feed, water and environmental temperature [52]. Heat-stressed cows have been reported to exhibit a significant decrease in urine frequency.



*Figure 3. Behavioral patterns leading to cooling in different species of domestic animals*

•There is also an increased need for water during severe ambient conditions. Water consumption rises under heat stress conditions and cows typically prefer water with a moderate temperature that is neither too cold nor too hot. Experts often recommend providing cold water during hot conditions or water below body temperature to help maintain body temperature.

The ability of farm animals to exhibit certain forms of behavior during heat stress reflects their innate and instinctive understanding of environmental cues and their ability to adapt their daily routines to survive.

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# HUMAN ADAPTATION STRATEGIES TO CLIMATE CHANGE IN LIVESTOCK PRODUCTION

The IPCC defines adaptation as actions taken to decrease the vulnerability of both natural and human systems to the impacts of present or anticipated climate change. Human adaptation strategies encompass breeding, modifications to production and management systems, as well as institutional and policy changes that will be discussed in next chapter. Figure 1. provides a concise overview of livestock management adaptation strategies, followed by a detailed discussion. In short, human adaptation involves implementing practices that aid animals in adapting to climate change and enhancing livestock performance.

| **Animal Genetics** |
|---|
| •Choose species that are more heat-tolerant<br>•Genetic selection to changed conditions |
| **Physical Modification** |
| •Provide shade and sprinklers for outdoor animals<br>•Improve/supply cooling systems indoors |
| **Feed And Pest Management** |
| •Modify diet composition and feeding lime<br>•Supplemental feeding<br>•Adoption of integrated pest management |
| **Livestock System** |
| •Diversify livestock species<br>•Adjust slacking rate<br>•Integrate livestock system with forestry or crops |

*Figure 1. Summary of human adaptation strategies [1].*

## Animal Genetics

The application of selective breeding in farm animals has led to improvements in their production performance over the years, contributing to an overall increase in product yield. However, this one-sided selection has favored highly productive genotypes with high energy requirements and increased metabolic heat production. As a result, under climate change conditions, there is a risk that such genotypes may be more susceptible to heat stress due to their metabolic load [2]. With climate change projections indicating warmer conditions and more frequent extreme temperatures, one of the measures for human adaptation involves manipulating the genetic material of farm animals. It has been observed that certain breeds and types of farm animals exhibit greater resistance to heat stress, which is closely linked to their adaptive abilities, as discussed in detail in the previous chapter on animal adaptations. Farm animal breeds originating from tropical regions have evolved to thrive in warmer climates and cope with water scarcity, granting them an evolutionary edge in the context of climate change. Adaptations such as light, short and slick hair, larger limbs, increased skin and lung surface area, smaller body size, among others, play crucial roles in their ability to adapt. Moreover, akin to locally adapted breeds, specific physiological and immunological traits enhance the resilience of these tropical breeds in less-than-ideal rearing conditions.

## Conventional, marker-assisted and genomic selection

Since the phenotypic expression of traits is largely determined by the genotype, various forms of genetic manipulation are considered as one of the possibilities within the scope of human adaptation measures. Therefore, the heritability and additive genetic variation of traits important for thermal resilience are parameters on which the success of implementing such methods depends. Nevertheless, physiological markers of heat stress such as respiration rate (RR), rectal temperature (RT), and drooling score (DS) exhibit low heritability [3, 4, 5], and are controlled by numerous quantitative trait loci (QTL),

each with minor effects. Consequently, the potential for significant genetic advancements through conventional selection methods is limited. Another challenge, for example in dairy cows, is to identifying heat-tolerant animals due to the complex nature of heat stress and the negative correlations between heat tolerance and productivity traits. This underscores the necessity to pinpoint genomic variations linked to heat tolerance traits, thereby adding another dimension to the advancement of genomic selection (GS) for heat-resistant dairy livestock [6]. Leveraging Genome-wide association studies (GWAS) to pinpoint the genes governing climate adaptation traits, such as efficient thermoregulation, feed utilization and immunity, could expedite the selection of animals that are more resilient to climatic challenges [7]. So far, in dairy cattle a progress has been made in pinpointing candidate genes like HSF1, SPAG17, DNAJC8, HSPA9 and DNAJC18 associated with heat tolerance and milk production traits, facilitating marker-assisted selection, genomic selection and gene editing initiatives [8].

In addition to the marker-assisted selection and genomic selection mentioned above, other options like crossbreeding and gene editing offer avenues for manipulating animal genetics to address the impacts of climate change on livestock.

Adapting tropical farm animal breeds to climate vulnerability zones could be a viable strategy to cope with the changing climate. However, there are some factors to consider, such as the animals' ability to thrive in different environmental conditions, their resistance to local diseases and their overall suitability for the new climate. In addition, these breeds are generally characterized by lower productivity, which is not in line with modern breeding goals and food needs.

Crossbreeding tropical & locally adopted breeds and high-output farm animal breeds emerges as a superior alternative. For instance, the development of crossbreeds between Bos taurus and Zebu (Bos taurus indicus cattle) has proven effective in enhancing performance while preserving environmental resilience [9]. These crossbred animals exhibit improved adaptability to elevated temperatures, humidity and resistance to parasites, notably *Boophilus microplus* ticks, which increases proportionally with the Bos taurus indicus ancestry in the cross [10]. Breeding crossbreeds between tropical and high-output breeds yields a dual impact in the battle against climate change. Firstly, these hybrids exhibit heightened resilience to heat, particular diseases and water scarcity. Simultaneously, they attain enhanced productivity, thereby reducing the overall carbon footprint [11].

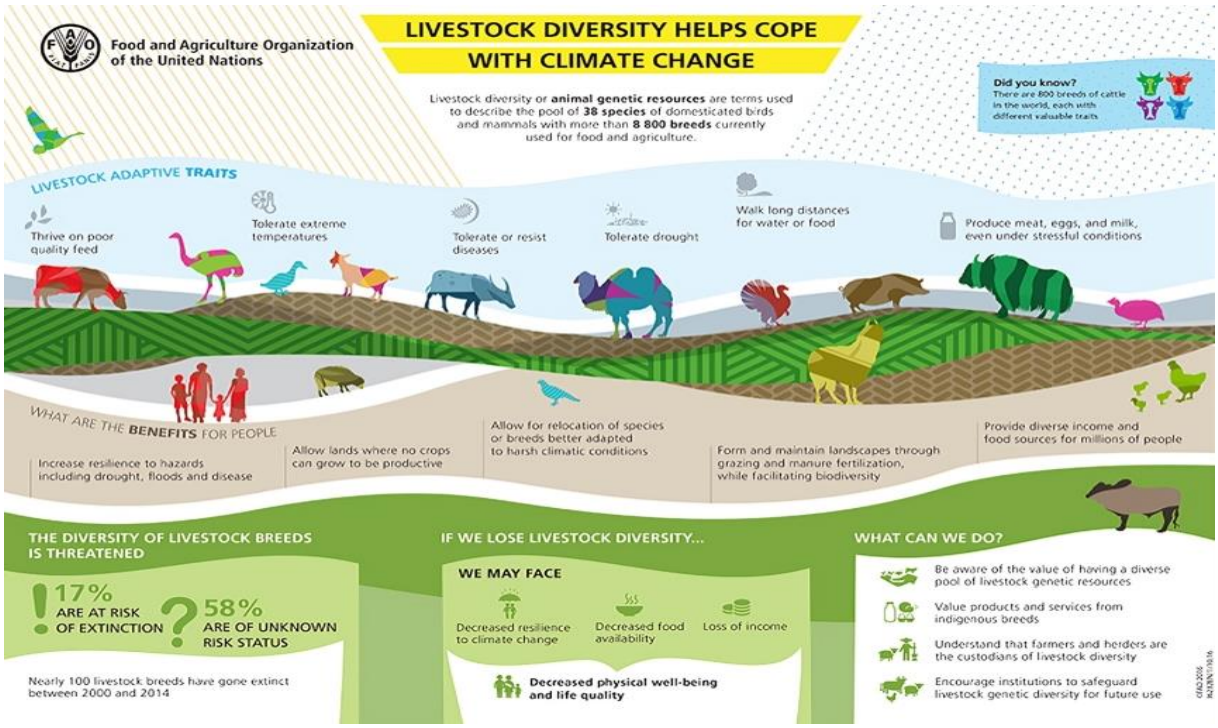



*Figure 2. An overview of AnGRs roles and benefits regarding adaptation strategy to climate change [14].*

Starting from the morphological characteristics of livestock that allow better adaptation of animals from tropical regions, genetic studies have revealed the genes and mechanisms of inheritance that define these specific traits. Some breeds of cattle have very short hair and reduced follicle density, giving a phenotype called "SLICK". According to some findings, the effect of SLICK is most likely realized through increased sweat production, rather than a reduction in hair length and density [12]. The SLICK variant has now been introduced into other breeds, including the highly productive Holstein dairy breed, creating more heat tolerant animals [13].

In addition to tropical breeds, locally adapted breeds, often defined as genetic resources (AnGR), certainly have their importance in adaptation measures to climate change as shown in Figure 2. Their evolution took place in conditions of adaptation to extreme climatic conditions and accompanying, different types of pathogens and parasites, as a result of which they acquired specific characteristics. Hence, these breeds serve as invaluable assets and if thoroughly investigated, they can be leveraged to develop breeds well suited to the changing conditions brought about by climate change [15]. Many locally adapted species and breeds are primarily concentrated in arid regions. Camels, for example, are predominantly found in arid zones, showing variation in adaptation to altitude and climate. Yaks, on the other hand, are specialized for thriving in extremely difficult conditions at high altitudes throughout the arid lands of Asia. According to FAO [16], over 70% of donkey breeds, about 50% of sheep and goat breeds and 30% of cattle and horse breeds are adapted to dry regions. However, most indigenous breeds lack comprehensive characterization and their adaptations include not only heat resistance but also the ability to thrive, develop and reproduce in the face of seasonal nutritional deficiencies, as well as challenges posed by parasites and diseases.

Currently, out of the myriad mammal and bird species, only 40 are domesticated, playing a crucial role in the production of meat, dairy and eggs. A significant portion of this production is shouldered by key species such as cattle, buffalo, goats and sheep. Unfortunately, 26 percent of livestock breeds are now at risk, with 6 percent already extinct. Strategies focusing on animal genetic resources can shape populations by selectively breeding more resilient breeds, crossbreeding for higher temperature or disease resistance, or transitioning to alternative species when these approaches are no longer viable. The diversity within animal genetic resources offers the ability to adapt to climate change, emerging diseases, limited food and water resources and evolving market demands.

The use of genetic biotechnology to introduce thermo-resilience genes-gene editing into livestock breeding is a promising approach in climate change adaptation strategies. Researchers have identified several genes associated with thermo-tolerance in livestock. These genes include heat shock proteins, heat shock transcription factors, thyroid hormone receptor, mitochondrial inositol protein, isocitrate dehydrogenase and butyrophilin phosphofructo kinase [17]. Studies have shown that these genes play critical roles in regulating various physiological processes that contribute to thermo-tolerance. For example, heat shock protein 70 is a highly conserved stress-inducible protein that helps protect cells from damage and maintain cellular integrity. In addition to heat shock proteins, other genes involved in regulating the immune response and cell cycle arrest have also been found to be upregulated during heat stress conditions in livestock. By using gene editing techniques, such as CRISPR-Cas9, scientists can potentially introduce thermo-resilience genes into livestock genomes, thereby enhancing their ability to withstand and adapt to heat stress.

## Physical Modification

Environmental alterations represent a viable approach to mitigate heat stress in livestock and can be broadly categorized into outdoor and indoor modifications.

## Outdoor

For animals housed outdoors in grasslands or pastures, effective physical modifications involve providing shelters that shield against solar radiation while facilitating cooling during hot weather [18].

Grazing animals benefit from natural shade sources such as broad, dense tree canopies, which promote increased evaporation of heat and moisture from their bodies [19]. Alternatively, various constructed shelters offer viable solutions, with Figure 3. showcasing a modern solar-based design that delivers significant energy savings [20]. Additionally, the implementation of sprinkler and misting systems can further lower body temperatures as shown in Figure 4. [21]. Combined systems demonstrate superior efficacy, generating a synergistic effect, particularly in arid conditions [22]. Thus, integrating sprinkler systems with covered pens has been shown to enhance the daily weight gain of pigs compared to using sprinklers alone.



*Figure 3. The example of innovative-solar shading system [20].*



*Figure 4. The example of sprinkler system for grazing cows [21].*

## Indoor

Due to the specific nature of closed-space farming systems, livestock housed indoors are typically more susceptible to microclimatic conditions. Continuous monitoring of temperature, humidity, gases and other parameters within barns is essential, especially in intensive systems with a large concentration of animals. In modern times, advancements in precision agriculture technology offer the ability to adapt systems appropriately to detected changes, ensuring a consistent provision of desirable microclimates throughout the entire production cycle. Pigs, in particular, are highly sensitive to heat stress, necessitating highly efficient cooling and ventilation systems [23]. An illustrative example of such a system is provided in Figure 5.

In general, physical modifications within buildings include the installation or enhancement of ventilation systems, utilization of heat-reducing building materials such as insulation and optimization of barn orientation. Additional measures such as forced air velocity, misting, fogging, spraying and substrate cooling systems can also be implemented [24]. Various air conditioning and substrate cooling systems have demonstrated superior performance in mitigating heat stress [24]. However, it's important to consider the significant investment and operational costs, as well as the energy consumption associated with their operation. The development and implementation of green technologies will undoubtedly contribute to their wider adoption and environmental efficiency [20].

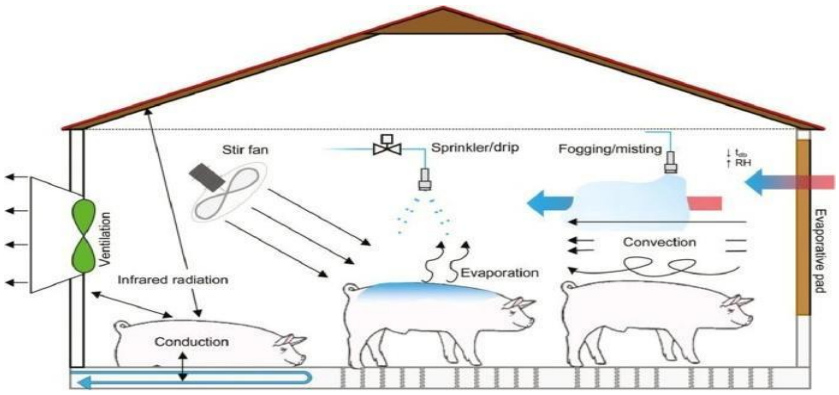



*Figure 5. Example of ventilation and cooling systems for large-scale pig farms [23]*

## Feed Management

Utilizing feeding strategies help maintain hydration, electrolyte balance and antioxidant status, thereby reducing the physiological strain associated with heat stress while offers a means to enhance animal performance. These strategies encompass adjustments to diet composition, alterations in feeding timing and frequency and effective water management practices [18].

Effective water management: Implementing effective water management strategies, such as providing adequate access to clean drinking water and optimizing water use efficiency in feed production, can help mitigate the impacts of water scarcity and drought on livestock farming. Ensuring clean, abundant water near feeding areas is essential, particularly in warm climates where water may be warm. Chilled water provision has shown promise in improving animal performance by reducing body temperature, particularly for lactating sows, enhancing feed intake and milk production [25, 26]. Combining self-feeding with the option for sows to wet their feed has also improved feed intake in lactating sows during summer, comparable to hand-fed dry feed systems [26].

Electrolyte supplementation is a key nutritional strategy for mitigating heat stress in livestock due to their loss by sweating and/or panting. Furthermore, Renaudeau et al. [18], highlight the importance of providing supplementary antioxidants, such as vitamins E and C, to combat oxidative stress induced by heat stress.

Incorporating fat into the diets can effectively alleviate heat stress, improve energy intake and support overall performance during elevated temperatures. Fat serves as a dense energy source, crucial when animals reduce feed intake during heat stress, it boosts energy density, aiding in meeting nutritional needs with smaller volumes. Additionally, fat metabolism generates less heat than carbohydrates or protein, potentially minimizing heat-related health risks and maintaining thermal balance. Moreover, fat supplementation enhances feed palatability for poultry, ensuring adequate nutrient intake, while promoting growth and carcass quality in pigs under heat stress, thus sustaining productivity and profitability in affected production systems [27, 28].

Amino Acid Supplementation: Supplementing pigs diets with specific amino acids, such as lysine and methionine, helps maintain protein synthesis and muscle mass during heat stress, supporting growth performance and carcass quality in pigs raised in hot climates [18].

Heat Stress Additives: Some feed additives, such as heat stress modifiers or heat-reducing compounds, are specifically designed to alleviate the physiological effects of heat stress. These additives may include substances that enhance heat dissipation, improve water retention, or regulate hormonal responses to heat stress, thereby improving pig comfort and performance during periods of elevated temperatures. Probiotics, prebiotics and phytogenic compounds, have been shown to improve gut health and nutrient absorption, enhancing resilience to heat stress. Additional feed supplements like niacin, fungal culture and conjugated linoleic acid have been shown to mitigate the impact of elevated temperatures on the performance of both ruminants and poultry [18].

Adjustments in feeding regime (time and /or frequency) can help animals cope with heat stress. During hot weather, animals can be fed early in the morning or late in the evening when temperatures are cooler [29, 30]. Feeding during these times reduces heat stress and allows them to consume their feed more comfortably. Providing smaller, more frequent meals throughout the day helps regulate digestion and nutrient absorption, reducing the metabolic heat generated during digestion.

Beside above mentioned, some other measures of adaptation regarding feeding management are available. Utilizing alternative feed sources such as agro-industrial by-products and insect-based feeds helps mitigate the impact of climate change-induced feed fluctuations, offering valuable supplements resilient to climatic variability. Concurrently, optimizing feed efficiency through selective breeding and precision feeding techniques minimizes resource inputs, reducing production costs while enhancing productivity. Additionally, integrating climate-resilient forage crops like drought-tolerant grasses and legumes sustains livestock production in water-scarce regions, requiring fewer inputs and enhancing resilience to climate variability.

## Livestock Management System

Livestock management adaptations encompass a range of strategies, including:

1) The diversification of livestock species offers a multifaceted approach to adapting to climate change in livestock farming. By maintaining a diverse mix of species and breeds, farmers can enhance resilience, improve resource utilization and enhance adaptability to changing environmental conditions thereby fostering the sustainability of livestock operations [31]. Furthermore, traditional livestock farmers commonly employ it to maintain high diversity within on-farm niches and mitigate against climatic and economic challenges [15, 16]. Therefore, their application could play a crucial role in adapting to climate change. Research by Seo and Mendelsohn [32], suggests that small farms in developing countries exhibit greater resilience to climate change due to their diverse species portfolios, flexibility in shifting between species and reliance on goats and sheep. Conversely, commercial dairy and beef operations face heightened vulnerability as their specialized nature makes transitioning to other species more challenging. Various livestock species-level models accounting for the direct impacts of climate change alongside alterations in agroecological conditions and production systems indicate a shift from cattle and chickens towards goats and sheep as temperatures increase [32]. As previously shown in Figure 2, animal genetic resources (AnGR)-the pool of 38 species of domesticated birds and mammals with more than 8800 breeds currently used for food and agriculture, could have important role within this strategy.

2) Adjustments in stocking rates represent a proactive and adaptive approach to climate change mitigation in livestock production systems. Studies by Diaz-Solis et al. [33] and Mu et al. [34], demonstrates the effectiveness of flexible stocking rate management in reducing the vulnerability of livestock systems to drought and other climate-related stressors. By implementing flexible stocking rates that account for environmental variability, producers can optimize livestock performance while minimizing the risk of overgrazing and depletion of forage resources during periods of drought, therefore maintaining ecosystem health and enhancing overall resilience to climate-related challenges.

3) Integrating livestock with forestry or crops offers synergistic advantages, including enhanced soil quality and nutrient circulation. Such combined approaches aid in soil preservation, lessen dependency on chemical substances and foster economies of scale within farm operations.

Ryschawy et al. [35], have demonstrated that mixed crop-livestock systems provide an economically and environmentally friendly approach to farming. These systems involve the simultaneous production of crops and livestock on the same land, allowing for synergies between different components of the agricultural system. By diversifying income streams and nutrient cycling, mixed crop-livestock systems can improve farm resilience to climate variability and market fluctuations. Similarly, Alves et al. [36], have explored the prospects for integrated crop-livestock-forestry systems as a sustainable form of

agricultural intensification. These systems integrate tree crops or forests with traditional crop and livestock production, creating diverse agroecosystems that offer multiple benefits. By sequestering carbon, enhancing soil fertility and providing additional sources of income, integrated crop-livestock-forestry systems contribute to climate change mitigation while also supporting rural livelihoods.

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# POSSIBILITIES FOR ENCOURAGING AND IMPLEMENTING MITIGATION AND ADAPTATION STRATEGIES

Livestock production undoubtedly plays a vital role in global food security and economic development. Given the imminent threat of climate change, it is crucial to promptly and effectively deploy all available tools based on our current understanding. Previous chapters extensively explored the correlation between climate change and livestock production, alongside detailed discussions on adaptation and mitigation strategies to alleviate current and projected impacts. To expedite and enhance the successful implementation of these strategies, robust support within societal and governmental institutions is imperative. This chapter examines the opportunities for encouraging and implementing adopted strategies in livestock production, focusing on policy interventions, training initiatives and technological advancements.

## Policy and Institutional Support

Policies and regulations are instrumental in creating a supportive framework for climate adaptation and mitigation in livestock production. Given the variability in climate change impacts across various livestock systems, comprehending these distinctions is essential for crafting effective policies and practices [1]. To reduce greenhouse gas emissions, minimize environmental impacts and enhance climate resilience, governments can establish regulatory standards for livestock farming practices. These standards may include limits on emissions from livestock operations, requirements for waste management and nutrient management plans and guidelines for sustainable land use practices. Some of the most commonly employed regulations and measures applied by governments, primarily in developed countries, include the following [2].

## Carbon Pricing

Implementing carbon pricing mechanisms, such as carbon taxes or cap-and-trade systems, can create economic incentives for livestock producers to reduce their carbon footprint. By putting a price on carbon emissions, these policies encourage farmers to invest in technologies and practices that lower emissions and increase efficiency.

•**Land Use Planning:** Land use planning regulations can help prevent the expansion of livestock production into environmentally sensitive areas, such as forests or wetlands and promote sustainable land management practices. Zoning regulations, protected area designations and conservation easements can help preserve critical habitats and ecosystem services while promoting climate resilience.

•**Water Management:** Regulations governing water use and management can help address water scarcity and quality issues associated with livestock production. These regulations may include restrictions on water withdrawals, requirements for water conservation measures and guidelines for protecting water resources from pollution.

•**Livestock Welfare:** Legislation and regulations aimed at promoting animal welfare in livestock production can indirectly support climate adaptation and mitigation efforts by improving animal health and productivity. Standards for housing, handling and transport of livestock can reduce stress and disease incidence, leading to more efficient resource use and reduced greenhouse gas emissions per unit of output.

•**Supporting Renewable Energy:** Governments can enact policies to promote the adoption of renewable energy technologies, such as solar panels or biogas digesters, on livestock farms. Incentives such as feed-in tariffs, tax credits, or grants can help offset the costs of installing renewable energy systems and encourage farmers to generate clean energy on-farm, reducing reliance on fossil fuels and lowering emissions.

On the other hand, governments can introduce incentives, subsidies and other policy instruments to promote the adoption of sustainable and climate-resilient farming techniques, such as agroforestry, rotational grazing and water conservation measures. For instance, the recent reforms of the European Union's Common Agricultural Policy (CAP) have emphasized environmental sustainability, including measures to encourage climate-smart agriculture and support agroecological approaches. [3]. These Environmental initiatives are integral components of the CAP:

•Cross-compliance criteria tie financial assistance to adherence to EU regulations regarding environmental standards, as well as human, plant and animal health.

•Green direct payments mandate specific actions (such as preserving permanent grasslands, promoting crop diversity and establishing ecological focus areas), each aimed at environmental protection and addressing climate change.

•Rural development policies endorse investments and agricultural practices that promote climate action and sustainable natural resource management.

The CAP significantly contributes to combating climate change, allocating approximately 1/4 of its funding from 2014-20, to climate-related actions. These include reducing greenhouse gas emissions through improved livestock management and investing in manure storage, enhancing carbon sequestration through soil protection and forest restoration and aiding farmers in adapting to climate challenges with new methods and technology. As a result, agricultural emissions decreased by 21% between 1990 and 2017 without compromising production levels. The CAP 2023-27 aims to further strengthen support for climate mitigation, aligning with the EU's Green Deal objective of achieving net zero greenhouse gas emissions by 2050 [3]. Beside the CAP as the EU's main agricultural policy tool several other important legislative and regulatory measures are in place regarding climate change and sustainable livestock production [3]:

•**Environmental Regulations:** The EU has implemented various environmental regulations that affect livestock farming, including the Water Framework Directive, the Nitrates Directive and the Industrial Emissions Directive. These regulations aim to protect water quality, reduce pollution from agricultural activities and promote sustainable resource management.

•**Greenhouse Gas Emission Targets:** The EU has committed to reducing greenhouse gas emissions by at least 40% by 2030 compared to 1990 levels, as part of its overall climate goals under the Paris Agreement. To achieve this target, the EU has adopted policies such as the Effort Sharing Regulation, which sets binding emission reduction targets for sectors not covered by the EU Emissions Trading System, including agriculture.

•**Animal Welfare Legislation:** The EU has established comprehensive legislation on animal welfare, which applies to livestock farming practices. This includes regulations on housing and husbandry systems, transport of animals and slaughter methods, aimed at ensuring the well-being of animals throughout their lives.

•**Renewable Energy and Energy Efficiency:** The EU has implemented policies to promote renewable energy sources and improve energy efficiency, which can benefit livestock farms. Initiatives such as the Renewable Energy Directive and the Energy Efficiency Directive provide incentives and support for the adoption of renewable energy technologies and energy-saving measures on farms.

•**Research and Innovation Funding**: The EU provides funding for research and innovation projects aimed at improving sustainability in agriculture, including livestock production. Programs such as Horizon 2020 and the Common Agricultural Policy Strategic Plans include funding opportunities for projects focused on climate change adaptation, mitigation and sustainable farming practices.

These legislative and regulatory measures form a comprehensive framework for addressing climate change and promoting sustainable livestock production in the EU.

From global perspective, similarly to the EU, policymakers can promote investments in resilient infrastructure, research and extension services by aligning agricultural policies with climate objectives [4]. For instance, one of the biggest world consortiums of funds-The Global Environment Facility (GEF) have allocated over $22 billion and leveraged $120 billion in co-financing for over 5,000 national and regional initiatives in the last 30 years [5]. Providing institutional support, such as access to credit, insurance, or technical assistance, can help overcome barriers to adoption of climate-smart practices, particularly for smallholder farmers or those operating in resource-constrained environments [6].

In general, variety of financial mechanisms such as carbon credits, payments for ecosystem services (PES), or climate finance can provide financial incentives for livestock producers to adopt climate-friendly practices. These incentives can help offset the costs associated with implementing new technologies or transitioning to more sustainable farming methods [7].

## Building Awareness and Understanding

Farmers frequently harbor doubts regarding the veracity of claims surrounding the existence of climate change, despite experiencing firsthand the detrimental impacts on their production. Hence, there is a need to cultivate trust in scientific knowledge, as well as in government actions guided by these facts. Training programs can enhance farmers' awareness and understanding of the impacts of climate change on livestock production. By providing education on the potential risks and vulnerabilities, as well as available adaptation and mitigation measures, farmers can make informed decisions to safeguard their livelihoods [8].

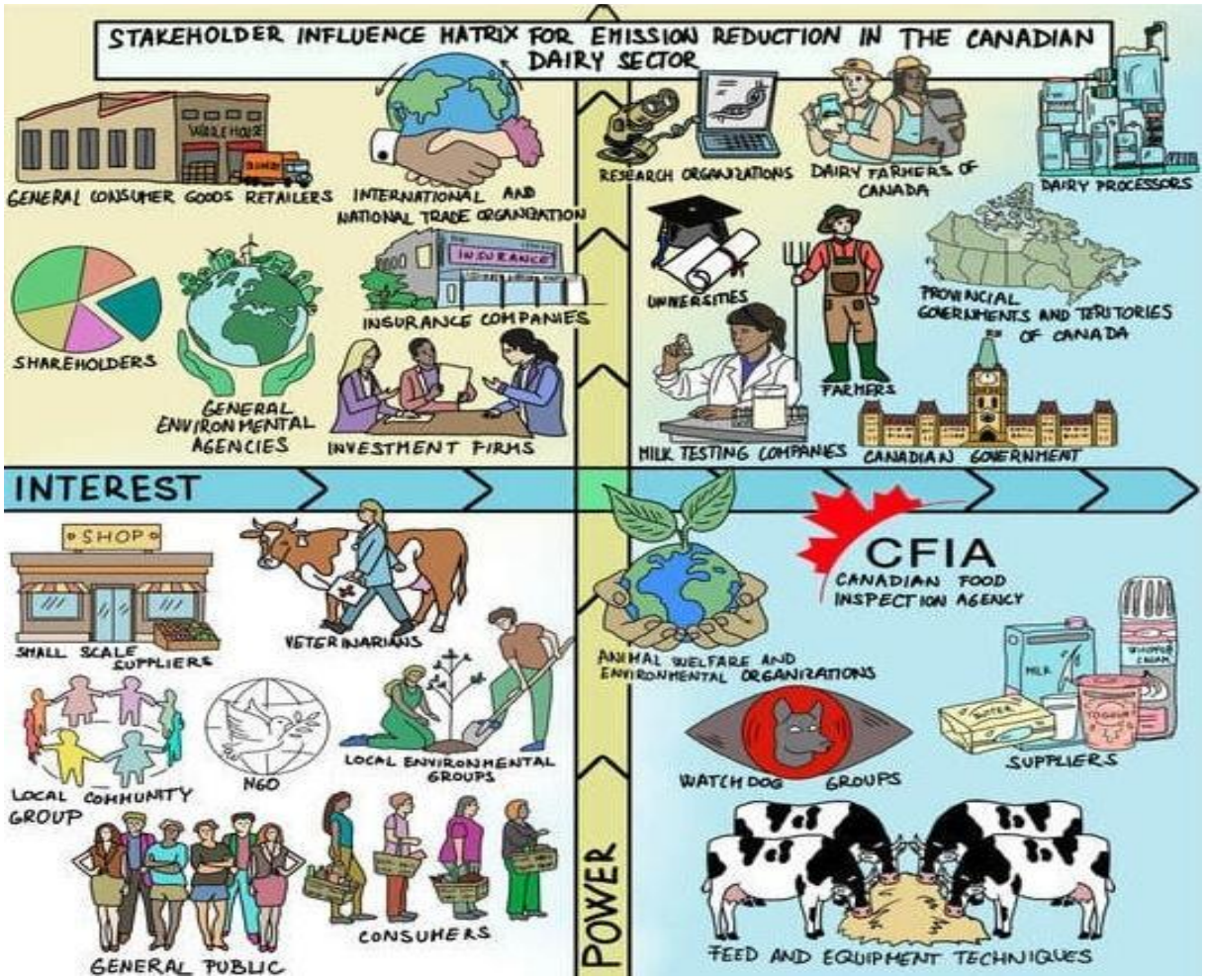



*Figure 1. An example of how different groups or individuals can impact efforts to reduce greenhouse gas emissions within the dairy industry in Canada [10].*

Apart from farmers, raising public awareness about the importance of sustainable livestock production and the role of consumers in driving change can create demand for climate-friendly products and practices. Educational campaigns, media outreach and consumer labels can help inform consumers about the environmental impact of their food choices and encourage demand for sustainably produced livestock products. [4, 9, 10].

## Training Programs and Capacity-Building Initiatives

Training programs can be developed to educate livestock farmers about the impacts of climate change and the strategies available to mitigate and adapt to these changes. Extension services, workshops and demonstration farms can help disseminate knowledge and best practices. Training initiatives play a crucial role in building the capacity of livestock producers to implement climate-smart practices. Farmers may lack knowledge or technical skills required to adopt sustainable farming techniques.



*Figure 2. The training activities within the CLIAVE Erasmus+ project aim to enhance farmers' knowledge of climate-smart animal husbandry practices.*

Training programs can fill this gap by providing practical guidance and hands-on experience in areas such as soil conservation, water management and animal health. Moreover, by providing education on climate-smart practices, such as improved animal management, feed efficiency and resource conservation, these programs can empower farmers to mitigate and adapt to climate change. Therefore, training programs offer valuable opportunities to build capacity and disseminate knowledge among livestock producers [2, 4].

## Access to Resources

Training and policy interventions can improve farmers' access to resources and technologies needed for climate adaptation and mitigation. This includes access to climate-resilient crop varieties, drought-tolerant forages, improved animal breeds and renewable energy solutions. By facilitating access to these resources, policymakers and training programs can empower farmers to enhance their resilience to climate change [6].

## Research, Innovation, Collaboration and Knowledge Sharing

Investing in research and development of new technologies and innovations tailored to the livestock sector can help improve resilience to climate change. This may include breeding more heat-tolerant livestock breeds, developing feed supplements that reduce methane emissions, or designing energy-efficient housing systems. Advances in precision agriculture, remote sensing and digital monitoring tools enable farmers to optimize resource use, minimize environmental impacts and respond effectively to climate variability. For example, wearable sensors can monitor animal health and behavior in real-time, helping farmers identify and mitigate heat stress risks [11]. Research must integrate climate change impacts with livestock keepers' adaptation efforts to inform policy decisions and effectively support targeted adaptation options. Establishing this evidence is crucial for ensuring adaptation aligns with the needs of the livestock sector and meets the growing demand for animal-based products [9].




*Figure 3. Contemporary model for sustainable dairy farming [10].*

Encouraging collaboration and knowledge sharing among stakeholders, including farmers, researchers, policymakers and industry representatives, can facilitate the exchange of ideas, experiences and best practices. Platforms such as farmer networks, research consortia and multi-stakeholder partnerships can foster collaboration and collective action. Enhancing innovation capacity and offering farmer support are vital for expanding sustainable and regenerative agriculture, thereby maximizing its positive effects. Agriculture holds significant potential in mitigating climate change impacts and by fostering collaboration among farmers and other food system actors, challenges can be addressed

more comprehensively. Initiatives like Test Farms [12], facilitate farmer-startup partnerships, allowing farmers to acquire new skills and startups to pilot their solutions with support for scalability.

## Risk Management

Livestock producers face a range of climate-related risks, including heat stress, drought, disease outbreaks and feed shortages. Adaptation and mitigation strategies can help mitigate these risks and build resilience in the face of uncertainty. By providing training on risk assessment and management techniques, as well as access to insurance and financial support mechanisms, farmers can better cope with climate-related challenges [13].

In conclusion, mitigation and adaptation strategies are essential for building climate resilience in livestock production systems. Training programs, policy interventions and technological innovations offer promising avenues for encouraging and implementing these strategies. By investing in education, policy support and research and development, stakeholders can promote sustainable practices that enhance the productivity, profitability and environmental sustainability of livestock farming.

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MODULE 6

# Energy Efficiency Improvements and Renewable Energy Supply into the Agricultural Sector

**Burçin ATILGAN TÜRKMEN, Levent BURGU**

## Outline

•Energy

•Sustainable Agriculture

•Energy Usage in the Agricultural Sector

•Energy Production in the Agricultural Sector: Bioenergy

•Energy Management in Agricultural Production

•Renewable Energy Applications in Agriculture-1

•Renewable Energy Applications in Agriculture-2

• Energy Efficiency in Agriculture Sector

## Introduction

Agriculture is one of the most important sectors of many countries' economies. Energy is critical for economic growth and is a necessary component for agricultural productivity, competitiveness and sustainability. Population growth, urbanization and economic development increase the demand for food and energy.

Agriculture is an energy conversion process that converts solar energy into food energy for humans and animal feed via photosynthesis. Agriculture makes extensive use of human, animal and mechanical energy in its production. Modern agriculture necessitates the use of energy at all stages of production, including direct energy use in agricultural machinery, water management, irrigation, planting, drying, storage and harvesting. Furthermore, many indirect energy inputs are used in agriculture, such as mineral fertilizers and chemical pesticides, insecticides and herbicides.

Agricultural energy demand is currently primarily dependent on energy supplied by fossil fuels. The environmental impacts and energy security issues caused by agricultural energy use can be reduced by encouraging the efficient use of energy and renewable sources such as solar, wind, biomass, tidal, geothermal, small-scale hydropower, biofuels and wave-generated energy. It is also critical in agricultural activities to use various technologies and resources to increase energy efficiency in order to improve financial situation, reduce energy consumption and reduce environmental impacts.

Solving the agricultural sector's energy problem is critical to aligning with the Sustainable Development Goals and the Paris Agreement on Climate Change. Combining energy efficiency with increased use of renewable energy will reduce agriculture's reliance on fossil fuels, reduce greenhouse gas emissions and help to solve the food security problem.

# ENERGY

The energy demand is increasing rapidly due to factors such as the growing global population, urbanization, industrialization and technological developments. Since it is a fundamental component of all products and is used in almost every aspect of daily life, energy is a crucial component for raising the welfare level of societies. It is directly related to all aspects of human welfare, including necessities, agricultural issues, health care, employment, education and sustainability [1]. The percentage of people who have access to electricity worldwide increased from 83% in 2010 to 91% in 2020. The number of individuals without access to electricity decreased throughout this time, from 1.2 billion to 733 million. Only 92% of the world's population would have access to electricity in 2030 if things continue as they are, leaving 670 million people without power [2]. Energy service delivery must be safe, affordable and have minimal negative environmental effects for development to be sustainable [3].

## Energy Sources

Energy is defined as the ability to perform tasks. It comes in a variety of forms, including mechanical (potential and kinetic), thermal, electrical, chemical and nuclear energy. It can also be converted from one form to another for use in a variety of applications and it can be categorized in a variety of ways [4].

Primary energy contains all energy sources that have not been transformed, exploited directly, or imported. As presented in Figure 1, there are two different kinds of primary energy sources: non-renewable and renewable. Oil, coal, gas, uranium and all other forms of renewable energy, such as hydropower and wind, are examples of primary energy. While renewable energy is produced from resources that can be replenished naturally over time and are thus suitable for use, non-renewable energy sources have a finite supply because they typically take a long time to replenish [5, 6]. Secondary energy is created when primary energy is transformed or processed, examples include the production of electricity from the combustion of natural gas or the processing of hydroelectricity. The production of oil products like gasoline from the refining of crude oil and the production of coke from coal are two additional examples of secondary energy [7].

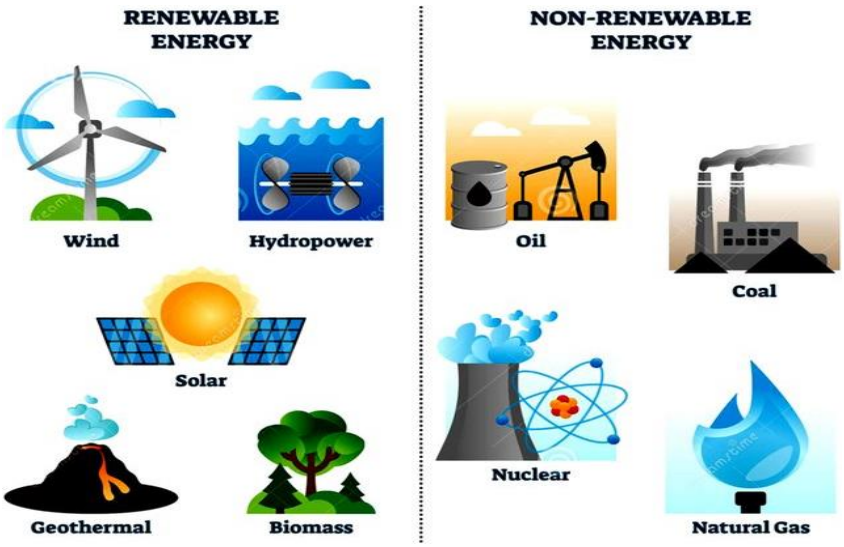



*Figure 1. Energy sources [8]*

## Non-renewable energy sources

Non-renewable energy comes from resources that either cannot be replenished in the near future or whose rate of replenishment is significantly slower than the rate of use. Because these primary energy

sources are found in limited quantities in nature, they are considered non-renewable resources. Non-renewable energy resources include fossil fuels (coal, oil and gas) and radioactive minerals, which are used in nuclear power generation [5].

Coal is a sedimentary rock that is black or brownish-black in colour and can be burned to generate energy. Although coal can be used to produce heat in industry, its main purpose is to produce electricity and many nations rely on its availability for a consistent source of energy. Petroleum is a mixture of hydrocarbons that can be found in liquid, gaseous and solid states. Liquid and gaseous petroleum, the two most prevalent types of petroleum, are typically extracted from reservoirs by drilling wells and pumping the finished product to the surface. Diesel is a crude oil product that is widely used in energy-related applications such as transportation, heating and electricity generation. Natural gas is a gas that can be found both separately and dissolved in crude oil. It has more energy per unit of fuel and typically has less of an impact on the environment than crude oil or its products, which is its main advantage. Natural gas has a variety of applications ranging from residential to commercial to industrial. Residential applications include cooking and heating, while commercial applications include space and water heating. Radioactive minerals (uranium or plutonium) release energy within their atoms when the nucleus is broken apart by nuclear fission, releasing heat that can then be used to generate electricity [1, 6]. Burning coal, oil, or gas at fossil fuel power plants produces heat in the form of steam, which powers massive turbines that generate electricity. These machines consistently generate electricity for extended periods [3].

## Renewable energy sources

Renewable energy sources are those that can be replenished naturally, making them virtually limitless. The sun, the Earth's heat, wind and water are just a few examples. Biomass-derived energy is also considered renewable [9]. Renewables have enormous potential to provide all necessary energy services. Further developing and utilizing renewable energy sources using modern conversion technologies would improve global energy security, lower the long-term price of conventional fuels and conserve fossil fuel reserves for other applications and future generations [10].

A wide range of technologies are available or in development to provide affordable, dependable and long-term renewable energy services [10]. Solar energy is created by converting sunlight into heat or electricity. Solar energy is used in a variety of technologies. These include solar heating, photovoltaic cells and solar thermal electricity generation technology. By burning biomass, energy can be produced from biomass in two ways: directly as heat or electricity, or indirectly as a liquid or gas that can produce energy. Wood, corn, sugarcane, animal waste and municipal solid waste are a few examples of biomass. Energy can also be derived from landfill gas, or methane, which results from the decomposition of biomass in landfills. Biomass technologies include biomass power systems and transportation biofuels. Wind turbines can transform wind energy into electrical or mechanical power. In order to harness the power of the wind, wind turbines typically consist of blades mounted on shafts and towers. Flowing water creates energy that can be captured and converted into electricity, making hydropower the cleanest and most efficient way to generate electricity. Using geothermal technology, heat from the earth's subsurface is extracted and either used directly for heating and cooling purposes or transformed into electricity [3, 9, 11].

Compares the benefits and drawbacks of renewable and non-renewable energy sources.

*Table 1: Comparison of energy sources [5]*

| Energy Source | Advantages | Disadvantages |
|---|---|---|
| Nuclear | •Zero greenhouse gases.<br>•Capable of converting energy effectively.<br>•Resources of uranium are plentiful.<br>•Annual refueling, as opposed to coal plants, which require trainloads of coal every day. | •Higher capital costs resulting from storage, radioactive waste management, containment and safety concerns.<br>•Issue with storing radioactive waste for an extended period of time.<br>•The issue of possible nuclear proliferation. |
| Coal | •A plentiful supply.<br>•Extraction is currently inexpensive.<br>•Dependable and capable of producing large amounts of power. | •Produces significant amounts of greenhouse gases and acid rain.<br>•Mining and burning have a high environmental impact, though cleaner coal-burning technology is being developed.<br>•Mining can be hazardous to miners' health. |
| Oil | •The basis for many products, from medicine to plastic.<br>•Produced at a low cost.<br>•Effective and simple to transport. | •Significant greenhouse gas emissions.<br>•Only found in a few places.<br>•Natural gas/coal resources may be depleted before supply.<br>•The potential environmental impact of drilling and transportation. |
| Natural gas | •It is widely available.<br>•The cleanest-burning fossil fuel, frequently used in conjunction with other fuels.<br>•The output can be adjusted to meet demand. | •Transportation costs are prohibitively expensive.<br>•Gas resources are unavailable in some areas due to a lack of infrastructure.<br>•Burns cleanly but produces emissions.<br>Pipelines have an impact on ecosystems. |
| Solar | •It is non-polluting.<br>•The most plentiful energy.<br>•Systems have a lifespan of 15-30 years. | •Expensive initial investment.<br>•In areas with little sunlight, extra energy may be required.<br>•Photovoltaic cell panels necessitate a lot of physical space.<br>•Limited accessibility |
| Wind | •There are no emissions.<br>•Reasonably priced.<br>•Minimal disruption to ecosystems.<br>•Extremely high output. | •The output is proportional to the wind speed.<br>•It is not possible in all geographic areas.<br>•Expensive initial investment and upkeep.<br>•Extensive land use. |
| Hydropower | •There are no emissions.<br>•Reliable and capable of producing large amounts of power | •Environmental effects from changing the environment around the dam.<br>•Hydroelectric dams are costly to construct.<br>•Drought may have an impact on dams. |
| Biomass/ Biofuel | •Plenty of supply.<br>•Lower emissions than fossil fuels.<br>•It is suitable for use in diesel engines.<br>•Automobile engines can easily be converted to run on biomass fuel. | •To reduce transportation costs, the source must be close to the usage.<br>•Produces some pollution in the form of waste.<br>•Increased nitrogen oxide emissions.<br>•Some fossil fuels are used in the conversion process. |
| Geothermal | •Low environmental impact.<br>•Effective.<br>•Power plants emit little pollution.<br>•Lower costs after initial investment. | •Only a small number of locations on earth have geothermal fields.<br>•Significant start-up expenses.<br>•Wells could eventually dry up. |

## Global Energy Sector

Global energy demand is rapidly increasing due to urbanization, population and economic growth, particularly in emerging market economies. As presented in Figure 1, the total world primary energy supply (TPES) grew more than 2.6 times between 1971 and 2019 and reached 606 EJ [12]. The majority

of the global energy supply comes from Organization for Economic Co-operation and Development (OECD) countries. As of 2019, the OECD countries received 37.1% of total energy supplies. China came in second with a supply share of 23.5% [12].

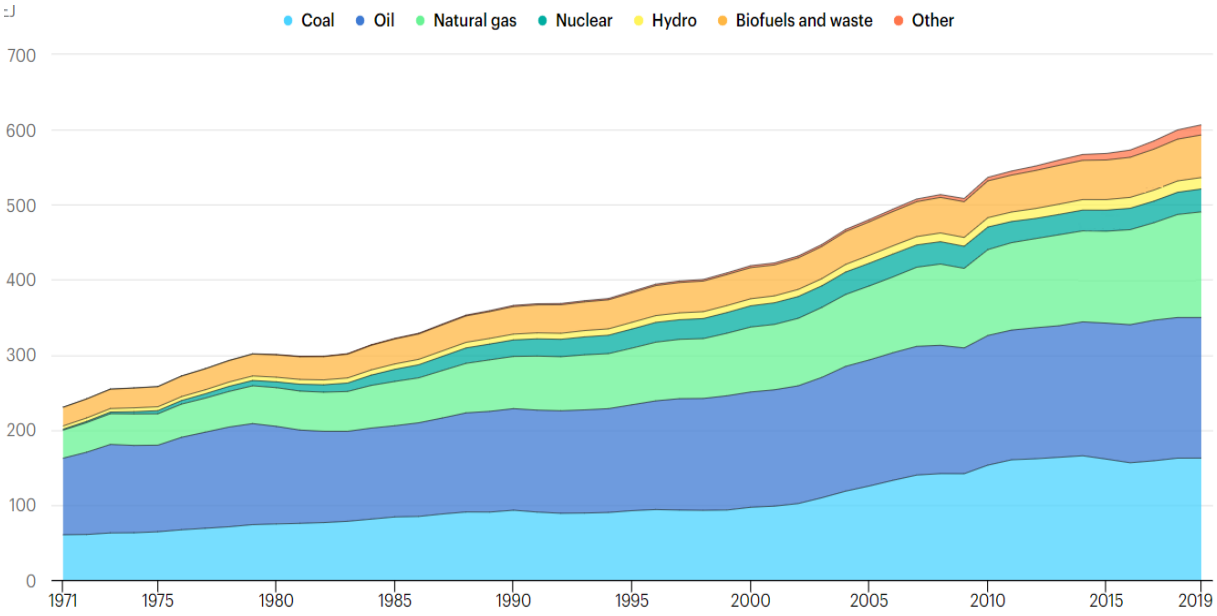



*Figure 2: World total energy supply, 1971-2019 [12]*

As shown in Figure 3, in 2019, oil provided 30.9% of the world's primary energy supply, coal 26.8%, and natural gas 23.2% of the world's primary energy supply. Following these are combustible renewable sources and waste (9.4%), nuclear (5.0%), hydropower (2.5%), and wind, geothermal and solar (2.2%) [12]. China dominated the global markets for concentrating solar thermal power, hydropower, solar PV and wind power, accounting for nearly half of all installations in 2020 [9]. In developing countries, biomass accounts for more than 20% of total energy supply. In these countries, the majority of biomass is used for cooking and heating [13].

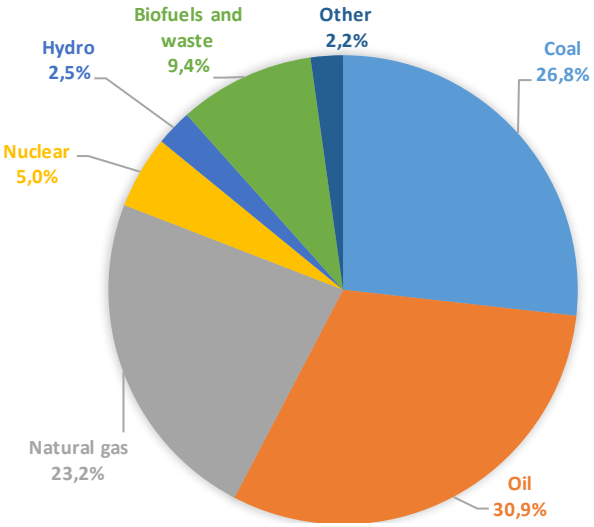



*Figure 3. Global share of total energy supply by source, 2019 [12]*

Global energy demand increased by less than half the rate of growth seen in 2018, reaching 418 EJ (Exajoule) in 2019. As presented in Figure 4, oil (40.4%) remained the dominant fuel for the final consumption of energy followed by electricity (19.7%), natural gas (14.5%), biofuels (10.4%), coal (9.5%) and others (3.6%) including wind, solar, hydropower and geothermal [12].

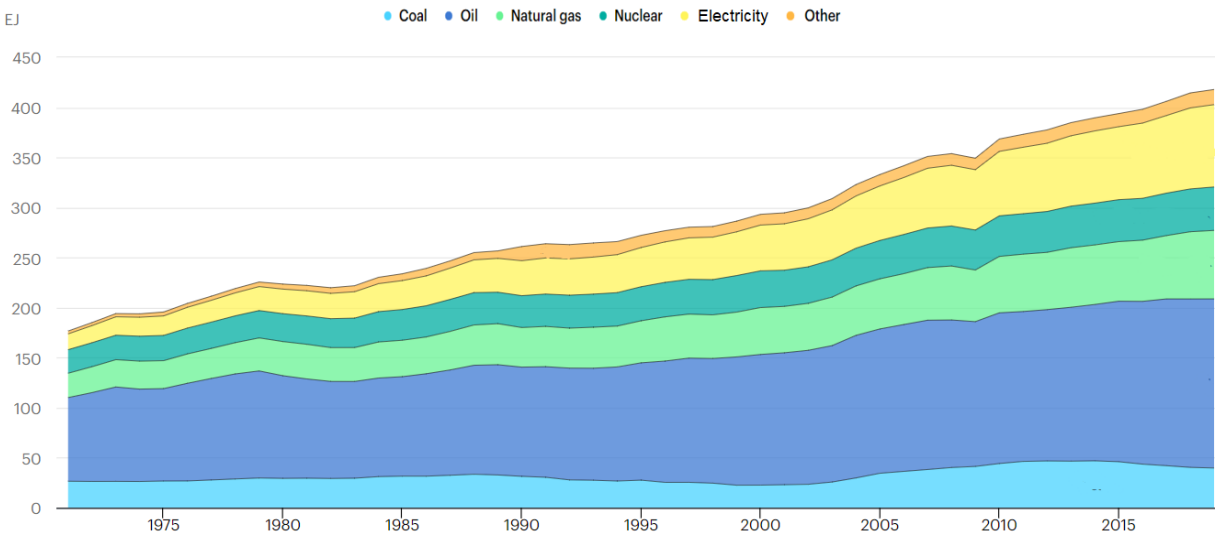



*Figure 4. World total final energy consumption, 1971-2019 [12]*

Regionally, with a 3.4% increase, China accounted for 90% of net global energy demand growth in 2019, while energy demand fell in almost all advanced economies. Energy demand in the European Union fell by 2%, while it fell by 0.8% in the United States. While demand in Southeast Asia increased at a rapid pace of 3.4%, growth in India fell from 4% in 2018 to 0.9% in 2019, the lowest level since 2007 [12].

Despite using the most renewable energy (26%), the power industry accounted for only 17% of total final energy consumption in 2019. Renewables continue to play a minor role in industrial energy demand, particularly in industries requiring high processing temperatures. Renewable energy accounts for approximately 14.8% of total industrial energy demand and is primarily used in businesses that require low-temperature process heat. Renewable electricity accounts for 10% of renewable industrial heat, but only 1% of total industrial heat consumption in 2019. The transportation sector continues to have the lowest renewables share, with oil and petroleum products (along with 0.8% non-renewable electricity) meeting nearly all global transportation energy needs (95.8%). Only 3.1% and 0.3% of those requirements were met by biofuels and renewable electricity, respectively. Renewable energy is meeting a growing portion of building final energy demand, but it still accounts for less than 15% of total energy demand [9].

Energy sector is a critical sector for any country's long-term development, however, its production and consumption have environmental, economic and social consequences, such as climate change, pollution and energy poverty. Sustainable energy is defined as energy that can be used repeatedly and meets our current energy needs without endangering its life or becoming depleted [3, 14]. When coal, oil, or gas are burned in fossil fuel power plants, heat is produced in the form of steam, which powers massive turbines that generate electricity. These machines produce electricity on a consistent basis for extended periods of time. In contrast, the combustion of fossil fuels emits large amounts of greenhouse gases and other harmful gases and solids into the atmosphere, causing climate change, acid rain and soil and water contamination. Using renewable energy resources to generate electricity instead of fossil fuels reduces emissions from the power sector [3, 15]. It is essential to establish an energy system that meets economic needs while protecting the environment because energy production, conversion and use have a substantial negative influence on the environment. The global $CO_2$ emissions related to energy levels stagnated in 2019 at about 33 gigatonnes (Gt). Carbon emissions from energy use increased by 0.5% between 2018 and 2019, less than half the 10-year average annual growth rate of 1.1% [12, 16].

The advantages of renewable energy for the environment, such as lower carbon emissions and less air pollution, are well known. But only in recent decades, as the use of renewable energy technologies has spread, have its many socioeconomic advantages become clear. Each year, a sizable number of jobs

are created worldwide thanks to renewable energy. A record 10.3 million people were employed globally in the renewable energy industry. More than a billion people live in areas without access to electricity and another billion rely on erratic supplies. For the 80% of people without access to rural areas or small developing island states, micro renewable electricity solutions are now financially feasible thanks to increased reliability, rapidly declining technology costs and supportive policies [15].

## Energy Efficiency

Energy efficiency is the ratio of energy input to output in terms of performance, operation, products, or energy. It means doing the same amount of work with less energy. Energy efficiency is typically expressed as the amount of energy output for a specified energy input and is expressed as a percentage between 0% and 100%. From energy production to energy consumption, there are multiple places throughout the chain where energy efficiency can be increased [17].

Energy efficiency has several advantages, including lower greenhouse gas emissions, lower demand for energy imports and lower household and economic expenditures. Every area of the economy has significant potential for efficiency improvements, whether it is buildings, transportation, industry, or energy generation. Energy efficiency initiatives can lead to the creation of new jobs in the energy sector and the industry [6, 17].

Global primary energy efficiency increased by 1.9% per year from 5.6 megajoules per US$ in 2010 to 4.7 in 2019. To reach the energy efficiency target, the yearly rate of increase must average 3.2% per year until 2030 [2].

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# SUSTAINABLE AGRICULTURE

The only source of human food is agriculture. While ensuring global food security, sustainable agriculture should support sustainable management of land, water and natural resources. In order for agriculture to be sustainable, it must provide the goods and services that will satisfy the needs of both the present and the future generations while maintaining profitability, environmental health and social and economic equity [1, 2]. Food production systems, as well as the policies and institutions that support global food security, are increasingly incapable of reducing food insecurity or ensuring environmental sustainability [3].

## Sustainable Development

Sustainability is based on the principle that “meet the needs of the present without compromising future generations' ability to meet their own needs”. A major objective of sustainability is for people to live peacefully and long-term on Earth. Decisions at the international, national and individual levels can be guided by the idea of sustainability [4].

As presented in Figure 1, environmental, economic and social pillars are used to describe sustainability. There are numerous issues associated with environmental sustainability, ranging from pollution to natural resource management. The main aim of environmental sustainability is to reduce the environmental impact of human activities while also encouraging the restoration and preservation of our natural habitat. Environmental protection is frequently the first thing that comes to mind when considering sustainability. However, the sustainability concept also embraces social and economic sustainability [5].

Economic sustainability refers to an economy's ability to sustain a specific level of economic production indefinitely. It involves achieving a balance between economic expansion and profit-making with the effects on the people and the environment. [6]. The social pillar of sustainability refers to values that promote equality and individual rights. In order to ensure social sustainability, impacts of both the positive and negative on people must be identified and managed [7].

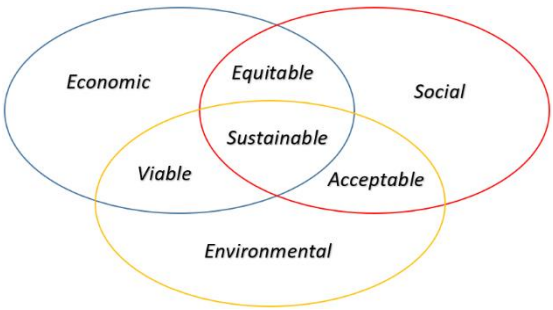



*Figure 1. Three pillars of sustainability*

The Global Goals, also referred to as the Sustainable Development Goals (SDGs), were established by the United Nations (UN) in 2015 as a component of the 2030 Agenda for Sustainable Development. Due to climate change, this agenda seeks to reduce poverty, health issues, illiteracy and slow economic growth. SDGs are a "blueprint to achieve a better and more sustainable future for all" and include 169 targets in addition to 17 goals to address these problems (Figure 2). Over the next 15 years, the SDGs will guide national development plans [8].

Since the SDGs are interconnected, many sectors and industries have an impact on a variety of SDG-related issues, including agriculture, which is essential to achieving the SDGs by 2030 as set forth by the UN. Agriculture is a focal point for many of the Sustainable Development Goals [9]. SDG #2, which relates to food production, calls for "ending hunger, achieving food security and improved nutrition and promoting sustainable agriculture." However, without a successful and sustainable agricultural sector, other SDGs cannot be achieved. For example, food production is inextricably linked to other

SDG challenges including ensuring access to clean water and sanitation (SDG #6), ensuring access to affordable and clean energy (SDG #7), promoting decent employment and economic growth (SDG #8), and promoting responsible consumption and production (SDG #12). Agriculture indirectly affects the SDGs for life on land (SDG #15), gender equality (SDG #5), climate action (SDG #13), and poverty (SDG #1). Food and agriculture are central to the 2030 Agenda, from eradicating poverty and hunger to combating climate change and conserving natural resources [8, 10].




*Figure 2. Sustainable Development Goals (SDGs)*

## Agriculture and Sustainability Issues

Agriculture is facing many challenges in the 21st century. The main sustainability concerns that the food and agriculture industry must address are hunger in developing countries, obesity in developed countries, rising food prices, persistent climate change, rising fuel and cost of transportation, flaws in the global market, global pesticide pollution, pest adaptation and resistance, loss of soil fertility and organic carbon, soil erosion, declining biodiversity and desertification [11, 12].

Sustainable agriculture is a viable option for dealing with fundamental and applied food production issues in an environmentally, economically and socially responsible manner. It entails creating and putting into practice management practices that support organic processes in order to preserve all resources, cut down on waste and safeguard the environment while preserving or enhancing farm profitability. It is critical to work with natural soil processes [13, 14]. Furthermore, concerns about animal welfare must also be addressed in farm enterprises that include livestock [1].

The current rate of growth in agricultural production is unsustainable due to the detrimental effects on natural resources and the environment. Up to 75% of crop genetic diversity has been lost, one-third of farmland has been degraded and 22% of animal breeds face extinction. Thirteen million hectares of forest are lost each year to other land uses and more than half of fish stocks are fully utilized. The main issues are the growing scarcity and quick depletion of natural resources at a time when demand for agricultural products and services, such as food and feed, is rising quickly. The areas with the highest rates of food insecurity and agricultural dependence are predicted to experience the fastest population growth [15].

In sustainable agriculture systems, the already-existing soil energy flows, nutrient and water cycles, beneficial soil organisms and natural pest controls are all fully utilized [13]. Agriculture is both a

significant contributor to and one of the most vulnerable economic sectors to climate change. Greenhouse gas emissions from agriculture occur both within the farm gate and at the land use change boundary between natural ecosystems and agricultural land. They account for roughly 20% of all human-caused emissions [16].

As presented in Figure 3, as a result of a balance between rising farm gate emissions and falling emissions from land use change, worldwide agricultural emissions (including those from farm gate and land use change processes) were close to 11 billion tonnes of $CO_2$ equivalent ($CO_2$ eq.) in 2019 [16]. Only crop and livestock-related GHG emissions contribute roughly 5 billion tonnes of $CO_2$ eq. to the atmosphere each year [17].

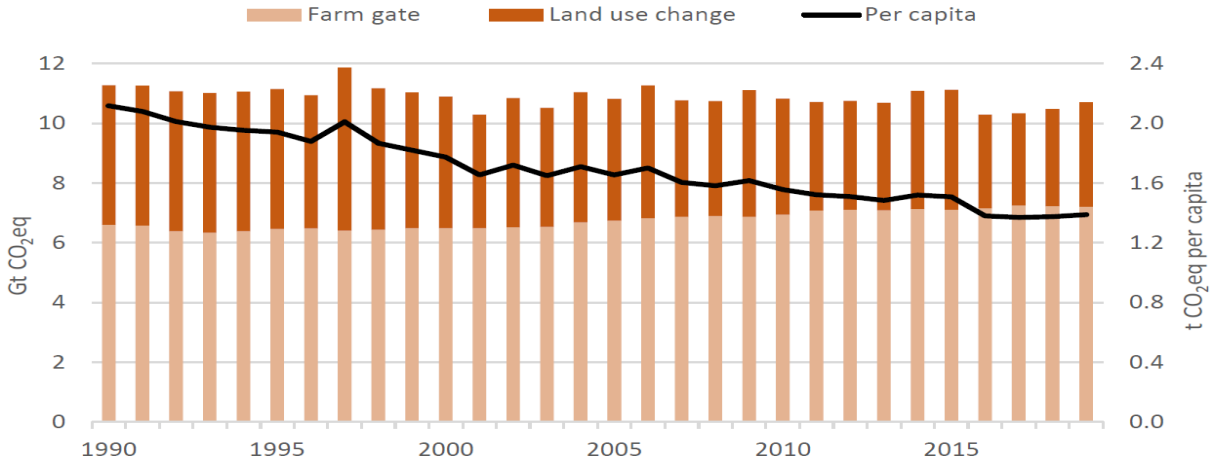



*Figure 3. Agriculture's global absolute and per capita emissions from 1990 to 2019, with farm-gate and land use change [16]*

Asia had the largest absolute emissions (4 billion tonnes) in 2019, whereas Oceania and Latin America had the highest per capita emissions (4-6 tonnes per capita). Africa has had the biggest increase (30%) since 1990, while Latin America has seen the greatest reduction (20%). More over half of worldwide agricultural emissions were accounted for by Brazil, Indonesia and China. In Brazil and Indonesia, deforestation and peat fire emissions dominated national agricultural emissions, respectively, but farm-gate emissions were the major contributor in China [16].

Within the farm gate, methane, nitrous oxide and $CO_2$ emissions contributed more than 7 billion tonnes of $CO_2$ equivalent (eq.) in 2019, a 9% increase since 1990. Livestock accounted for two-thirds of methane and nitrous oxide emissions. Land use change contributed 3.5 billion tonnes of $CO_2$ eq., the majority of which came from carbon losses from deforestation and peatland fires. Since 1990, the former has decreased by about 30%, while the latter has increased by nearly 60% [16].

## Sustainable Agriculture and Energy

In order to meet the world's increasing demand, make them more inclusive, secure and sustainable and comply with the Paris Climate Agreement and the 2030 Agenda for Sustainable Development, the energy and food systems must be transformed. The systems for supplying food and energy have a significant impact on the environment, economies and society as a whole, which makes them essential for achieving many SDGs [18].

The food system's current energy use is unsustainable. Due to the lack of affordable, dependable and sustainable energy for millions of people and small and medium-sized agri-food businesses, there are significant food losses in the post-harvest stages. Before it even reaches the market, about 14% of the food produced worldwide is lost [19]. Food losses are addressed throughout the supply chain, as reducing waste leads to lower demand for land, water and energy, as well as lower emissions [20]. In 2019, more than 2.6 billion people paid a disproportionate amount of money to live without access to clean cooking fuels and technologies [18].

A third of the world's total final energy demand is accounted for by the agriculture and food systems, the majority of it in post-harvest processes and as fossil fuels [21]. At some point along the value chain, food losses result in the loss of about 30% of that energy [18].

All phases of food production, processing and distribution up until final consumption are included in agri-food supply chains [12]. In the global agri-food system, agriculture is the primary source of greenhouse gas emissions. 10% to 15% of the world's greenhouse gas emissions are directly attributable to agriculture. Up to 30% more emissions result from adding land use changes and deforestation to the production of animal feed. Methane and nitrous oxide, which together account for about 22% of global emissions, is also primarily produced by agriculture [22].

Energy can help to achieve sustainable agriculture. This can be accomplished by incorporating efficient energy technologies and renewable energy into agricultural systems, utilizing waste from the agri-food industry to generate renewable energy, reducing waste-related GHG emissions and trapping carbon in soils and energy crops using biofertilizers made from biomass. Having enough energy in food chains might help with climate change adaptation by increasing resilience to changing weather patterns and possibly increasing income through product and service diversification, value-added activities and local job creation [18].

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# ENERGY USAGE IN THE AGRICULTURAL SECTOR

In many countries, agriculture is the most important economic sector. Energy has always been required for agricultural production and value addition. Agriculture makes extensive use of human, animal and mechanical energy [1]. The modernization of many agricultural production activities increases mechanical energy consumption. The agricultural sector, like other sectors, has become dependent on energy sources such as oil and electricity as a result of the changes in the agricultural sector [2].

Energy efficiency is required to sustain agricultural production due to economic savings, conservation of fossil resources and reduction in air pollution. Furthermore, because agricultural land is limited, the only way for producers to increase total output is to use more inputs. Given the agricultural sector's reliance on energy to feed a growing population, as well as the impact of energy use on the environment and human health, as well as limited natural resources, it is critical to investigate energy use and energy efficiency in the agricultural sector [2, 3].

## Agricultural Energy Use

Through the process of photosynthesis, agriculture transforms solar energy into food energy for humans and feed for animals. Simple farming practices like scattering seeds on the ground and accepting the meagre yields that followed constituted primitive agriculture. Today, modern (intensive) agricultural practices, in which various methods are used to obtain high yields from the soil, have largely replaced primitive agriculture [4]. As a result of the implementation of modern agricultural production processes, a shift from human or animal power, which is widely used in agricultural production processes, to mechanical energy using fuels has occurred [5].

Energy has always been crucial for agricultural production and rural development. From small organic farms to large industrial farms, agriculture uses a lot of energy [6]. Today, energy use in crop and animal production processes in the agricultural sector is categorized into two groups: direct and indirect [7].

Direct Energy Usage in Agriculture: The phrase "direct energy used in agriculture" refers to energy used directly in agricultural operations like harvesting, irrigation, drying, storing, heating greenhouses and marketing, as well as in infrastructure, farm machinery, tractors and lorries [7]. In animal production, electricity, biomass, coal and natural gas are used for activities such as feed preparation-distribution, manure cleaning, milking, lighting, heating, ventilation and cooling in agricultural buildings such as animal shelters [8].

Indirect Energy Usage in Agriculture: The phrase "indirect energy used in agriculture" refers to the energy used in the production of mineral fertilizers and chemical pesticides, insecticides, herbicides and other agricultural chemicals, as well as the chemical substances used in their processing [7]. Indirect energy, as the name implies, is not used directly on the farm. These energy inputs are usually found in the industrial sector [8].

Today's agriculture frequently uses an intensive farming system because of the growing population and the high demand for food. Given the quick crop rotation in the field and high input use, intensive farming requires a farmer to invest significant financial resources and knowledge in managing the land and crop [5]. As shown in Figure 1, modern agriculture necessitates the use of energy at all stages of production, including energy use in farm machinery, water management, irrigation, sowing and harvesting. Energy is used in agricultural production stages such as farming, fertilizer production, transportation and processing. Agriculture includes crop cultivation and harvesting, as well as livestock care and slaughter. Transportation is the process of transporting agricultural products to the next stage of production using any mode of transportation. Foods that cannot be consumed immediately after leaving the farm must be processed. Post-harvest energy use includes energy used for food processing, storage and transportation to markets. Furthermore, many energy inputs, such as mineral fertilizers and chemical pesticides, are used in agriculture [9-11].

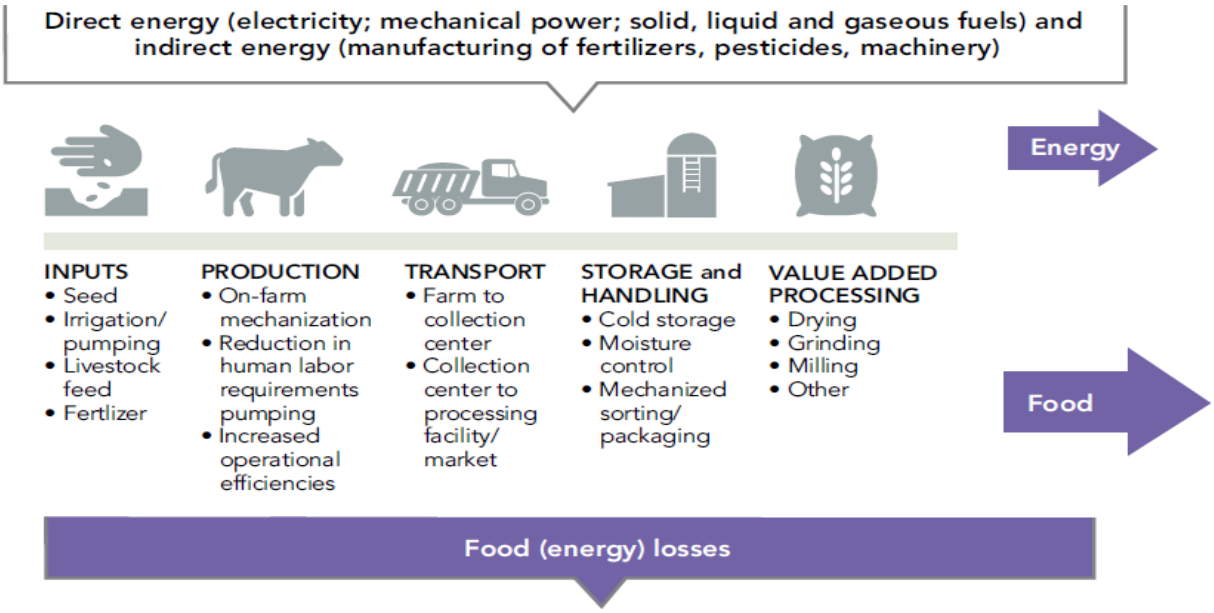



*Figure 1. Energy and agriculture, modified from [12]*

Agriculture, which includes crop cultivation and animal husbandry, is one of the most energy-intensive stages of the food chain, accounting for roughly one-third of total energy consumed in the food production chain [3]. Tillage operations, the first stage of crop production, are typically carried out using the most energy-intensive operations [13].

Crop drying and storage is also a major step in fuel utilization. For each hectare of crop harvested/dried, a high temperature dryer consumes 55 liters of fuel oil. To reduce moisture from 20% to 15%, approximately six liters of fuel (diesel) are required for each tonne of crop to be dried [14].

Nowadays, most irrigation systems consume high amounts of energy. Irrigation system energy consumption is primarily seen as a technical challenge with the aim of improving performance [15]. Most farms use wells and groundwater sources to pump water, though some have access to public water sources. The majority of pumps use electricity, but remote locations may also have diesel or propane pumps [16, 17].

The energy consumed in livestock operations is almost entirely direct energy consumption and it is relatively low in comparison to crop operations, both as a percentage of total operating expenditure and in terms of total energy consumption. Energy is directly consumed by livestock enterprises for ventilation systems, refrigeration, lighting, heating, irrigation, motors and waste handling, whereas crop enterprises use energy for sowing, harvesting, irrigation and drying [16].

Energy accounts for a significant portion of most crops' operating expenses, particularly when indirect energy expenditures on fertilizer are considered, because fertilizer production is extremely energy-intensive, necessitating large amounts of natural gas. Energy and fertilizer expenditures account for more than half of the total operating expenses for some crops, such as oats, corn, wheat and barley. The ratio of direct to indirect energy consumption varies by crop [16, 18]. Detailed information on energy use in agriculture is presented in Table 1.

*Table 1. Energy uses in agricultural production [19]*

| Direct Use of Energy | Fuel |
|---|---|
| Operating farm machinery and large trucks:<br>Field work (tractors, combines, mowers, balers, etc.)<br>Input purchase and deliveries (large trucks) | Diesel fuel |
| Operating small vehicles (cars and pickup trucks):<br>-Farm management activities | Gasoline |
| Operating small equipment:<br>-Irrigation equipment<br>Drying of grain or fruit<br>Ginning cotton<br>Curing tobacco<br>Heating for frost protection in groves and orchards<br>Crop flamers<br>Heating/cooling of cattle barn, pig or poultry brooder, greenhouse, stock tanks, etc.<br>Animal waste treatment<br>Standby generators | Diesel fuel Natural Gas<br>LP Gas<br>Electricity |
| General farm overhead<br>Lighting for houses, sheds and barns<br>Power for farm household appliances | Electricity |
| Custom operations<br>Field work (e.g., combining)<br>Drying<br>Other | Diesel<br>Gasolin<br>Natural Gas<br>LP-Gas<br>Electricity |
| Marketing<br>Transportation: elevator to terminal, processor, or port<br>Elevating | Diesel Gasoline |
| Indirect Use of Energy | Fuel |
| Fertilizer | Natural Gas |
| Pesticides (insecticides, herbicides, fungicides) | Petroleum<br>Natural Gas |

## European Union Agricultural Energy Use

In 2020, the European Union's direct energy consumption was 886 million tonnes of oil equivalent (toe), including direct usage of oil and petroleum, electricity, natural gas, renewables and solid fossil fuels. Agriculture and forestry consumed 3.2% of total direct energy consumption in the EU in 2020 [20]. As presented in Table 2, the Netherlands had the highest proportion of its total direct energy consumption in the agricultural and forestry sector, the share of 9.0% shows the significance of the glasshouse production of horticultural plants, fruits and vegetables. Also having substantial percentages were Latvia (5.4%) and Poland (5.5%) [20].

In the EU, oil and petroleum products accounted for the majority (56.0%) of total direct energy use in the agricultural and forestry sector excluding biofuels in 2020. This was a substantially bigger share than the whole economy (35.0%) [20]. As presented in Figure 2, oil and petroleum products were the most often utilized fuel types in the agricultural and forestry sectors in the EU. There were, however, some significant outliers. In the Netherlands, direct consumption of energy from oil and petroleum products accounted for just 10.6% of total direct consumption by the agriculture and forestry industry in 2020, with natural gas accounting for the majority (53.5%) and electricity accounting for one-quarter (24.3%). In Greece, electricity accounted for nearly three-quarters (74.0%) of total direct energy use by the agriculture and forestry sectors. Renewables and biofuels contributed to about one-third (37.1% and 31.1%, respectively) of total direct energy consumption in Sweden and Austria [20, 21].

*Table 2. Direct energy consumption in the European Union [20]*

| | Direct consumption of energy by agriculture and forestry (1000 toe) | | | Total direct consumption of energy (1000 toe) | | | Share of total direct consumption of energy by agriculture and forestry (%) | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2018 | 2019 | 2020 | 2018 | 2019 | 2020 | 2018 | 2019 | 2020 |
| EU | 27,515 | 27,842 | 28,008 | 926,013 | 937,857 | 885,764 | 3.0 | 3.0 | 3.2 |
| Belgium | 800 | 902 | 806 | 33,636 | 32,580 | 31,039 | 2.4 | 2.8 | 2.6 |
| Bulgaria | 185 | 187 | 188 | 8,595 | 9,707 | 9,513 | 2.2 | 1.9 | 2.0 |
| Czechia | 620 | 635 | 638 | 23,991 | 24,222 | 23,753 | 2.6 | 2.6 | 2.7 |
| Denmark | 596 | 581 | 568 | 14,017 | 13,547 | 13,131 | 4.2 | 4.3 | 4.3 |
| Germany | 3,302 | 3,573 | 3,626 | 207,170 | 200,804 | 193,617 | 1.6 | 1.8 | 1.9 |
| Estonia | 124 | 113 | 109 | 2,408 | 2,823 | 2,727 | 5.2 | 4.0 | 4.0 |
| Ireland | 223 | 222 | 222 | 10,188 | 11,317 | 10,840 | 2.2 | 2.0 | 2.0 |
| Greece | 264 | 277 | 277 | 17,914 | 15,401 | 14,483 | 1.5 | 1.8 | 1.9 |
| Spain | 2,457 | 2,604 | 2,715 | 76,338 | 81,514 | 72,323 | 3.2 | 3.2 | 3.8 |
| France | 4,085 | 4,037 | 4,170 | 145,126 | 139,131 | 128,169 | 2.8 | 2.9 | 3.3 |
| Croatia | 218 | 221 | 234 | 5,937 | 6,726 | 6,432 | 3.7 | 3.3 | 3.6 |
| Italy | 2,798 | 2,719 | 2,759 | 119,742 | 113,119 | 103,057 | 2.3 | 2.4 | 2.7 |
| Cyprus | 42 | 43 | 45 | 1,367 | 1,627 | 1,529 | 3.1 | 2.6 | 2.9 |
| Latvia | 181 | 202 | 205 | 3,228 | 3,925 | 3,798 | 5.6 | 5.1 | 5.4 |
| Lithuania | 108 | 111 | 114 | 3,742 | 5,460 | 5,284 | 2.9 | 2.0 | 2.2 |
| Luxembourg | 27 | 24 | 24 | 3,185 | 3,790 | 3,265 | 0.8 | 0.6 | 0.7 |
| Hungary | 647 | 673 | 703 | 15,642 | 17,970 | 17,602 | 4.1 | 3.7 | 4.0 |
| Malta | 5 | 6 | 7 | 319 | 544 | 500 | 1.6 | 1.2 | 1.4 |
| Netherlands | 3,934 | 3,927 | 3,818 | 47,520 | 44,317 | 42,262 | 8.3 | 8.9 | 9.0 |
| Austria | 530 | 521 | 511 | 21,810 | 26,228 | 24,817 | 2.4 | 2.0 | 2.1 |
| Poland | 3,919 | 3,813 | 3,868 | 53,561 | 71,891 | 70,251 | 7.3 | 5.3 | 5.5 |
| Portugal | 384 | 380 | 411 | 17,214 | 16,356 | 15,215 | 2.2 | 2.3 | 2.7 |
| Romania | 566 | 557 | 531 | 21,947 | 23,713 | 23,472 | 2.6 | 2.3 | 2.3 |
| Slovenia | 75 | 73 | 72 | 4,542 | 4,863 | 4,429 | 1.6 | 1.5 | 1.6 |
| Slovakia | 133 | 129 | 132 | 9,925 | 10,248 | 9,611 | 1.3 | 1.3 | 1.4 |
| Finland | 689 | 684 | 666 | 23,282 | 24,729 | 23,191 | 3.0 | 2.8 | 2.9 |
| Sweden | 604 | 624 | 589 | 33,667 | 31,305 | 31,454 | 1.8 | 2.0 | 1.9 |

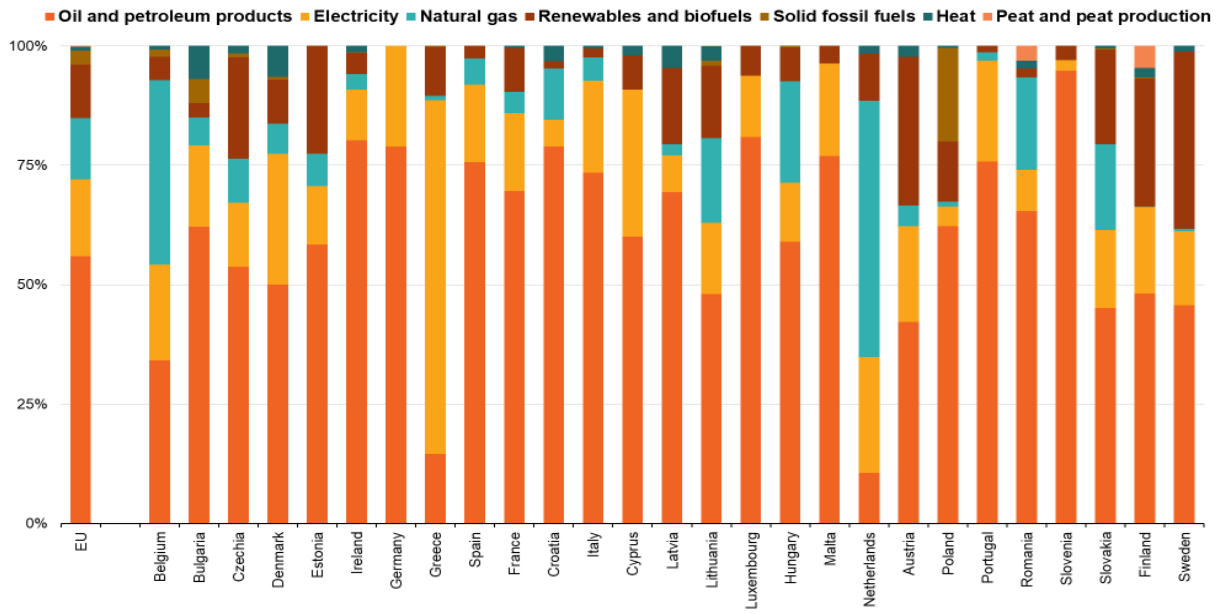



*Figure 2. Share of fuel type in energy consumption by agriculture and forestry in 2020 [20]*

Since countries vary in size, it is impossible to compare total energy consumption directly between them. It is necessary to designate a common denominator in order to compare trends across nations. The indicator and the denominator should ideally be strongly correlated. The usable agricultural area is a common denominator to evaluate agri-environmental parameters across nations (UAA). As shown in Figure 3, the average direct energy consumption of the EU agriculture and forestry sector was 173 kilos of oil equivalent per hectare (kgoe/ha) in 2020 [20].

The large-scale production of fruits, vegetables and plants in greenhouses in the Netherlands helps to explain the substantially higher average direct energy consumption per hectare of UAA in 2020 (2 104 kgoe/ha) than in other European countries. Between 2000 and 2020, apparent energy consumption per hectare of UAA fell most dramatically in Greece (-64.2%) but climbed most sharply in Hungary (+ 54.2%) [20].

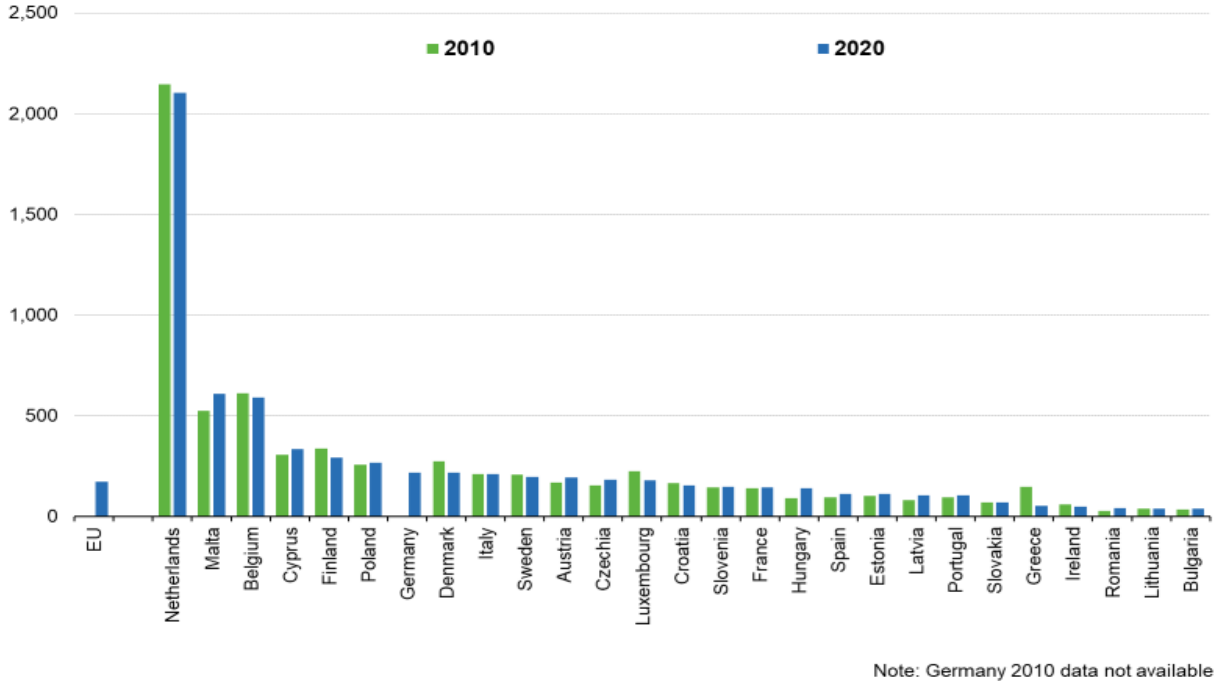



*Figure 3. Energy consumption by agriculture, 2010 and 2020 (kilograms of oil equivalent per hectare of UAA) [20]*

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# ENERGY PRODUCTION IN THE AGRICULTURAL SECTOR: BIOENERGY

Agriculture and energy have a special relationship because agriculture is both energy production and energy consumption. Photosynthesis is the process by which plants absorb solar energy and convert it into their own biomass. The biomass can be burned directly or converted into fuel-grade liquid biofuels or biogas products. Agriculture, on the other hand, necessitates energy inputs at all stages of production, including direct energy use in agricultural machinery, water management, irrigation, planting and harvesting. Energy used for food processing, storage and transportation to markets is included in post-harvest energy use. Furthermore, many indirect energy inputs are used in agriculture in the form of fertilizers and pesticides [1].

In line with the growing awareness of agricultural production, biomass energy is one of the renewable energy sources that is gaining popularity and funding each year. This energy is a crucial source of renewable energy that can sustainably meet the rising energy demand brought on by the industrialization and rapidly growing population [2]. This energy can reduce reliance on an overloaded power grid and replace costly fuels used in local industry. Biomass can generate all forms of energy, including electricity, gas, liquid fuels and heat and its use can provide rural employment, prevent migration to cities, increase agricultural profitability and help restore degraded land. This energy is also beneficial to the fight against global warming [3, 4].

## Biomass

Biomass is an important energy source that can meet the rapidly increasing energy demand caused by population growth and industrialization [5]. Biomass is defined as "the biodegradable fraction of products, waste and residues from biological origin from agriculture (including vegetal and animal substances), forestry and related industries including fisheries and aquaculture, as well as the biodegradable fraction of industrial and municipal waste" by Directive 2009/28/CE [6].

Biomass is a source of chemical energy from the sun. Sunlight is used by organisms that use photosynthetic processes to produce glucose from carbon dioxide and water, such as plants and algae. This process, known as photosynthesis, converts solar energy into chemical bond energy and results in the production of biomass. A sustainable energy source is biomass. Biomass is produced by plants through photosynthesis [7].

Biomass is defined as living or recently deceased organisms, as well as their plant or animal byproducts. The term is widely understood to exclude coal, oil and other fossilized remains of organisms, as well as soil. In this strict sense, biomass includes all living things. However, in the context of biomass energy, the term refers to crops, residues and other biological materials that can be used to replace fossil fuels in the production of energy and other products. Living biomass absorbs carbon as it grows and releases it when used for energy, resulting in a carbon-neutral cycle that does not increase the concentration of greenhouse gases in the atmosphere [8, 9].

The transition to renewable energy sources has gained importance due to the annual increase in global population and the depletion of energy resources. With 55% of all renewable energy and over 6% of the world's energy supply coming from modern bioenergy, it is the most significant source of renewable energy worldwide. Between 2010 and 2021, the use of modern bioenergy increased by an average of 7% annually and is on the rise [10].

## Bioenergy Resources

Biomass resources are resources that we come across in a variety of settings and can be found almost anywhere. As shown in Figure 1, biomass energy sources include [11]:

•Wood and waste products from wood processing, such as firewood, wood pellets, wood chips, sawdust and waste products from furniture and lumber mills, as well as alcohol from pulp and paper mills.

•Waste products and crops, including corn, soybeans, sugar cane, switchgrass, woody plants and algae, as well as crop and food processing leftovers, principally for the creation of biofuel.

•The presence of biological materials in municipal solid waste, such as waste food, yard trimmings and wool, cotton and paper goods.

•Production of biogas and renewable natural gas from animal manure and human sewage

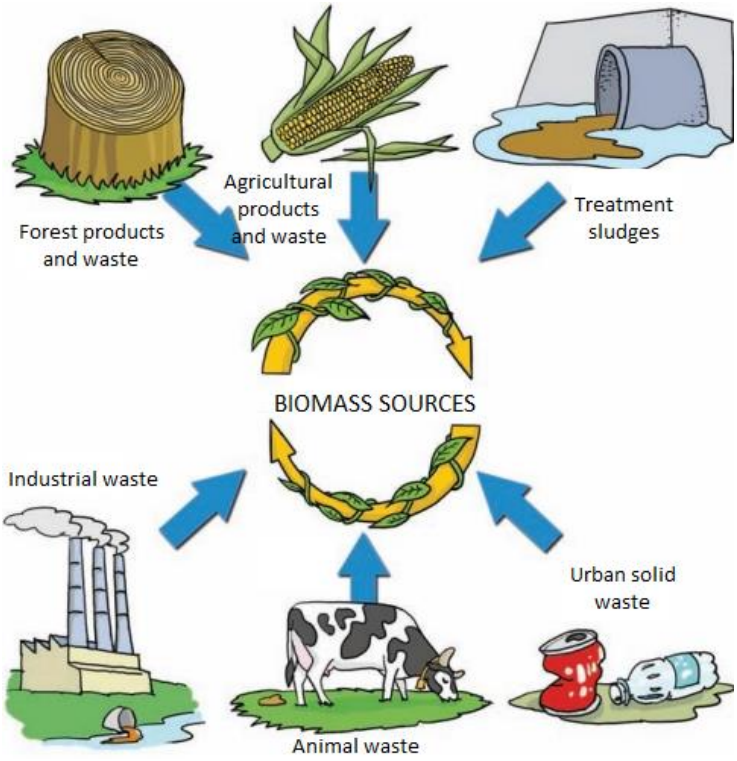



*Figure 1. Types of biomass energy sources [12]*

## Biomass Utilization

The two types of biomass utilization are categorized as traditional (classical) and modern. The traditional use of biomass is the production of locally gathered wood, charcoal, agricultural wastes and animal wastes using simple conversion techniques. In other words, energy is traditionally provided by direct combustion of biomass material such as wood, plant and animal wastes and is widely used, particularly in developing countries [13].

The traditional method's output, which is typically less efficient, is primarily used for cooking and heating. Given the rising population trends in many countries, reducing the use of traditional biomass continues to be a difficult task. For a more sustainable and effective use of biomass resources, incentives for modern biomass use are critical. The production of plants for feedstock is prioritized in modern biomass utilization. The direct combustion of biomass produced today as well as the indirect utilization of pre-processed, solid biomass with high energy density for the production of electricity and/or heat are two examples of modern biomass utilization. Incentives and support for bioenergy technologies need to rise in each nation for modern bioenergy utilization to rise globally [8, 10].

In modern biomass use, conversion methods from biomass materials such as animal and agricultural wastes, domestic, urban and industrial wastes/wastewater with organic content, energy crops, energy forestry products, forest wastes, algae and moss growing in aquatic ecosystems can be used to

generate process heat, electricity and liquid or gaseous fuel [13]. Modern applications include direct combustion of the biomass produced and indirect use of high energy density, pre-processed solid biomass for electricity and/or heat generation. To increase the global use of modern bioenergy, each country's support and incentives for bioenergy technologies must be increased [8, 10].

While the primary applications of biomass are electricity, heat and transportation, other applications of biomass include the reuse or marketing of byproducts generated during biomass processes. The following industries use biomass [8]:

•**Energy Sector:** Biomass is used to generate electricity in the form of solids, liquids and gases.

•**Industry Sector:** In this industry, energy from biomass is used for a variety of tasks, including the production of steam, cogeneration, process heating, cooling, lighting and heating.

•**Transportation Sector:** Biofuels provide alternative fuels, particularly for road and air transportation.

•**Building Sector:** It is primarily used in heating and cooking in this industry.

## Converting Biomass to Energy

Organic materials such as forest, agricultural, domestic and animal wastes are examples of biomass, which is defined as biological material produced directly or indirectly through photosynthesis. Various conversion methods are used to convert biomass into bioenergy [14].

Biomass energy is a type of solar energy that is released and stored as chemical energy as a result of various biological and thermo-chemical processes involving chemical bonds between oxygen, carbon and hydrogen molecules. Biomass can be converted into solid, liquid, or gaseous fuels, making it a versatile renewable energy source. It can be used to generate heat and/or electricity, as well as as a transportation fuel [14, 15].

Several process steps are required to convert biomass into useful energy. The applied technologies are tailored to the physical structure, chemical composition and energy services required by the feedstocks. Outputs such as biogas, biodiesel, bioethanol and synthetic gas are produced using various conversion methods applied to biomass raw materials. These outputs are used in areas such as heating, electricity and transportation [8, 16].

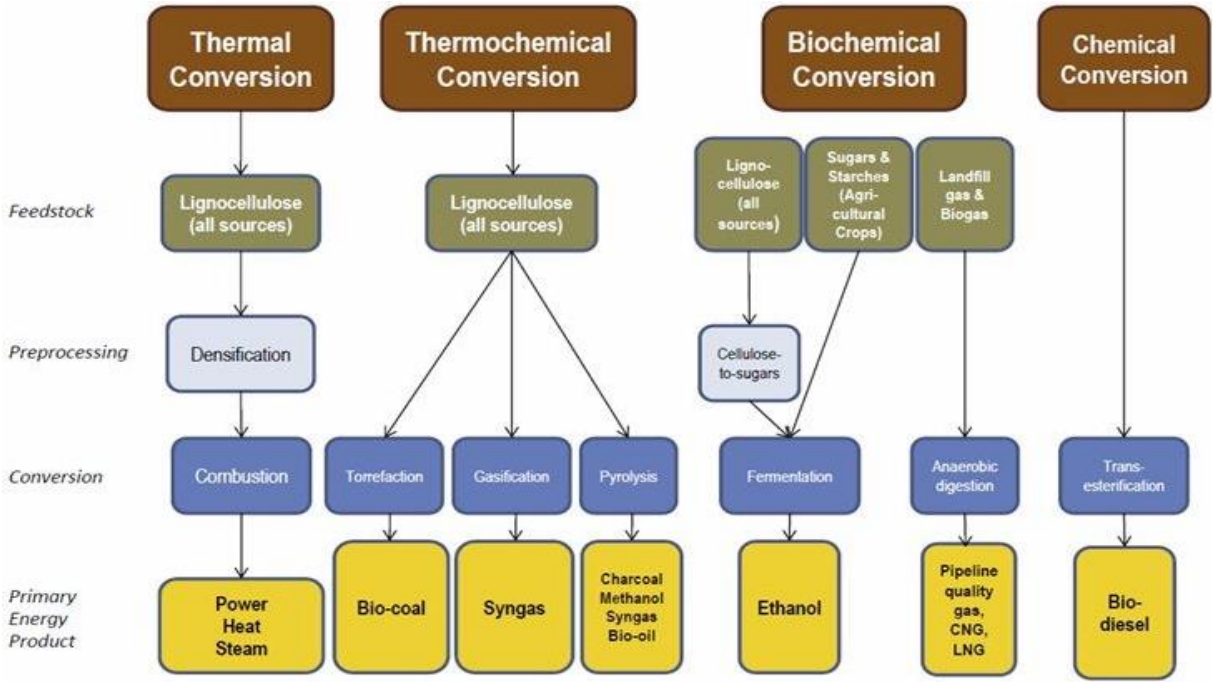



*Figure 2. Biomass Conversion Technologies [17]*

As presented in Figure 2, various processes are used to convert biomass to energy, including [11]:

•Thermal conversion-direct combustion

•Thermochemical conversion

•Chemical conversion

•Biological conversion

## Thermal conversion-direct combustion

Direct combustion is the most common and mature method of converting biomass into useful energy. Combustion is the rapid chemical reaction of combustible components in biomass with oxygen. As a byproduct of this chemical reaction, heat, carbon dioxide, water vapour and some metal oxides are produced [18].

They have a capacity range of a few MW to 100 MW or more. The steam boiler, which generates high-temperature and high-pressure steam and the turbines, which use this steam to generate electricity, are the two main components of the direct combustion process. Furnaces and boilers are typically used to generate steam for use in district heating/cooling systems or to drive turbines to generate electricity. All biomass can be burned directly to heat buildings and water, heat industrial systems as well as generate electricity in steam turbines. Although new combustion systems have been developed to increase efficiency, the heat obtained is typically close to the heat that would be produced from medium-quality coal depending on the type of biomass. Fluidized bed combustion systems are also available in the industry as highly efficient combustion systems [11, 12, 19].

Incineration is the most commonly used technology for utilizing biomass to generate electricity and heat. In Europe alone, there are over 1000 active biomass power plants. Biomass combustion is widely used for energy production in Finland and Sweden, which have large forested areas. Outside of Europe, the majority of the plants are in Brazil, China and India. Plants in China or India is typically designed to generate electricity. In Europe, biomass power plants generate both electricity and process heat for district/central heating systems [15].

## Thermochemical conversion

The process of using heat to create various types of solid, liquid, or gaseous fuels is known as thermochemical conversion. This conversion produces combustible gas as a result of the high-temperature decomposition of carbon-containing biomass. Pyrolysis, torrefaction, gasification and liquefaction are all examples of thermochemical conversion processes. Using a variety of process conditions and reactor configurations, the energy stored in the structure of biomass can be converted into solid fuels by carbonization (charcoal), liquid fuels by pyrolysis or liquefaction (bio-oils), or gaseous fuels by gasification (syngas) [15].

Pyrolysis is the oldest and most basic method for producing gas from biomass. It is defined as a sequence of chemical and physical events that occur when wood is heated to 900°C in an oxygen-free environment. Gases, tar, organic compounds, water and charcoal are produced as a result of pyrolysis [20]. Pyrolysis is a preferred method because all of the inputs can be recycled into products, it can be used to process any type of organic waste or waste, it uses less energy because it heats with the gas produced in the system and it allows for parameter adjustment to produce the desired product. There are three ways to perform pyrolysis: slowly, quickly and instantly. If the intended product is solid, the waste should go through a slow pyrolysis process, if it is liquid, a fast pyrolysis process should be used [5].

Torrefaction, like pyrolysis, is the conversion of biomass using heat in the absence of oxygen, but at lower temperatures than pyrolysis typically uses. Temperatures in torrefaction typically range

between 200°C and 320°C [17]. Pulverized biomass is hydrophobic and has a high energy density. As a result, it can be stored outside and transported over long distances without significantly absorbing water and losing calorific value. Pelletizing layered biomass can further cut processing and transportation costs [5].

Gasification is the high-temperature decomposition of solids such as carbon-containing biomass to produce combustible gas. During the gasification process, biomass is burned with controlled air supplied to the fuel cell. Combustible gases such as hydrogen and methane, as well as carbon monoxide, carbon dioxide and nitrogen, are among the byproducts. Approximately 85% of the energy in biomass can be converted into gas during the gasification process. These are thermal decomposition processes that involve heating biomass raw materials to high temperatures in closed, pressurized vessels known as gasifiers. They are distinguished primarily by process temperatures and the amount of oxygen available during the conversion process [21, 22]. The ash left over from waste combustion is also converted into biochar, which varies depending on the chemical properties of the waste. The gas produced after this point is used to generate heat and power in combustion engines, microturbines, heat engines and gas turbines [14].

## Chemical conversion

Chemical conversion involves the use of chemical agents to convert biomass into liquid fuels. Chemical conversion of biomass is the process of converting biomass into other forms of usable energy through chemical interactions [17]. The most common type of chemical-based conversion is transesterification. Transesterification is the chemical reaction that bonds fatty acids from oils, fats and greases to alcohol. This process reduces fatty acid viscosity and makes them combustible. Biodiesel, glycerin and soaps are all common byproducts of transesterification. Glycerin separates from biodiesel as a result of the reaction because it has a higher density than biodiesel and settles to the bottom. Then, distillation is used to recover the alcohol that was combined with the biodiesel. Alcohol and oil react together to produce glycerin, biodiesel and alcohol. Biodiesel can be made from almost any bio-oil (such as soybean oil), animal fat or tallow, or tree oil [17, 23].

## Biochemical conversion

Biochemical conversion describes the process of utilizing bacteria or other microorganisms' enzymes to break down biomass. The term "biochemical conversion methods" describes the biological processes used to transform biomass. These procedures seek to separate various microorganisms or enzymes from biomass to produce products and intermediate products. Biogas, hydrogen, ethanol, butanol, acetone, various organic acids and chemicals are produced as a result of the process. [5].

Key biochemical conversion processes include anaerobic digestion and fermentation [19]. The use of microorganisms in the absence of oxygen to break down organic matter is known as anaerobic digestion or airless digestion. This process is also referred to as the conversion of biomass to methane and carbon dioxide. Anaerobic digestion, a bio-chemical translation system, is a method applied to produce methane and carbon-rich biogas from crop residues, food residues and manure (human and animal). Anaerobic digestion is widely used in wastewater treatment and to reduce landfill emissions. Anaerobic digestion is a multi-stage procedure. First, bacteria are used in hydrolysis to break down carbohydrates into digestible forms for other bacteria. The resulting sugars and amino acids are converted by the second group of bacteria into carbon dioxide, hydrogen, ammonia and organic acids. The byproducts are then transformed by additional bacteria into methane and carbon dioxide [5, 17]. Anaerobic digestion can biodegrade almost all biomass, with the exception of woody materials and is suitable for moist feedstocks like animal wastes, sewage sludge, moist agricultural wastes and organic fractions of municipal waste. In landfills, anaerobic digestion is also used to produce energy from landfill gas [5].

The use of yeasts to convert carbohydrates into alcohol, specifically ethanol, also known as bioethanol, is known as fermentation. Heat is used in this process to convert starch in organic matter into sugar. The sugar that results is fermented to produce ethanol. There are several stages to the overall process. The crop materials are pulverized or ground before being mixed with water to form a slurry. Heat and enzymes are used to process the ground materials into a finer slurry. To convert the starches into glucose sugar, additional enzymes are added. The sugary slurry is then pumped into a fermentation chamber and yeasts are added. After 48-50 hours, the fermented liquid is distilled to separate the alcohol from the remaining solids [5, 24].

The conversion of biomass through fermentation is crucial because it makes it possible to produce a variety of products under straightforward circumstances. The structure and composition of the biomass feedstock have an impact on how much organic matter ferments. The choice of raw materials for this process should take into account the demand competition that exists between them and food products. However, it is acknowledged that forestry and agricultural wastes are the best sources of biomass [5].

## Advances In Biomass Technologies

Because of advances in energy technologies, biomass, which has historically and primarily been used for home heating for centuries, is now being used in transportation and for the production of electricity. By being transformed into energy forms like hydrogen, ethanol, methanol, methane and pyrolysis oil, it also aids in technological advancement and the nation's economy [14].

The production of various biomasses has become an important issue with the modern utilization of biomass. Energy forests and energy agriculture stand out in this regard. In addition to energy crops containing energy-rich components, plants grown in various climatic regions include reed canary grass, reed grass and kenger grass. Other biomass feedstock options include aquatic biomass such as algae and mosses, as well as non-food oil seed species such as Jatropha [5, 25].

Ash, fertilizer and biochar are the most valuable byproducts of biomass processing. Waste ash produced by biomass plants can be used as an additive material for cement in the production of road briquettes or as fertilizer in land reclamation. Another byproduct of pyrolysis is biochar, which can be reincorporated into electricity generation processes, used for heating, or applied as fertilizer. One of the most promising approaches to generating renewable energy is biogas production from anaerobic digestion of resources such as animal waste and sewage sludge. This process produces digested organic biomass with properties useful for soil fertilization [14, 26].

## Advantages and Disadvantages of Biomass Energy

The use of biomass, like any other form of energy generation, has both advantages and disadvantages. Bioenergy has enormous potential among alternative energy sources and can provide continuous energy. Another advantage is that bioenergy is easily stored. The following are some of the advantages of biomass energy [8, 27, 28]:

•As a natural component of the cycle, the use of biomass lowers the amount of carbon released into the atmosphere when compared to other fossil fuels.

•Biomass can transform waste into a renewable energy source because society produces waste continuously.

•Numerous energy outputs from biomass can be produced for a variety of uses.

•Nearly everywhere has a plentiful supply of biomass resources.

•In terms of resource potential, biomass is among the most significant sources of renewable energy.

•In contrast to other energy sources, biomass power plants have high availability and can run continuously because they can run at baseload.

•When sustainable methods are employed, biomass improves the quality of the soil, the air and the water. For instance, by restoring degraded lands, the use of biomass feedstocks can improve the soil. In addition to the numerous environmental advantages that biomass can offer, it also slows down the rate of climate change.

•Local production and processing of biomass fuel reduces reliance on imports in energy consumption and boosts the local economy by generating jobs. reducing the buildup of waste

•Utilizing solid wastes helps reduce the formation of waste. As a result, landfill land requirements and disposal costs are both decreased.

The most serious issue confronting the biomass sector is a lack of long-term and consistent policies, as well as the uncertainty created by the unpredictability of future regulations and incentives. The disadvantages of biomass are listed below [8, 27]:

•Some biofuels need to be boosted with fossil fuels to increase efficiency even though bioenergy is not sufficiently efficient.

•Although biomass is carbon-neutral, methane gas is produced when some of its wastes are used, which is bad for the environment.

•Deforestation for energy production destroys forest areas and threatens biodiversity.

•Production losses could result from management and staff who operate bioenergy plants not having the necessary industry expertise.

•Not every type of waste can be used directly as biomass. In order to utilize waste more effectively, waste segregation should be encouraged.

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# ENERGY MANAGEMENT IN AGRICULTURAL PRODUCTION

While global energy demand continues to rise, the world's fossil energy resources are rapidly depleting. As a result, one of the most important goals has become the effective utilization of energy. In line with this goal, it is critical to implement an energy management system by organizing an energy program with the highest possible efficiency. This system includes activities that aim to continuously improve energy performance, such as energy efficiency, energy audit studies and activities that necessitate a comprehensive study [1].

Considering the agriculture sector's reliance on the energy sector, as well as the rising costs and negative consequences of using fossil fuels, energy management in this sector is critical. Farmers can enhance earnings while having a good influence on the environment by better understanding farm energy consumption and applying best practices for on-farm energy management [2, 3].

## Problems with Agricultural Energy Use

As the world's population continues to rise at an alarming rate, the demand for modern agriculture and the ability to feed enormous numbers of people grows by the day. With rising food consumption, the agriculture sector's energy requirements are likewise rising [4].

Energy is a vital element in production in agriculture. In addition to human and animal power, the agricultural sector uses energy in buildings (lighting, cooling/heating), agricultural operations (tools and machinery for land preparation, irrigation, sowing, fertilization, harvesting and transport), and commercial activities (transport, construction and facility operation). Energy is required in the agricultural industry to pump water for irrigation, to operate agricultural machinery for various agricultural operations during the growth phase, such as sowing, weeding, fertilizing, spraying and harvesting, to transport crops, to cool and dry or process products [5].

The amount of energy used in agricultural production varies significantly depending on the level of development, type of activity, production practices used, location of the production area and environmental factors like soil and climate [6]. Because of inadequate facilities, restricted access to contemporary technologies and a greater reliance on manual labour, developing countries frequently confront more serious energy restrictions. Developed countries, on the other hand, are attempting to optimize energy use, minimize emissions and include renewable energy options. To attain dependable and environmentally acceptable renewable energy alternatives, the energy sector must undergo a thorough transition that includes the use of renewable energy sources. Poor rural infrastructure, restricted biomass utilization, heavy reliance on fossil fuels, reliance on energy for irrigation and limited access to modern energy are some of the key types of energy problems and challenges in agriculture [5].

Energy use in agriculture is critical for modernizing agricultural practices and increasing productivity [7]. The increase in agricultural productivity that can be achieved through the use of modern energy production cannot be realized due to insufficient use of electrical and mechanical energy in agriculture [8].

All agricultural production must be economically sustainable in order to ensure long-term food security. As one of the most important agricultural inputs, energy is critical to ensuring food security. Efforts to support energy's critical role should be coordinated with efforts to reduce hunger, advance rural development and improve food security. These efforts should not be viewed as an end in themselves, but rather as an important component of a larger project. Food supply and production are frequently hampered by low quality and limited quantities of available energy [9, 10].

Due to the fact that agriculture also has a negative impact on climate change, concerns about it have increased interest in energy efficiency and usage in agriculture. The majority of the energy used in agricultural activities comes from fossil fuels, which are used in almost all of them. This is a result of

various types of farm equipment used, livestock-related methane emissions, farm-related greenhouse gas emissions and more [11, 12].

The importance of the energy issue is highlighted by the need to use scarce natural resources efficiently, reduce greenhouse gas emissions, reduce energy costs and increase the competitiveness of the agri-food sector [13]. It is crucial to find sustainable and renewable alternatives for each of these factors, even though there are many direct and indirect energy factors that affect how much energy is consumed overall in agriculture [14].

The energy-agriculture nexus will undoubtedly require significant effort to move forward. Technological, environmental and social aspects should be further developed and assessed [9]. Reducing input costs and grid load through the use of efficient energy management techniques and renewable energy in agriculture will help address issues with food security [5].

## Energy Management

The term "energy management" refers to the measurement, monitoring, planning and implementation processes used to ensure the best possible use of both the energy resources used and the energy produced. The systematic process of energy management maximizes energy savings while also continuously improving energy performance [15, 16].

Energy management is the use and application of technology in the planning and operation of both energy production and consumption to ensure optimal energy supply and utilization. The primary goals of energy management are resource conservation, budget savings and climate change prevention, as well as ensuring easy and continuous access to energy for all [17].

Energy efficiency and optimum utilization are critical for achieving sustainable growth, as are many other aspects such as investment regulation and the adoption of appropriate technology. Reducing energy costs and waste without impacting production or quality and with little environmental impact is a basic factor for sustainable development in energy management. Energy management include reducing energy consumption by implementing energy-efficient techniques, as well as determining the proper type of energy and energy tariff for the relevant unit, such as a power plant, a manufacturing plant, a building, or agricultural practices [17, 18].

Energy audits is a critical activity in energy management. It is a systematic technique that aims to balance total energy inputs against total energy usage, as well as to identify all energy flows and justify energy use based on its specific functions. The ultimate goal is to boost energy efficiency, which will lower energy expenditures in the long run, leading to more sustainable economic development. Furthermore, increased energy efficiency would assure energy security as well as environmental preservation [17, 19].

## Energy Management in Agricultural Production

Energy is one of the most important agricultural inputs. From agricultural processes to the execution of diverse economic operations, energy is a key component for meeting fundamental human needs. To feed the world's rising population and satisfy other social and economic goals, agricultural production, processing and distribution require a substantial amount of energy. Because crop yields and food supply are inextricably related to energy, controlling energy consumption in agriculture is critical [11, 20].

In order to achieve the aims of sustainable agriculture, it is crucial to adopt and maintain a balance between economics and energy demand. The world's less developed nations are attempting to find ways to meet the rising demands for food, clean water and alternate energy sources while combating climate change [21]. Due to fast population increase, economic and technological development, urbanization and climate change, energy consumption is rapidly increasing. This increase in energy

consumption is expected to raise electricity prices, which would have a direct impact on the agricultural sector due to the high energy demand for diverse agricultural activities. Food prices will rise as a result of the high input costs required to produce food from agriculture, resulting to hunger and poverty and jeopardizing food security, particularly in developing countries. Improved energy management strategies can help to address the intensification of energy usage and high input costs in agriculture [5, 22].

Agriculture needs energy to carry out its activities, but it may also be utilized to produce energy, making energy management a crucial issue given the strategic importance of the agricultural sector. As a result, optimizing consumption, production and efficiency are all part of energy management in the agriculture industry [23].

The following are the primary goals of energy management in agricultural production [11]:

•Ensuring and maintaining optimal energy supply and use throughout the product's life cycle,

•Reducing energy costs/waste while maintaining production and quality,

•Minimizing environmental impact.

Farmers are being forced to reduce costs through energy efficiency and the use of renewable energy sources by rising energy costs in the agricultural sector. In general, higher energy-related input costs raise the total cost of producing agricultural goods, which lowers farm income [24]. Figure 1 shows an energy pyramid for agricultural applications. This pyramid is a decision-making tool that can be used in a variety of energy-related settings, including agriculture. As one progresses from energy assessment activities to alternative or renewable energy projects, the cost and complexity of this tool rise [11].

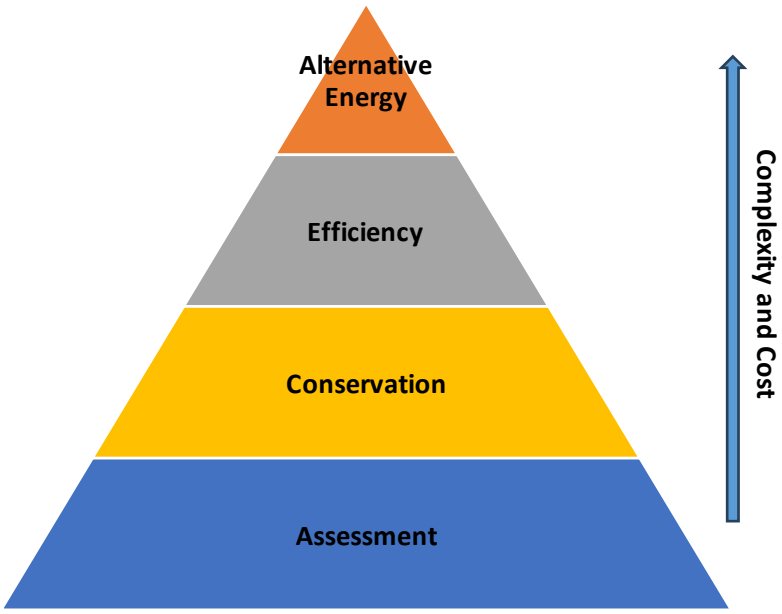



*Figure 1. Energy Management Pyramid for the Agricultural Activities [24]*

The energy pyramid begins with an energy assessment on the farm. Before implementing any concrete measures, the energy assessment allows you to assess your energy use and needs. Energy consumption on the farm can be controlled using energy monitoring, target setting and energy audit systems. Energy monitoring is accomplished by regularly recording energy performance data from a single part to all parts. After monitoring, the data must be analyzed and an energy audit performed. The energy audit includes activities to determine the measures that can be taken to achieve higher efficiency with less energy in the energy-using system [11]. Due to the scarcity of labor, energy is the most reliable resource for agricultural production and analyzing the energy required for each process is an important tool [22].

Following that, simple conservation practices must be implemented, followed by energy efficiency practices. Energy efficiency is frequently confused with energy conservation. Energy conservation is the practice of using less energy by altering one's behavior or habits. On a farm, for example, energy is saved by turning off unnecessary lights. Energy efficiency means using less energy to accomplish the same task. Energy efficiency is demonstrated by replacing incandescent bulbs on the farm with LED bulbs. Energy conservation is concerned with limiting use, whereas energy efficiency is concerned with using energy more efficiently [25, 26]. Savings and efficiency improvements have numerous advantages in and of themselves. Opportunities to increase agricultural productivity by implementing innovative techniques and practices must be identified for each crop and ecology. Organic farming, better soil and water management, integrated pest management and crop fertilization are just a few of the strategies and practices that can assist the agricultural sector in moving toward greater energy efficiency and sustainability [27].

The final step is to invest in and use renewable energy. While energy efficiency measures are frequently the quickest and cheapest way to reduce farm energy costs, it is also critical to consider renewable energy generation systems to generate energy to power many agricultural activities. The use of renewable energy sources in agricultural activities will result in improved energy use, food security and environmental change, all of which will benefit ecological farming goals [5].

Monitoring the performance of energy used in agricultural activities through the adoption of an energy management system in the agricultural sector can promote higher efficiency and capacity utilization, reduced resource waste and pollution and lower operation and maintenance costs. As a result, energy and product prices can be cut while value creation increases, resulting in stable economic growth. Uninterrupted economic growth mixed with environmental conservation provides the foundation for human society's secure and sustainable development [3, 17].

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# RENEWABLE ENERGY APPLICATIONS IN AGRICULTURE-1

Human food is only produced through agriculture. The focus of sustainable agriculture is on the need to employ tools and techniques that increase food production without compromising environmental resources or ecosystem services [1].

The energy requirements for heating, cooling, traction and other farm energy functions can be met with a variety of technologies. Rural areas can produce renewable energy using geothermal, bioenergy, solar, wind and solar energy sources. Farmers can use a variety of technologies simultaneously. In other circumstances, the farm's renewable energy production can be injected into the gas or electricity grids. Both at the farm level and across the entire agricultural sector, there are a wide range of options and potential for the production and distribution of renewable energy [2].

Most agricultural equipment is run by fossil fuels, which produce greenhouse gases and hasten climate change by releasing them into the atmosphere. By promoting the use of renewable energy sources like solar, wind, bioenergy, hydropower and geothermal energy, such environmental sustainability issues can be reduced [3, 4]. New opportunities for cooperation in the production, sale and distribution of renewable energy are presented by numerous small-and medium-sized installations. They replace fossil fuels, promote economic growth in rural areas and contribute to energy security [2].

## Renewable Energy for Agriculture

Energy provision to agricultural systems has always been a crucial aspect of agricultural development and is crucial to guaranteeing food security. For many tasks in agriculture, including seeding, irrigation, harvesting and soil preparation, electrical and mechanical power is necessary. Furthermore, reliable and regular energy sources are required for the pumping and distribution of water via irrigation systems [4, 5].

Agriculture technology is rapidly changing and developing. These advancements improve farm machinery and equipment, farm facilities and farm buildings for crops and animals on farms [6] New and modern agricultural technology applications increase energy consumption even more. Alternatives to fossil fuel energy sources are required as agricultural production modernizes to ensure that food systems are constructed on safe, environmentally sustainable and resilient foundations. Replacing fossil fuels in agriculture with low-carbon and clean energy solutions is crucial to addressing the energy needs of food systems in both developed and developing countries [7, 8].

Energy costs are one of the most important factors influencing the prices of agricultural products [9]. Increasing energy costs raise fuel and electricity prices directly, as well as feed, fertilizer and transportation costs indirectly. Energy-saving practices and the use of renewable energy are critical for lowering agricultural production costs and ensuring local production continuity [10]. Farmers can produce their own energy and become more self-sufficient by using renewable energy [11].

Although the use of renewable energy technologies in agriculture dates from ancient times, widespread adoption with technological infrastructure has only occurred in the last century. Renewable energy is used in agriculture not only for electricity generation, but also in many other areas, both directly and indirectly [3, 10]. The table below contains data on the use of renewable energy sources in agriculture and the sections that follow provide a detailed description of the agricultural application of renewable energy technologies.

*Table 1. Use of Renewable Energy Sources in Agriculture [12]*

| ***Power Supply*** | ***Application Type*** | ***Application Area*** | ***Requirements*** | ***Advantages*** |
|---|---|---|---|---|
| *Solar energy* | Lighting | Natural lighting | Natural agricultural structures should be designed in accordance with lighting. | Lighting costs are reduced.<br>Production increase is provided.<br>It requires little maintenance. |
| | Photovoltaic | Electricity generation | Solar radiation should not be obstructed. | Electricity requirement is met.<br>It can be placed in the building design or on the roof. |
| | Ambient Heating | Heating | Underfloor heating is required.<br>Walls need sun exposure. | Living conditions improve.<br>Air quality improves. |
| | Water Heating | Hot water | Solar radiation should not be obstructed. | Hot water requirement is met. |
| *Geothermal energy* | Heat pump | Greenhouse heating<br>Ambient heating<br>Product drying | Space for horizontal or vertical wells is necessary.<br>Chemical of geothermal fluid is important. | Heating and cooling with heat exchangers<br>Practices improve living conditions. |
| *Biomass Energy* | Biofuel | Electricity generation<br>Ambient heating and cooling<br>Water heating<br>Fuel | Organic material must be continuously supplied from agricultural and forestry waste. | Waste control is provided.<br>Operating costs are reduced.<br>Backup power is provided. |
| *Wind power* | Turbine | Electricity generation<br>Mechanical strength | Wind blowing at a certain speed is required. | With the developing technology, energy unit costs are decreasing. |
| *Hydropower* | Hydroelectric | Electricity generation | Reliable water flow is required. | The investment made can be used not only for energy but also for irrigation and flood purposes. |

## Use of Solar Energy in Agriculture

Solar energy accounts for the majority of the world's energy resources. Only a small amount of the sun's energy reaches the Earth's surface. However, the modest amount of solar energy that reaches the Earth's surface in a single hour exceeds the total amount of energy produced by all other accessible sources, including hydroelectric, nuclear and fossil fuels [6].

Solar energy has recently emerged as a viable option for both large and small-scale farms. It's a versatile and environmentally beneficial alternative energy source, especially in remote locations where diesel fuel is expensive or there's no reliable access to the power grid [5].

Solar energy technologies generate either electrical or thermal energy. Photovoltaic panels, which are typically made up of solar cells composed of layers of silicon that produce direct current electricity, can convert solar radiation into electricity. When necessary, inverters can convert this to alternating current for use by commercial electrical appliances, which are typically powered by grid electricity [13]. Solar panel technology, which is used to generate electricity from solar energy, is relatively new. Despite this, it is the world's fastest growing sector. People who live in remote areas or who require grid independence are particularly interested in these installations. When it is dark, the electricity produced by utilizing daylight for the use of electricity required in a home is also used through batteries with storage units. With daily increases in grid electricity prices and price decreases due to technological advancement in photovoltaic systems, generating electricity from the sun is becoming increasingly appealing. Photovoltaic panels are cost-effective for supplying electricity in remote locations such as farms, orchards and other agricultural activities in applications such as electric fence, field or house lighting and water pumps for animal watering or agricultural irrigation, photovoltaic systems can be significantly less expensive to install than power lines [3]. Figure 1 shows the applications of solar panels for agricultural use.

Cold storages are special isolated rooms with no outside air exchange that are built to extend the shelf life of food, reduce losses and prolong storage life in order to maintain product quality. Energy consumption in cold stores is high and this energy can be provided by installing photovoltaic panels on the cold store's roof. Solar energy is one of the best solutions for running small cold stores in rural

areas. The solar energy source can also help to reduce the operating costs of the cold storage system [14, 15].




*Figure 1. The most common solar panel-supported applications in agriculture*

The most prominent recent application of solar panels is in irrigation systems. Pumping systems are needed for irrigation. This is achieved through the use of electric pumping systems. As presented imn Figure 2, pumping systems powered by photovoltaic panels meet a wide range of water needs, from crop irrigation to animal watering and domestic use [3]. Solar panels, transmission pipes and batteries are all that is required to use solar energy in irrigation. Producers of agricultural irrigation aim to irrigate large areas by transmitting water under pressure. Drip irrigation, micro irrigation, sprinkler irrigation and surface irrigation can all benefit from solar energy. Irrigation is accomplished by transferring the energy collected in the solar panel to other parts via a battery [10]. Solar-powered irrigation technology is gaining popularity around the world and countries are developing policies to promote renewable energy solutions, including solar energy. Solar irrigation provides a solution to the frequent energy shortages that disrupt the supply needed to extract and distribute irrigation water in the agricultural sector [5]. Many of these systems also have the added advantage of storing water for usage when the sun isn't shining, which reduces expenses overall, increases simplicity, eliminates the need for batteries and increases system efficiency [3].

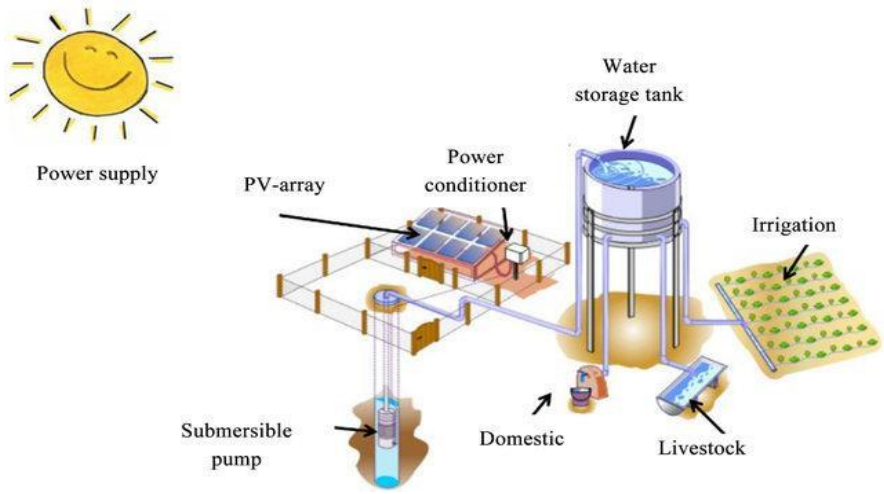



*Figure 2. Photovoltaic panel water pumping system [16]*

Another use for photovoltaic panels is to power electric fans for air circulation. Modern animal farms can increase production by doubling or tripling it by housing their animals in enclosed structures. Photovoltaic systems can provide electricity for the fans used to circulate air in these systems [3].

Solar collectors are a different type of solar energy application. These systems funnel heat to a central location. In many parts of the world, cooking stoves powered by heat generated are used [17]. Systems that run at a specific temperature make up greenhouse systems. Therefore, controlling temperature is the most crucial factor to take into account. It is one of the regions where solar energy systems are used. When it comes to regularly regulating the temperature, two approaches stand out. The initial technique makes use of solar collectors. Solar energy generation is an additional strategy. The solar energy system first generates electricity, which is then used to heat the water, heating the greenhouse in the process. In these systems, solar panels, batteries and inverters are employed [18, 19].

Solar energy is not only used to generate electricity in the agricultural sector. The second most common use of solar energy is to generate heat for various agricultural processes [13]. Solar heat applications include drying systems. There are various types of solar dryers available for drying agricultural products. Active dryers and passive dryers can be used depending on the heating scheme. External means for solar heat transfer, such as pumps and fans, are used in active solar dryers to transfer solar energy from the solar collector to the product drying beds, whereas heat is circulated naturally in passive dryers by wind pressure, buoyancy, or a combination of them [20].

Solar hot water systems have long been available. These systems feature a collector constructed of materials that absorb heat from the sun efficiently. Cold water is sent through the collector, where it is heated and returned to the tank. Cooler water is collected from the tank's bottom and returned to the solar collector as hot water climbs to the tank's top. Solar hot water can help reduce the amount of energy consumed to heat water in houses [8].

## Use of Geothermal Energy in Agriculture

Geothermal energy is the heat energy that is carried to the surface by hot water, steam and gases that may contain more dissolved minerals, different salts and gases than the nearby groundwater and surface water and that are above the regional atmospheric average temperature. Geothermal energy is created by heat and pressure that has built up at various depths of the earth's crust. The majority of the time, this energy comes from either wells specifically drilled for this purpose or from water that rises to the surface through weak zones created by cracks and fractures that extend from the subsurface to the earth's surface [21].

Geothermal energy is frequently employed in agriculture to produce electricity, but it is also a significant source for heating greenhouses, fish ponds, crops and grains that need to be dried. While many of the frequent uses of geothermal energy are comparable to those of other renewable energy sources, geothermal energy is more reliable and accessible since it is constantly present. Geothermal energy offers the economic and technological potential to enable the development of numerous agricultural products with added value in the future [22, 23]. An example of cascading use of geothermal power plants on a farm is shown in Figure 3.

Geothermal energy is the most commonly used agricultural application worldwide, particularly for greenhouse heating. In terms of operation and maintenance, the geothermal energy source is best suited for greenhouse heating applications due to its low depth and low temperature. This lowers the cost of excavation and fluid pumping [24]. Greenhouse heating systems powered by geothermal energy are assessed alongside the equipment used to transport the geothermal fluid from the extraction area to the area of use. The technical terms for these systems include combination heating systems, air heating systems using fans and heat exchangers and heating systems located in the soil, on the soil surface, or on growing tables. The ground or subsoil heating system is the most popular heating system in geothermal energy applications. The best solution is to support this system with an ambient air heating system fed from the same source. The ground heating system is made up of

heating pipes that are buried at various depths and intervals and through which hot fluid circulates. Plastic heating pipes are now widely used [25]. Using geothermal resources instead of conventional energy saves about 80% on fuel costs and 5-8% on total operating costs. Other benefits of geothermal heating for greenhouses include cleaner air and water, improved hygiene, a stable workforce and the ability to take advantage of tax breaks [23].

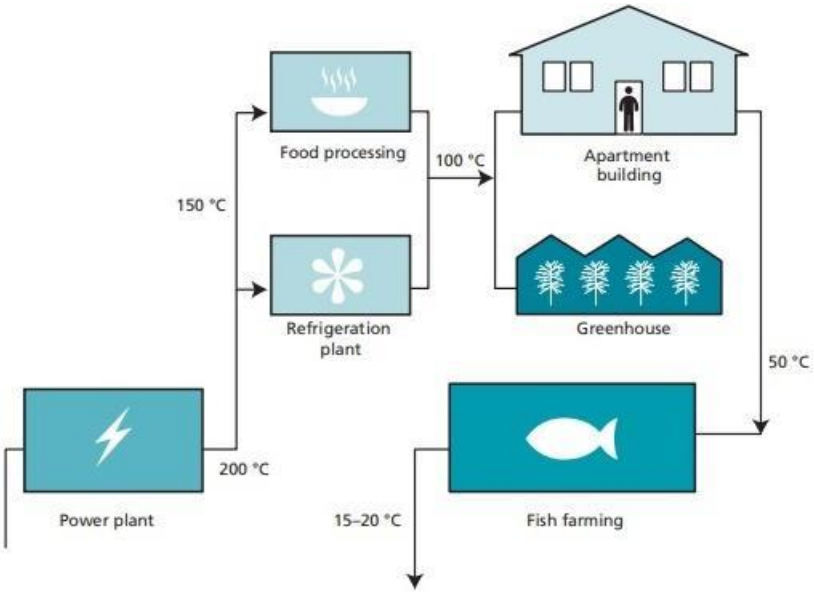



*Figure 3. Cascading utilization of geothermal power plant [23]*

Ponds and fisheries also use geothermal energy. The amount of heating needed for these facilities is substantial. In this use, geothermal energy is frequently utilized to warm water in tanks, pools and canals. To obtain the temperatures needed for fish farming, geothermal hot water is utilized to heat fresh water in heat exchangers or combined with fresh water. Such use of geothermal resources is suggested as a remedy for aquaculture in colder areas or in situations where conventional heating may not be economical [26, 27].

Around the world, geothermal heat is utilized to dry a wide variety of agricultural products. Geothermal energy is used to dry products in clean and sanitary settings. The temperature of the geothermal energy before drying and the temperature values necessary for the drying application are important criteria. Heat for drying can be obtained from geothermal wells in the form of hot water or steam, or from a geothermal plant's waste heat [23].

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# RENEWABLE ENERGY APPLICATIONS IN AGRICULTURE-2

Human food is only produced through agriculture. The focus of sustainable agriculture is on the need to employ tools and techniques that increase food production without compromising environmental resources or ecosystem services [1].

The energy requirements for heating, cooling, traction and other farm energy functions can be met with a variety of technologies. Rural areas can produce renewable energy using geothermal, bioenergy, solar, wind and solar energy sources. Farmers can use a variety of technologies simultaneously. In other circumstances, the farm's renewable energy production can be injected into the gas or electricity grids. Both at the farm level and across the entire agricultural sector, there are a wide range of options and potential for the production and distribution of renewable energy [2].

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## Use of Wind Energy in Agriculture

Wind is a type of solar energy that is received indirectly. This type of energy is constantly replenished by the sun and is produced by the sun's heating of the earth's surface. The different heating of the earth's surface causes variations in the temperature, humidity and pressure of the air and this variation in pressure causes the air to move. Wind characteristics vary in time and space due to geographical differences and inhomogeneous heating of the earth's surface [5, 6].

Wind energy is now one of the most important renewable energy sources, with the fastest development in technology and utilization and an economy that is competitive with conventional energy sources. Wind energy is the process of obtaining mechanical or electrical energy through turbines by utilizing the kinetic energy of the air already present. Wind energy is environmentally friendly, can provide energy security and is a viable alternative to traditional fossil-fuel-based energy [7, 8].

Wind energy applications in agriculture can be divided into two categories. These are:

•Mechanical application areas (such as water extraction and grinding),

•Electrical application areas (off-grid and grid-connected applications) [9].

Wind energy is used to create mechanical energy from wind turbines, electricity from wind turbines, or water from wells using wind pumps [10]. The use of wind energy in rural areas is known to have begun with windmills. Windmills have been used to draw water from wells and grind grain since the Middle Ages. Wind energy is converted into mechanical energy by a turbine, which causes two plates to rotate rhythmically and the products between these two plates to be ground. Windmills have long supported agricultural activities [11, 12].

Pumps are machines that convert liquid potential energy into kinetic energy. Wind-powered pumps only use wind energy to draw water. The kinetic energy of the wind flow is converted into mechanical energy by the shaft on the wind turbine and used for pumping water in agricultural areas and drawing water from wells, as shown in Figure 1. With the help of the device to which it is connected, the piston of the pump installed on the source moves up and down and discharges the water to the desired area on the surface. The water taken from the source is transferred out via hoses using pressure difference. Because wind energy is an intermittent source, it is used in conjunction with storage systems to meet water demand continuously [13-15]. A small amount of wind is required for the system to function. In

light winds, a wind pump can draw an average of 10-15 tons of water. Users can supply pumps of various sizes based on their requirements. The capacity varies according to the size of the rotor to which the pump is connected [16].

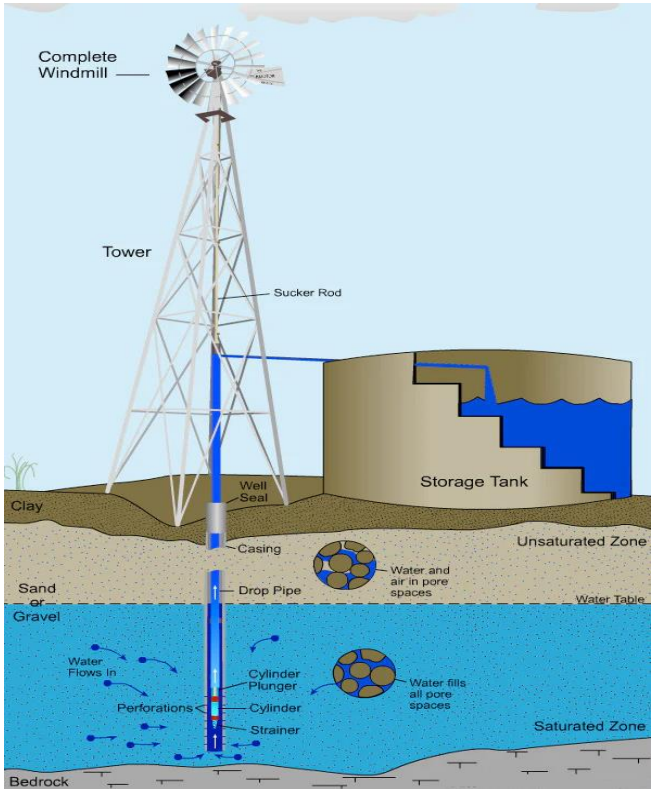



*Figure 1. Water pump powered by wind energy [15]*

Wind energy is important in the generation of electricity and the proportion of electricity generated using this energy source is steadily increasing [17]. R Wind turbines are the primary components of wind power plants. Although wind energy generation is a relatively new technology, the processing logic is identical to that of older windmills. A wind turbine is made up of several components, including a generator, a tower, electrical equipment, gearboxes, a propeller blade and body (rotor), and a foundation. With the rotational movement of the rotor shaft, the kinetic energy of the wind is converted into mechanical energy in the rotor and transferred to the generator in the body. The energy generated by the generator is stored in batteries or directly transmitted to electricity receivers [6, 10].

Wind turbines can be used both with and without a connection to the power grid. Grid-connected wind turbines are typically used for high-power applications. Off-grid tribunes are mostly used for minor requirements [18, 19].

Wind energy is a non-polluting, fuel-free energy source. Windmills installed in every farm or settlement unit in agricultural areas significantly reduce energy production costs and such systems installed in areas far from transmission lines are economical in every way. If these systems are connected to the electricity distribution network, additional income can be obtained by selling the portion of the electricity produced in excess of consumption by establishing the necessary legal ground. The most significant advantage of wind turbines is that they do not take up much space due to their small projection, allowing them to be installed in agricultural areas [19, 20].

## Use of Hydropower Energy in Agriculture

Since water has been essential to our survival since the beginning of time, humanity has always established living spaces near bodies of water. It has used water not only for daily needs, but also for transportation, hunting and even energy generation. Rivers provided the first simple mode of

transportation. One of the first examples of water transport is the flow of cut/collected trees and branches over water. This method, which is still widely used in forestry activities, also resulted in the development of rafts or boats, the first mode of transportation. This also aided the growth of commercial activities [21].

In agriculture, the energy of running water is used mechanically or electrically. For centuries, the power of water has been used to generate mechanical power. Mechanical power enables daily activities such as agricultural processing. The grain grinding process, which is the cornerstone of agricultural production with water mills still used today, is one of the important applications of the mechanical power of water in agriculture [22]. A water mill is a mechanical structure that employs a water wheel or turbine. This system works by directing water from a river or pond to a water wheel via a channel or pipe. Depending on the flow of water, water wheels can be horizontal or vertical. Horizontal water wheels are simpler, but they require a high-water velocity to function properly [23].

The most widely used renewable energy source is hydropower because it has several advantages over other sources, including high energy density, low cost and dependability [24]. The two main types of hydroelectric power plants are those that are located in reservoirs and those that are located along rivers. River-type hydroelectric power plants use the river's current to turn turbines, which then generate electricity. A dam is used to gather and store large amounts of water in hydroelectric power plants with reservoirs [25].

Hydroelectric power plants range in size from very small to very large. River-type micro or small hydroelectric power plants, typically in the kW range, are used to generate electricity in rural areas in many countries. As illustrated in Figure 2, these systems operate on a simple principle: water from streams or rivers flows through a turbine, which rotates and turns a generator, which generates electricity. To achieve reliable energy production, it is critical to understand local water resources and design the system accordingly [26, 27].

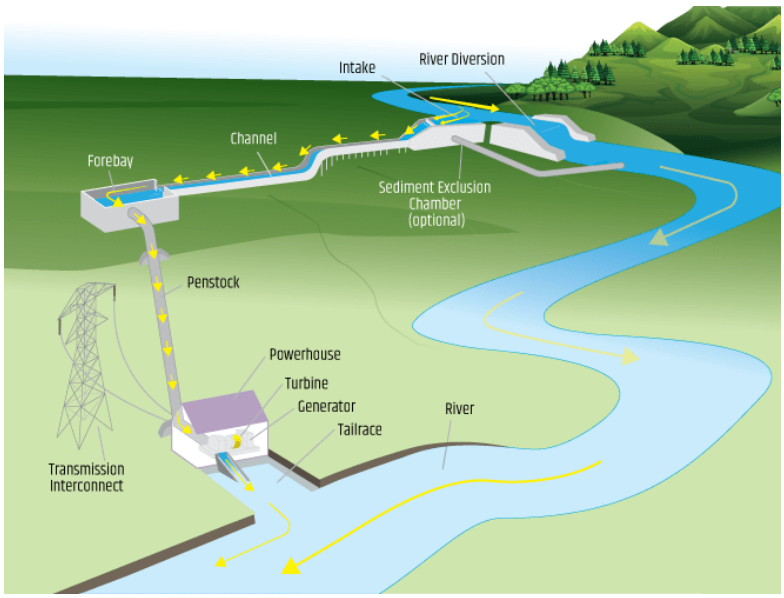



*Figure 2. Small-scale hydroelectric power plant [26]*

The use of small hydropower plants is growing because of how well they can be incorporated into the agricultural supply chain. The energy produced by the current flows in irrigation canals represents a significant untapped opportunity with the development of these systems. The irrigation canal is used in this way to operate together for effective irrigation service and energy production [28].

Hydroelectric power plants generate electricity that is used for lighting, heating greenhouses, processing and storing agricultural products and water pumping in agricultural areas. Dams are also utilized for fish farming and direct irrigation [29].

## Use of Bioenergy Energy in Agriculture

There are two types of biomass energy available today: traditional and contemporary. Modern biomass energy sources, also known as biofuels, include biodiesel, ethanol and biogas produced from energy crops, energy forests and waste materials. Traditional biomass energy is described as the simple combustion of wood and animal wastes [20]. Biomass is used on farms either directly for electricity and heat or indirectly as fuels in liquid, solid, or gaseous form. More than 30% of the energy used in households worldwide for heating, cooking and lighting is derived from biomass [30].

With rapid technological innovation and growing automation, the use of petroleum-based fuels in agricultural production activities such as tillage, fertilization, spraying, harvesting and transport to market is increasing. This raises agricultural enterprise production costs due to fuel consumption and causes environmental problems in rural areas. It is critical to use biofuels instead of petroleum fuels in agricultural activities [31].

Bioenergy from agricultural and forestry activities is critical for farms to generate their own energy. It is also critical for combating climate change and ensuring energy supply security [25, 32].

The previous sections provide detailed information on bioenergy and its agricultural applications.

## Use of Hybrid Energy Systems in Agriculture

Hybrid energy systems are energy systems that use multiple energy sources. A hybrid energy system generates energy by combining renewable and fossil sources [33]. Figure 3 demonstrates an example of a hybrid power generation system. A hybrid energy system is planned with a market focus rather than a technology focus: the priority is to select the most efficient and reliable energy systems to meet the needs of the users [34].




*Figure 3. Example of hybrid power generation system [35]*

A small hybrid system combines several advantages from a single system. Hybrid systems are those that use more than one energy source to achieve the best performance. It is an ideal system for places with a summer and winter energy requirement that should not be interrupted, or where the existing renewable energy system should be supported. Hybrid energy systems can take advantage of existing energy infrastructure while also adding components to help reduce costs, environmental impacts and

system failures [36]. A small hybrid system combines several advantages from a single system. Hybrid systems are those that use more than one energy source to achieve the best performance. It is an ideal system for places with a summer and winter energy requirement that should not be interrupted, or where the existing renewable energy system should be supported. Hybrid energy systems can take advantage of existing energy infrastructure while also adding components to help reduce costs, environmental impacts and system failures [37].

Hybrid energy systems provide an alternate energy source for agriculture. These systems combine one or more renewable energy sources with storage and may include a non-renewable energy source at times. Micro versions of these systems, such as a micro wind turbine with a few solar panels, can be used to power rural areas in low and middle-income countries. They can also help to overcome some of the challenges associated with traditional renewable energy systems by diversifying the energy source [38].

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# ENERGY EFFICIENCY IN AGRICULTURE SECTOR

While global energy demand is increasing, the world's fossil energy resources are rapidly depleting. Greenhouse gases released into the atmosphere as a result of energy production and consumption play a significant role in ecosystem degradation. It is critical for an economy to develop sustainably if it can obtain the energy it requires on a consistent and reliable basis, while also being cost-effective and environmentally friendly. Furthermore, it is critical to use energy effectively and efficiently in order to meet energy needs. In this regard, energy efficiency plays a critical role because it affects many processes ranging from resource production to resource consumption [1, 2].

Energy efficiency is the process of figuring out ways to use less energy while maintaining the same level of production and service [3]. Energy efficiency is the cleanest and least expensive "first fuel" for meeting our rising energy demand. Energy efficiency is critical for energy security and resource management. It means increased productivity and employment. It entails fighting climate change. It is assistance for rural development. It is a critical component in reducing the current account deficit. Energy efficiency is one of the areas that must be handled with caution because of its direct relationship with the sustainability of economic growth and social development goals, as well as the critical role it plays in reducing greenhouse gas emissions [4, 5].

## Energy Efficiency

The ability to do work is defined as energy. Energy efficiency is defined as lowering energy consumption per unit or product quantity without lowering living standards or service quality in buildings, as well as the quality and quantity of production in industrial enterprises and agriculture [3]. Energy efficiency, in a broader context, refers to all efficiency-enhancing measures such as preventing energy losses in systems using gas, steam, heat, light, air and electricity, recovering and utilizing various wastes, or reducing energy demand without reducing production through advanced technology, more efficient energy sources, advanced processes and energy recoveries. Energy efficiency is a key component of many developed countries' policies [6, 7].

Energy efficiency studies are conducted to improve or, if possible, completely eliminate the unnecessary use of energy by identifying the points of not needed energy use. Energy efficiency does not imply lowering or restricting energy demand, rather, it refers to lowering the amount of energy consumed per product rather than the rate of energy consumption [7].

Another critical component of energy efficiency is measurement or calculation. Many methods for measuring energy efficiency have been developed. In its most basic form, energy efficiency can be calculated by comparing the output of production to the amount of energy used in the production process. For example, the amount of energy required to produce a unit of product can be used to determine whether energy is being used efficiently. Following the calculations, energy efficiency can be interpreted by finding a value between 0% and 100% [2].

## Energy Efficiency in Agriculture

Energy inputs are used in agriculture at every stage of the process, including the creation and application of chemicals, the operation of various pieces of equipment like tractors, wheelbarrows, cultivators, etc., the heating of greenhouses, buildings and animal barns and the provision of water. Energy efficiency is a critical concern for farmers that cannot be ignored. Energy, a crucial input in production, is utilized effectively at a low level, requiring less input from farmers and increasing the profit realized in production [8].

Agriculture involves the use of machines. These machines run on energy sources like gasoline, diesel and fuel oil. The heating and water extraction processes both use electricity. For the manufacture of

agrochemicals, agricultural equipment and structures, agriculture also indirectly uses energy. Inorganic nitrogen fertilizers are made using a sizable amount of natural gas [9].

Various technologies and resources can be used in agricultural activities to improve energy efficiency, improve financial situation, reduce energy consumption and reduce environmental impacts. Energy efficiency measures, when implemented correctly, can help agricultural producers save energy while maintaining productivity. Effective policies, such as energy efficiency training and incentives, can assist farmers in improving their operations [10].

Various technologies and resources can be used in agricultural activities to improve energy efficiency, improve economic conditions, reduce energy consumption and reduce environmental impacts. Different approaches to energy management are required in different parts of the agricultural sector. Farms differ not only in size and financial capability. Farms vary according to geography and climate. Both of these physical parameters influence a farmer's energy needs. Cold climates, for example, necessitate greater heating energy consumption, whereas warmer climates necessitate greater energy consumption for air conditioning and climate control [11, 12].

There are several challenges to increasing agricultural energy efficiency. Differences in geography, climate and industry structure, as well as a lack of information and access to the capital required to implement efficiency upgrades, are all barriers. Federal programs aimed at removing these impediments have played an important role in driving the market toward more efficient equipment and practices [8].

## Energy Efficiency Applications in Agriculture

Reducing the cost of energy in agricultural products, as in other sectors, is critical. Agricultural vehicles, greenhouses, dryers, buildings, irrigation systems and farm equipment are all part of a crop and livestock farm's daily operations and can result in high energy costs [13]. Through efficient use of energy, it is possible to lower energy costs without losing product quality or efficiency. The efficient use of energy in agricultural activities can be ensured by a variety of policies and practices. Efficiency in agricultural enterprises can be attained through energy conservation as well as efficient use of natural resources [14, 15].

It is critical to have information about energy consumption. Energy audit refers to the entire study consisting of information collection, measurement, evaluation and reporting stages for increasing energy efficiency. Energy auditing also includes the measurement of all energy flows and utilization within the enterprise in order to include the total energy balance, which will serve as the foundation for energy efficiency plans and applications [16].

Before considering energy efficiency measures in agriculture, it is necessary to understand where and how energy losses occur, as well as the causes of these losses. Agriculture's energy use includes both direct and indirect energy use associated with all types of inputs used to produce agricultural products. Determining and recording the enterprise's energy inputs, as well as developing the necessary energy plans, are critical for energy efficiency. These figures are based on average production or best estimates. As a result, the points of high energy consumption are identified and appropriate applications are planned [17, 18].

Existing systems must be maintained at periodically. Checking lights, coils and fans for dust, replacing gaskets and maintaining boilers, for example, can improve equipment performance and reduce the need for additional labor and costs [17, 19].

The following are examples of agricultural energy efficiency practices.

•**Heating:** Depending on the activity, heating can have a significant impact on an agricultural enterprise, providing a significant opportunity for energy savings. The amount of energy used for heating is particularly high in greenhouse production [20]. Temperature controls are essential for

reducing the amount of energy used for this purpose. Thermostats should be installed in areas where they will not be affected by cold or sunlight. Boilers and pipework should be serviced on a regular basis. Heat losses in buildings, barns and storage structures should be avoided [17].

•**Agricultural Vehicles:** The use of diesel by machinery accounts for a significant portion of direct energy in agriculture, particularly arable farming and feed for intensive livestock rearing. As a result, careful maintenance and use of agricultural vehicles will significantly improve energy efficiency. It is critical for energy management to reduce the amount of fuel used in tillage and other field applications. This requires optimizing the use of tractors and implements/machinery in field applications. Field operations such as fertilizer spreading and sowing can be combined to reduce the number of field passes [13]. It is critical to change the filters, change the oil, inflate the tyres, adjust the balance, calculate the power requirement and determine the best operating conditions for the vehicles used in the field. Tire pressure and fuel efficiency should be monitored. Excess weight in vehicles should be reduced to reduce fuel consumption. It is also necessary to understand the vehicle's driving characteristics in order to maximize fuel efficiency [17, 21]. If the farm has fuel tanks, they should be kept cool and checked for leaks on a regular basis to reduce fuel evaporation. Another application is for heaters. Engine block heaters in agricultural vehicles ensure that your vehicle is ready to start in cold weather but does not have to run all night. Installing a timer in these engine blocks allows you to start heating the engine a few hours ahead of time. Using heaters to keep engines running well in the winter is less expensive than using fuel to warm the engine. Idling vehicles can consume up to 20% of total fuel consumption, so machines should be turned off when not in use [13, 14].

•**Lighting:** Farm buildings, greenhouses, poultry houses and barns all require lighting. Natural lighting systems use no energy to provide illumination. Transparent panels, which can take the form of light tubes, are used for natural lighting [16]. In areas where natural light is insufficient, additional light sources are used. Traditional light sources are inefficient and generate a lot of radiant heat. As a result, LED bulbs for energy efficient lighting should be preferred because they use less energy and last longer than incandescent bulbs without reducing productivity. LED bulbs can be used in barns, poultry houses and farm buildings in addition to greenhouses [22]. Furthermore, the automatic lighting control system ensures that the lights are turned on only when necessary, achieving the most efficient lighting level with the fewest lights [17].

•**Ventilation:** Ventilation accounts for an estimated 14% of total energy bills in the industry. Identifying and implementing ventilation system improvements can reduce energy consumption by up to 20%. Effective ventilation is critical for any farm, but these fans can consume a lot of energy, particularly in hot weather. If possible, use windows and doors that allow for natural ventilation. As a result, the fans are turned off or run less frequently. Replacing inefficient ventilation fans with more efficient ventilation fans reduces energy consumption and saves money. Without proper maintenance, the efficiency of ventilation systems can be reduced by up to 60%, resulting in increased operating costs and the risk of failure [17]. For this reason, it's crucial to keep the fan blades and grilles clean. Airflow is impeded by substances like dust, lint and others that stick to surfaces. Inverter fan motors can also benefit from variable frequency drives to improve efficiency, reduce energy consumption and extend motor life [14, 15].

•**Irrigation:** Every irrigation system uses electricity. Systems for watering animals and irrigation can be made to use less energy. According to the number of animals on the farm, animal drinkers need to be properly insulated and the appropriate size The choice of appropriate pumps, low-pressure irrigation, drip irrigation and distribution system optimization are crucial for crop irrigation. Low-pressure sprinkler nozzles for crop irrigation lower pumping requirements without reducing water flow. These systems last longer and deliver water more cost-effectively. Low-height sprinkler application and low-height precision application are two of the most effective irrigation techniques. These processes use less water and exert less energy. It is important to realize the use of low-or no-energy animal drinkers that consume less energy, keep the water fresh and prevent freezing. Electric pumps offer higher

reliability, lower operating costs and better efficiency when replacing diesel irrigation pumps. The drawback of these pumps is the potential need for three-phase electrical power for large motors. Rotary phase converters, which convert single-phase power to three-phase power, can be used for this purpose. Irrigation systems can become more efficient with the help of smart sensors. They can measure soil moisture and determine when to water crops. They can also detect nutrient deficiencies in the soil and determine when to fertilize [13, 23].

•**Drying:** In some cases, drying a crop consumes more energy than growing it. To ensure the product's dryness, a moisture meter should be used. Natural air or a low temperature drying system can be used if mechanical drying is required [13].

Improving energy efficiency on the farm usually requires less investment than installing new energy production systems. Energy efficiency innovations in agriculture must be developed and implemented in practice. The development and implementation of integrated energy efficiency measures is also critical for the yield's sustainability. Energy efficiency on the farm and throughout the supply chain will aid in mitigating the effects of rising energy costs for heat, electricity, gas and liquid fuels [13, 17].

## European Union Energy Efficiency Directive

As part of the "Fit for 55" package, the EU concluded inter-institutional negotiations on an improved legal framework for energy efficiency and submitted a revised Energy Efficiency Directive, which was officially adopted on July 24, 2023 [24].

The revised Directive sets a 2030 reduction goal for final energy consumption of 11.7% for EU member states. In addition, EU nations have set a goal to raise the average annual energy savings rate from the current 0.8% to 1.49% between 2024 and 2030. Within this framework, it aims to increase energy savings in crucial industries like construction, industry, agriculture and transportation [24]. By introducing a number of measures to aid in advancing energy efficiency practices, this directive reflects the high priority the EU places on energy efficiency [24].

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