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EFFECTS OF CLIMATE CHANGE ON SOIL PROPERTIES

Dr. Erdinç UYSAL

Climate Change and Soil

- ❑ Soil is formed under the interaction of a number of factors and after a very long process.
- ❑ Soil is the largest carbon sink after the oceans and is an important balancing factor against climate change.
- ❑ 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.



Source: 123RF/SARAYUTSY

Effects of Climate Change on Soil Moisture

- ❑ As a result of the climate changes, some changes in soil moisture is 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.



Source: Oyvind Martinsen Documentary Collection / Alamy Stock Photo

Effects of Climate Change on Soil Moisture

- The potential effects of four possible climate change scenarios on soil moisture components are summarized below.

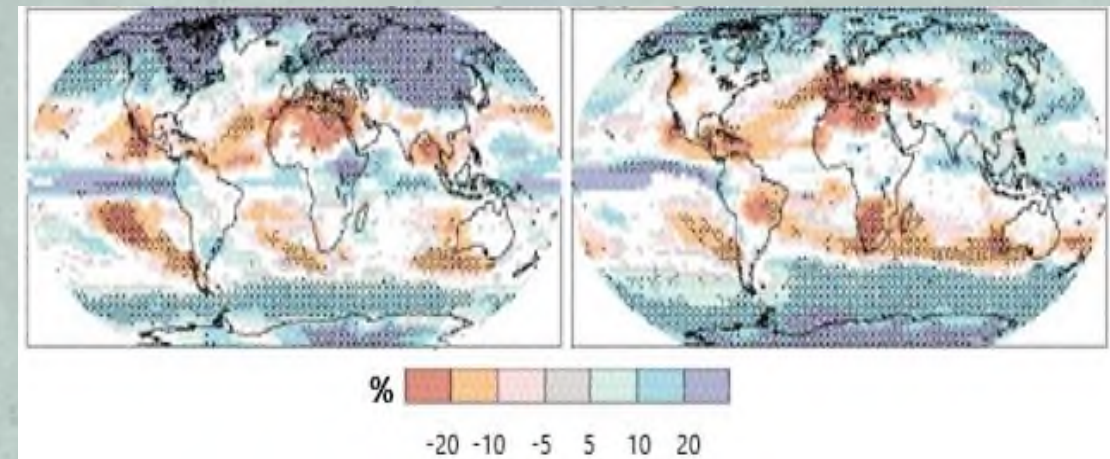
Factors	Cold, wet	Cold, dry	Hot, wet	Hot, dry
P	I	D	I	D
R	I	d, D	I	D
G	i	d	i	D
I	I	d	I	D
i	i	D	i	D
S	I	d	I	D
E	D	E	E	I
T	D	E	i	I
F	-	-	-	-
G _r	i	-	I	-
G _s	-	I	-	I

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

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

Effects of Climate Change on Soil Moisture

□ The change in soil moisture is closely related to the change in precipitation. In recent researches, 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.



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) (IPCC, 2007).

Climate Change and the Effects of Changing Precipitation Regimes on Soil Acidization

- ❑ It is expected that there will be changes in soil mineral decomposition and in soil reaction, related to the changes as 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 CO₂ 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**.



Source: DOI/Neal Herbert



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Climate Change and the Effects of Changing Precipitation Regimes on Soil Acidization

- ❑ 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.



Source: C. Kosmas

Effects of Climate Change on Soil Salinity and Alkaline

□ with 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 and accumulation of soluble salts in the soil solution over time.



Source: <https://agriculturistmusa.com/>



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Effects of Climate Change on Soil Salinity and Alkaline

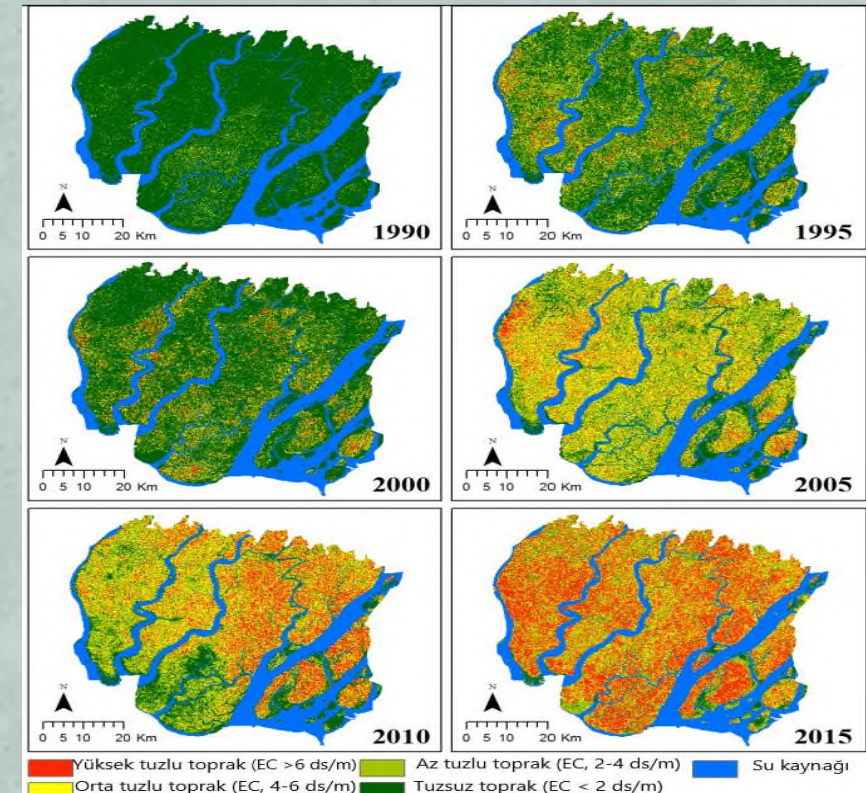
- ❑ Too much or too little precipitation can have significant effects on soil salinity in the root zone.
- ❑ Groundwater rises due to excessive precipitation. If the ground water falls below two meters, the movement of water towards the surface will occur with capillarity. If there is not enough rainfall 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 fresh water wells.



Source: Getty Images

Effects of Climate Change on Soil Salinity and Alkaline

- ❑ Rising ocean levels due to melting glaciers due to global warming may result in more seawater intrusion.
- ❑ Especially in case of direct salt water intrusion, great changes can be seen in soil salinity values in a very short time
- ❑ 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



Soil salinity map obtained in different years by remote sensing [Rahman ve ark., 2018]

Climate Change and Soil Structure

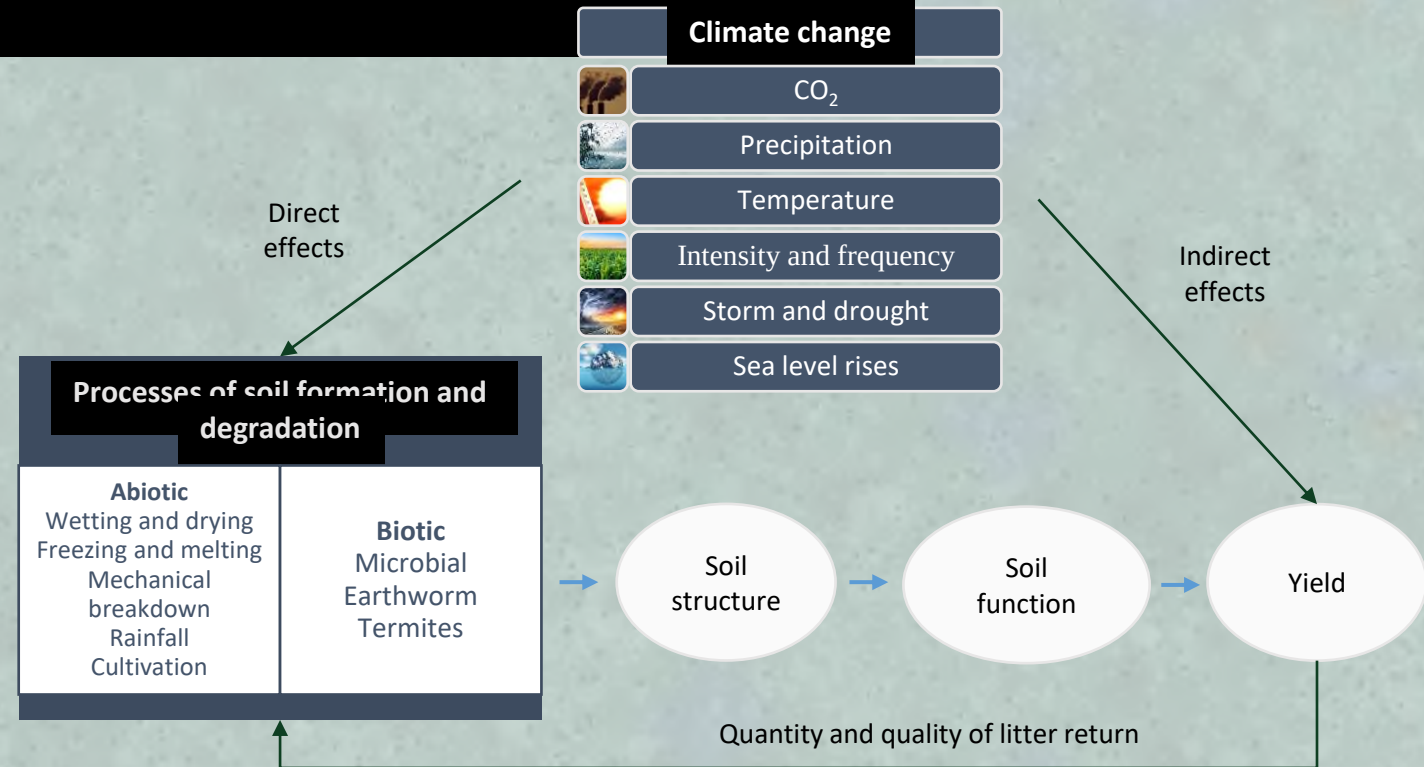
□ The particles in the soil coming together and clustered in groups form the soil structure. Soil structure is considered one of the important physical properties of soil due to its effects on water and gas movement.



□ Soil structure, which is not static but dynamic, may change depending on soil properties

Climate Change and Soil Structure

- 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.



- It is expected that the soil structure will deteriorate as a result of cultivating the soil when it is too humid or too dry.

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.



Source: Montreal Space For Life, <https://espacepourlavie.ca/>

It is expected that the changes that will occur in the soil habitat due to climate change will also affect the soil biota.



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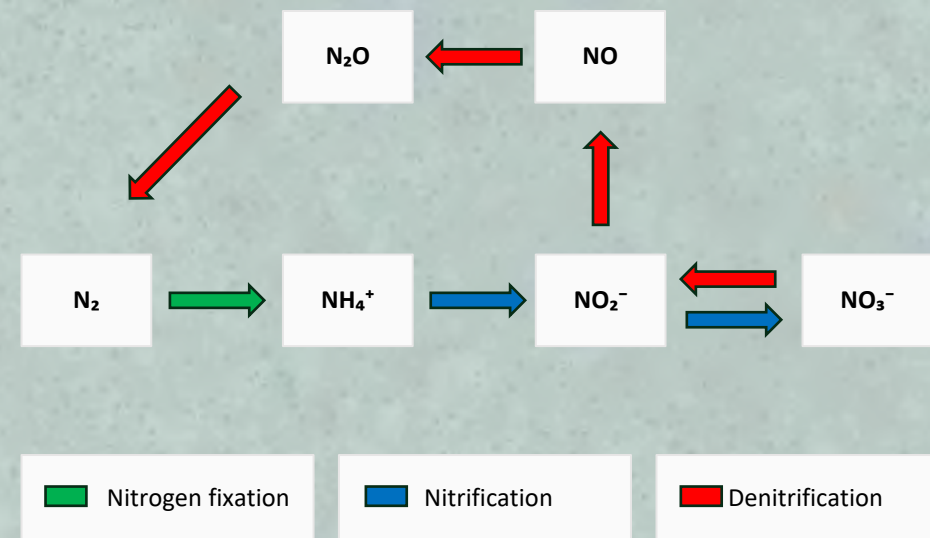


Effects of Climate Change on Soil Fauna and Soil Flora

- ❑ 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.
- ❑ Where climate change increases the soil's susceptibility to erosion, soil biota may be affected by erosion.
- ❑ In the presence of high CO₂, 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.
- ❑ It was stated that the fungal biomass in the soil increased with increasing precipitation.
- ❑ CO₂ 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.

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

- ❑ The conversion of nitrogen in organic form to inorganic N forms in soils is defined as **mineralization**.
- ❑ The conversion of ammonium to nitrate ions by some microorganisms in the soil is known as **nitrification** and occurs in the presence of oxygen.
- ❑ **Denitrification** is the reduction of nitrate to free nitrogen gas (N_2) after various processes. It is a process that takes place in the presence of anaerobic organisms.





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

- ❑ Climate-related environmental factors have important effects on nitrogen mineralization, nitrification and denitrification.
- ❑ 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.
- ❑ Higher mineralization and denitrification due to increased temperature under climate change may result in greater N₂O emissions from soils to the atmosphere.
- ❑ 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, N₂O flow from the soil.

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.

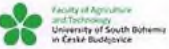


Source: Urban, 2014. What is Soil Organic Matter. <https://www.deeproot.com/>



Climate Change and Soil Organic Matter

- ❑ It is reported that at high CO₂ levels and especially in the presence of water and nitrogen in the soil, C3 plants perform photosynthesis at increased rates and produce more biomass.
- ❑ Additional nitrogen supply may not only increase the effect of high CO₂ concentration on soil organic carbon, but also slow down the rate of organic matter decomposition in some ecosystems.
- ❑ 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. 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 CO₂ and temperature.



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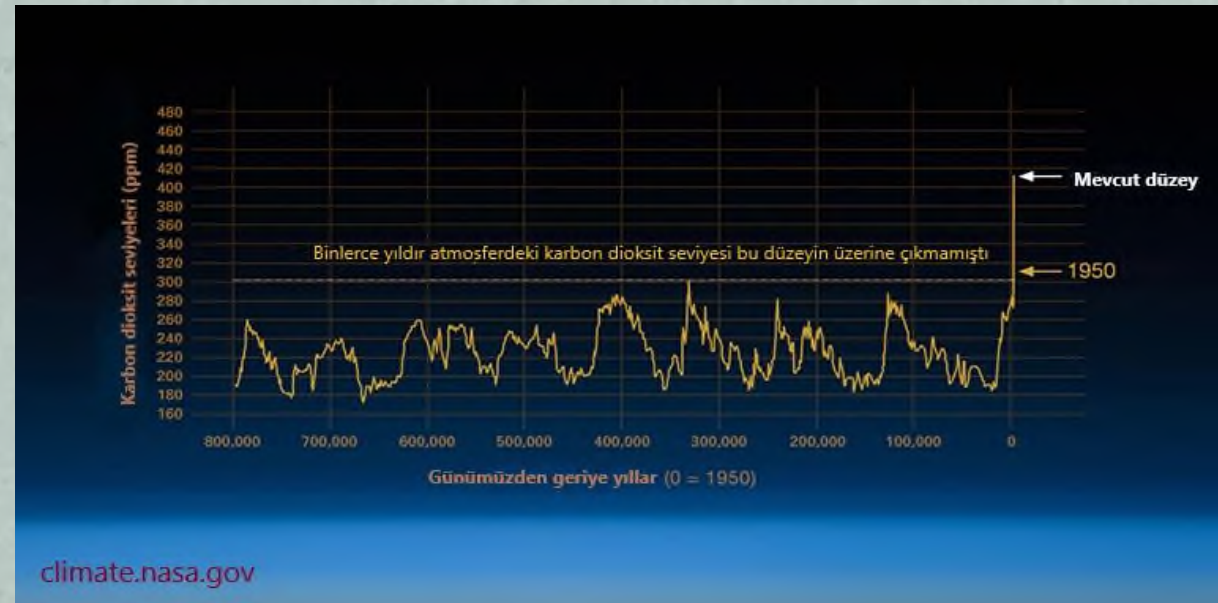
CARBON RINGET IN AGRICULTURAL LANDS

Dr. Erdinç UYSAL

Carbon Budget in Agricultural Soils

□ The rate of greenhouse gases in the atmosphere began to increase with the industrial revolution, which started in the mid-18th century, and has reached values approaching 400 ppm today.

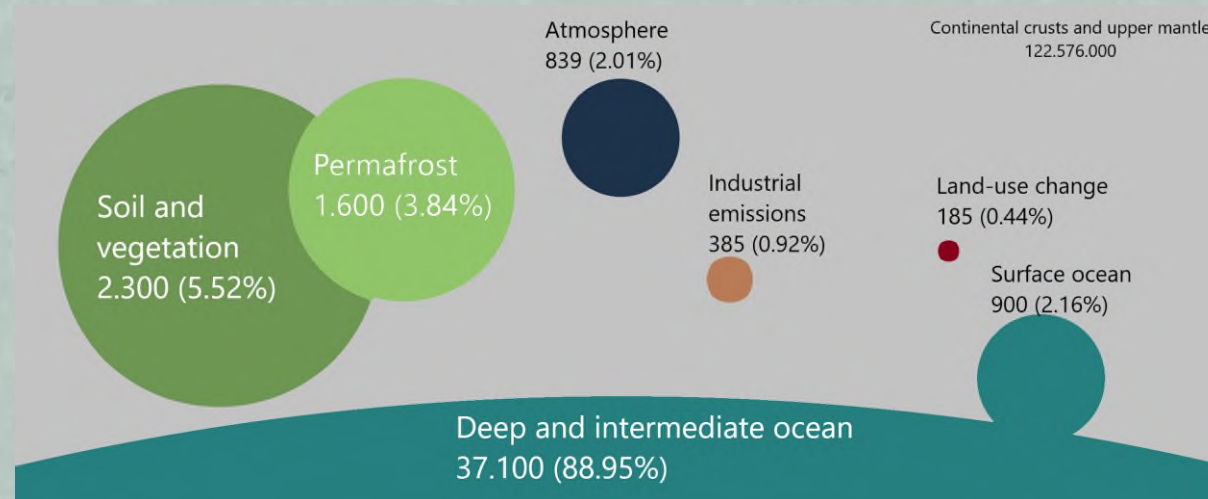
□ The increase in carbon dioxide is largely due to the **use of fossil fuels**. Another important factor in this increase is the **change in land use**, especially **deforestation**.



Changes in the amount of atmospheric CO₂ over the years

Global Carbon Cycle

□ The movement of carbon in inorganic and organic forms between the atmosphere, biosphere, hydrosphere and pedosphere is called **the carbon cycle**. The carbon cycle is a system that supports all life.



Carbon stocks on Earth - gigatons as (adapted from Janowiak et al., 2017)

□ Carbon is stored in different ways and areas. Its largest stock is in the world's continental plates and upper mantle. It is then found in the oceans, and a large part of it is not open to change. It is estimated that soils store around 3,500 Gt



Soil Organic Carbon

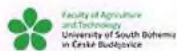
- ❑ **Soil organic carbon**, is the part that remains in the soil after the partial decomposition of waste from living organisms. Soil organic carbon is the main component of soil organic matter and is the energy source of the soil.
- ❑ After the oceans, terrestrial ecosystems are the largest carbon storage areas.
- ❑ Carbon is not stored only in plants on land, **it is stored in larger amounts in the soil**. Therefore, even small changes in the mass of soil organic carbon can have profound effects on atmospheric CO₂ concentration and hence on climate change.



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Estimated carbon stock in terrestrial ecosystems on Earth

Ecosystem	Global carbon stocks (Pg C)		
	Herb	Soil	Total
Tropical forests	212	216	428
Temperate climate forests	59	100	159
Boreal forests	88	471	559
Tropical meadows and grasslands	66	264	330
Temperate zone grasslands and shrublands	9	295	304
Deserts and semi-deserts	8	191	199
Tundras	6	121	127
Agricultural areas	3	128	131
Wetlands	15	225	240
TOTAL	466	2011	2477

[Janzen, 2004]

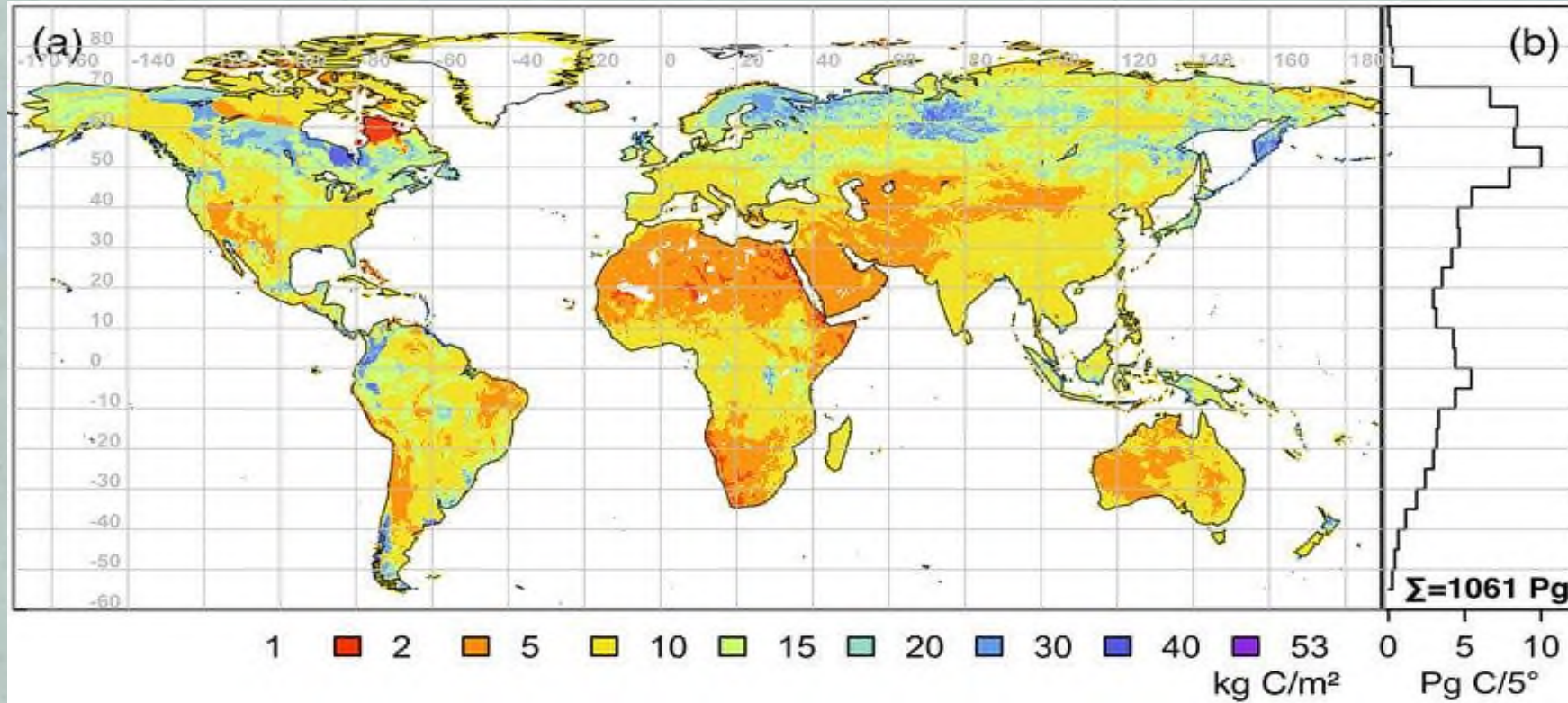
Global Carbon Stock

- The amount of carbon found in different depths of the soil also varies. Since the main source of soil organic matter is dead living things, **the upper depths of the soil** are mostly rich in organic carbon and it decreases towards the depths of the soil.



- The largest amount of soil organic carbon is stored in areas consisting mostly of peat soils **in northern latitudes**, with 190 Pg of carbon.

Global Carbon Stock



(a) Global organic carbon stock in the 1 meter top soil slice calculated via HWSD v.1.1 (b) Mass of organic carbon per 5° latitude in the same section [Köchy et al., 2014]



Changes in Carbon Stocks

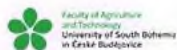
- ❑ Carbon stored in the earth's atmosphere is less compared to the the oceans and lands.
- ❑ Both the amount and direction of carbon moving between different carbon pools can have a major impact on climate change.
- ❑ The flow of carbon into the atmosphere due to fossil fuel consumption is considered the driving force of climate change .



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Global Carbon Budget for Different Time Periods (G C year^{-1})

	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 flux	-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)

*Numbers in parentheses reflect estimated ranges
[Denman et al., 2007]*

Global Carbon Budget

- ❑ There is a decrease in soil organic carbon in areas converted from forest areas to agricultural lands.
- ❑ Decomposition of organic matter accelerates with soil cultivation and becomes susceptible to transport due to erosion.



- ❑ The disappearance of forest areas means that these areas, which act as a carbon sink, become a source of carbon.

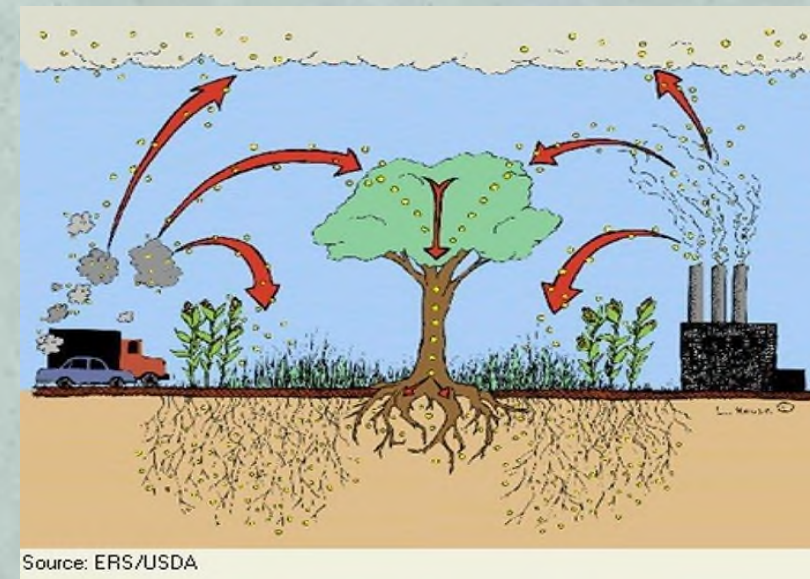
Global Carbon Budget

- ❑ Land 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 world's land surface has been degraded by 7-40% due to human causes.
- ❑ Because of the increasing urbanization, changes in land cover are observed, while biodiversity decreases, soil degradation increases. Consequently, biomass and carbon storage loss occurs.



The Importance of Carbon Sequestration in Soil

- ❑ **Carbon retention**; of CO₂ in the atmosphere is the process of transferring it in a way that it cannot be released back into the atmosphere in a short time and can be stored in soil organic carbon pools for a long time.
- ❑ A phenomenon that has attracted a lot of attention recently is, in order to be less affected by the negative effects of climate change by reducing CO₂ emissions into the atmosphere.



- ❑ It is estimated that 0.90 to 1.85 Pg of carbon can be sequestered annually in cultivated areas worldwide.

Carbon Sequestration Mechanism

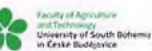
- ❑ Soil organic carbon **is the organic matter** mixed into the soil through the decomposition of dead vegetation.
- ❑ The organic substances in this cover layer can decompose and return to the atmosphere in the form of CO₂ and also mix with the soil to a significant extent.





Oxidation and Humusification

- ❑ Decomposition of dead vegetation occurs through two events called **oxidation** and **humusification**.
- ❑ If the conditions are suitable dead vegetations **are oxidized** and they become mineralized. Meanwhile, the plant nutritional elements contained in the organic matter are also released.
- ❑ **Humusification** occurs more slowly and ensures the decomposition of organic matter.



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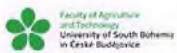


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Humi Substances

- ❑ The part that emerges as a result of decomposition loses its textural structure and turns into humus with **an amorphous and colloidal structure** that is unclear to which part of the plant it belongs.
- ❑ As a result of advanced decomposition, **humic substances** appear in the soil.
- ❑ Some compounds such as amino acids, carbohydrates and some organic acids found in the structure of organic matter are called non - **humic substances** .



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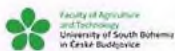


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Soil Organic Carbon

- ❑ The classification of organic matter in soil as humic and non-humic is related to whether the carbon that forms the basis of soil organic matter is stable or unstable.
- ❑ While **unstable soil organic carbon** is the part of organic matter that decomposes in a short period of time, the decomposition of **stable soil carbon** can take thousands of years.
- ❑ The flow of CO₂ between soil and atmosphere is driven by the oxidation of labile soil organic carbon.



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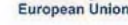
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Land Use Change in Carbon Sequestration

Land use type is of great importance in soil carbon retention. **Meadows, pastures and forests generally retain carbon at a higher rate than arable agricultural areas.**

When woodlands, grasslands or other local ecosystems are converted to arable agricultural land, soil organic carbon tends to decrease. On the contrary, when the opposite situation occurs, there is an upward trend in soil organic carbon.

Available . New	Meadow - pasture	Forest	Agricultural field
Meadow - pasture		no effect	loss of C
Forest	no effect		loss of C
Agricultural field	C gain	C gain	



Increasing Carbon Sequestration in Agricultural Fields

□ The main strategy in combating climate change is to increase the concentration of organic carbon in the soil, improve the depth distribution of carbon and stabilize carbon.

□ In this context, properly managing agricultural ecosystems is an important strategy to increase soil organic carbon sequestration.



Soil Organic Carbon Sequestration

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	Conservation tillage or no-till farming
Fallow practices	Cover crop application in off-season
Monoculture practices	High variety of crop rotations
Intensive use of chemical fertilizers	Compost, organic fertilizers and nutrient cycle, precision agriculture practices
Intensive cultivation	Integrating plant and animal production
Surface irrigation	Use of modern pressurized irrigation systems
Intensive use of pesticides	Integrated combat
Cultivation of marginal lands	Conservation reserve program, restoration of degraded lands through land use change



Soil Organic Carbon

- ❑ In line with the practices outlined, 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 fertility, and enhance the soil organic carbon pool.
- ❑ By transporting organic carbon to the subsoil, the retention period of carbon in soils is extended.



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Potential of Earth's Soils for Carbon Sequestration

- Globally, **more than 130 Pg of carbon is stored** in the top 30 cm of soils on agricultural land .
- The regions of North America, Eurasia (Russia), and Europe account for **more than 50%** of all organic carbon stocks in cropland in the world. Russia has the highest carbon stock in the world, with 21.9 Pg C in cultivated areas, with a rate of 17%. This is followed by the United States, China and India.
- Soils around the world have the potential to retain more carbon than their current stocks, and this is an important strategy to combat global warming.



Regional Soil Organic Carbon Totals

AREA	Arable Area (km ²)	Current C (Pg)	20 years later - Medium (C- Pg)	After 20 years - High (C- Pg)
Australia	659,834	3.75	4.50	5.29
Central America	139,742	1.22	1.37	1.52
Middle Asia	369,061	5.01	5.40	5.81
East Asia	1,262,134	9.14	10.52	11.97
East and Southern Africa	1,055,461	5.64	6.80	8.02
Europe	1,995,564	21.05	23.26	25.60
North Africa	258,602	1.51	1.83	2.17
North America	1,260,786	28.07	31.52	35.16
Russia	1,235,827	21.94	23.19	24.52
South America	1,753,039	9.42	10.72	12.09
south asia	852,619	7.68	9.87	12.18
Southeast Asia	1,307,174	8.15	9.06	10.03
West and Central Africa	891,532	4.83	6.35	7.95
West Asia	2,893,928	4.38	5.44	6.57
SPHERICAL	15,935,304	131.81	149.84	168.87

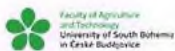
Zomer et al., 2017





Regional Soil Organic Carbon Totals

- According to the predicted scenarios, it is seen that there is a global storage potential of **0.90 and 1.85 Pg C** per year.
- **North America** has shown the highest total carbon storage potential globally, with values of 0.17 to 0.35 Pg C per year.
- **North Africa** has very little arable land and thus has the lowest potential for total carbon sequestration.



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EFFECT OF LAND USE CHANGES ON SOIL CARBON CONTENT



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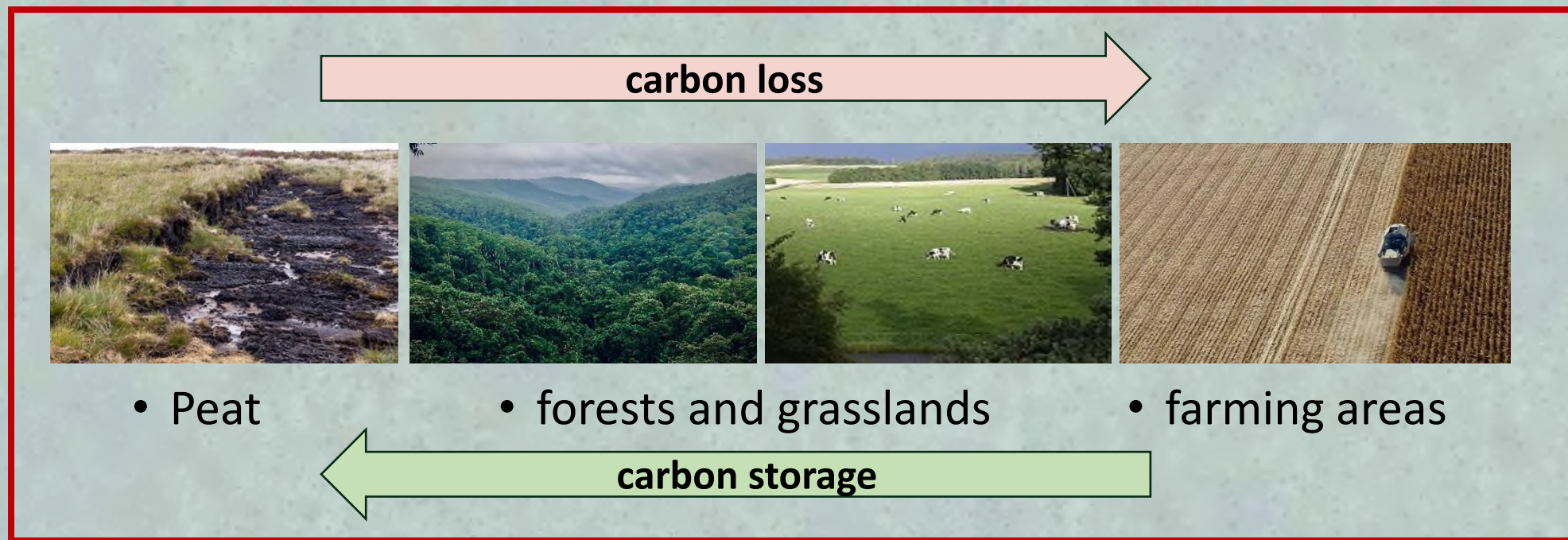
After the oceans, terrestrial ecosystems are the largest carbon storage areas.

Soil is the largest carbon reserve of 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.

Carbon in soil stocks also changes depending on differences in land use. When the direction of this change is from the soil to the atmosphere, the amount of atmospheric greenhouse gases increases.



Changes in land use and land surface cover can contribute to climate change by affecting the world's energy balance, and can also be affected by climate change.



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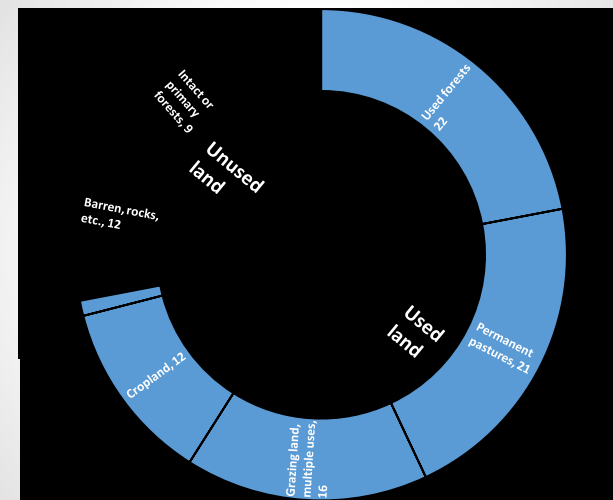


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Effects of Different Uses of Terrestrial Areas on Carbon Sequestration

There is uncertainty about exactly how the world's land is used. On the other hand, it is a known fact that these lands are constantly transformed.



Estimate of global uses of non-glacial land (adapted from Breewood and Garnett 2020)

There are 13 billion hectares of non-glacial land worldwide, one third of which (4.3 billion hectares) consists of permanent pasture and agricultural lands.



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The transition from one ecosystem to another may occur spontaneously in nature, but it often occurs as a result of human activities.

Each soil has a carbon carrying capacity and a balance carbon content depending on the type of plants on it and the climate characteristics of the region .

Land use changes creates differences in carbon input and output into the soil and this disrupts the balance. At the end of the process, soil C stocks will be changed to either a **carbon source** or a **carbon sink** .



Effects of Land use changes on soil C retention [Deng et al., 2016]

Land use changes	Soil carbon sequestration (Mg C ha ⁻¹ year ⁻¹)
From farmland to meadow	+0.30
From forest to meadow	+0.68
From meadow to farmland	-0.89
From forest to farmland	-1.74
from forest to forest	-0.63
From farmland to forest	No difference
From meadow to forest	No difference
in all	-0.39



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Forests and meadows are of vital importance in storing carbon. Considering the area they occupy on Earth, they play an important role in reducing emissions by sequestering carbon in the global carbon cycle.





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Effects of Land Use Changes in Meadow Pasture Areas

Meadow-pasture areas are of vital importance to the world in terms of their biodiversity and ability to prevent erosion. In addition, they are among the most important terrestrial carbon sinks.



Meadow-pasture areas are one of the main elements of the global carbon cycle, and although there is uncertainty about their efficiency and cycle times, it can be said that they retain approximately 0.5 Pg CO₂ annually.



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Conversion of grassland pasture lands into agricultural lands is one of the largest changes in land use and accelerates both soil erosion and loss of soil organic carbon.

Pasture areas that have been converted into arable lands causes an increase in atmospheric carbon.

However , there are many variables that affect organic carbon loss in such transformations.



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Apart from the direct loss of pasture lands, loss of productivity due to incorrect practices is a very common situation in the world. In this way, soil carbon stocks naturally decrease in damaged areas.

The practice that causes the greatest harm in this regard is **improper grazing**.

Mongolia, one of the countries with the largest grasslands in the world, In observations made over a 21-year period in Mongolia, approximately 60% of the biomass decrease in the grasslands was associated with decreasing rainfall and increasing temperature, increased goat production and the resulting overgrazing.



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It will be possible to increase productivity in these areas with correct pasture management to protect and improve pastures.

It was stated that C increase at rates ranging from **0.105 to over 1 Mg** per hectare was achieved annually with remedial practices such as improved grazing management, **fertilization in meadow pasture areas, enrichment of pasture areas with legume species** and irrigation.



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

Forests are the most important carbon sink areas among terrestrial ecosystems. While approximately half of the carbon sequestered globally on land is located in forests (1146×10^{15} g), approximately 2/3 of this amount is retained in soil pools. Since the amount of carbon entering the soil through decomposition on an annual basis exceeds the amount released by respiration, soils contribute to net carbon sequestration on a global scale.





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The disappearance of forest areas causes these areas, which serve as a carbon sink, to turn into a carbon source.

2.1 billion tonnes of CO₂ emission is caused annually due to degradation of tropical forests. It is claimed that 53% of this is by timber production, 30% by fuel wood and 17% by forest fires.



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- In a study conducted to measure the net annual changes in the above ground carbon density of living vegetation on the world's tropical forests, 12 years of satellite data were used and it was stated that the world's tropical forests are a carbon source with an annual net carbon release of **425.2 ± 92.0 Tg**.

Regions	Loss	Earning	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



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Due to changes in land use, it is inevitable that soil organic carbon will change in forest areas, and there are many factors that affect this change.

For example, in a study examining the effects of the transformation from forestland 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 decrease in carbon stocks reached 15% in an area converted from coniferous species .

Soil carbon was affected by the rainfall intensity, and losses reaching 56% were experienced in areas with rainfall over 1500 mm.



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It has been stated that the loss of soil organic carbon in lands converted from forest to agricultural land is 42% and this occurs in the first 60 cm depth of the soil .

In another study examining the effect of the transformation of agricultural lands into forest areas, *Pinus radiata* plantations were established and the results of soil carbon storage were shared. During afforestation, the annual carbon accumulation per square meter was given as 19 g in areas where vines were grown in the past , and 41 g in areas where grain was grown.



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Mangrove areas, which consist of trees and shrubs in coastal areas are important carbon sinks for the world with their potential to store up to 25.5 million tons of carbon per year, are also constantly decreasing. It is estimated that **0.15 to 1.02 billion tons of** carbon are released every year due to the degradation of mangroves , swamps and seagrasses .



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Changes in Carbon Stocks Due to Urbanization

Due to increasing urbanization, changes in land cover are observed and as a result, there are significant losses in terrestrial carbon stores.



Habitat losses reach higher levels, especially in areas less affected by urban expansion. It is clear that there has been rapid urbanization on a global scale in recent years.



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In 63 years from 1945 to 2007, it was calculated that the carbon emission into the atmosphere due to urbanization was 0.21 Pg .

Researchers, estimates that the carbon sequestration rate of the urban ecosystem decreases over time and almost disappears after two centuries.



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In another study that attempted to determine the impact of rapid urbanization on terrestrial carbon resources, the impact of land use changes on carbon sinks and emissions in Guangzhou, China, from 2000 to 2012 was analyzed.

During the study period, urbanization in Guangzhou city increased by 119%, and carbon emissions significantly exceeded carbon sink capacities. While the decrease in total carbon sink was 30%, total carbon emissions increased from 13.73×10^6 tons to 39.67×10^6 tons.



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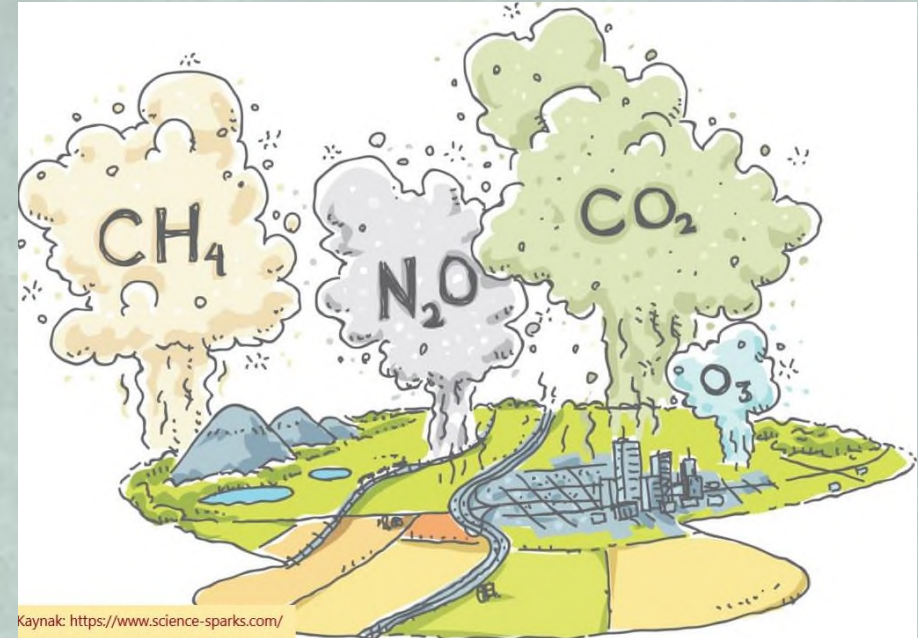


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EFFECT OF SOIL PROPERTIES ON GHG EMISSIONS

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 amounts of emissions into the atmosphere related to agriculture, forestry and land use.



After the transition to settled life and the start of agriculture, agricultural lands became one of the main sources of atmospheric greenhouse gases. It is estimated that the greenhouse gas emission from the soil to the atmosphere since the industrial revolution is $78 \pm 12 \text{ Pg CO}_2\text{-C}$.



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



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Greenhouse Gas Emissions Due to Soil Organic Carbon Content

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 CO₂.



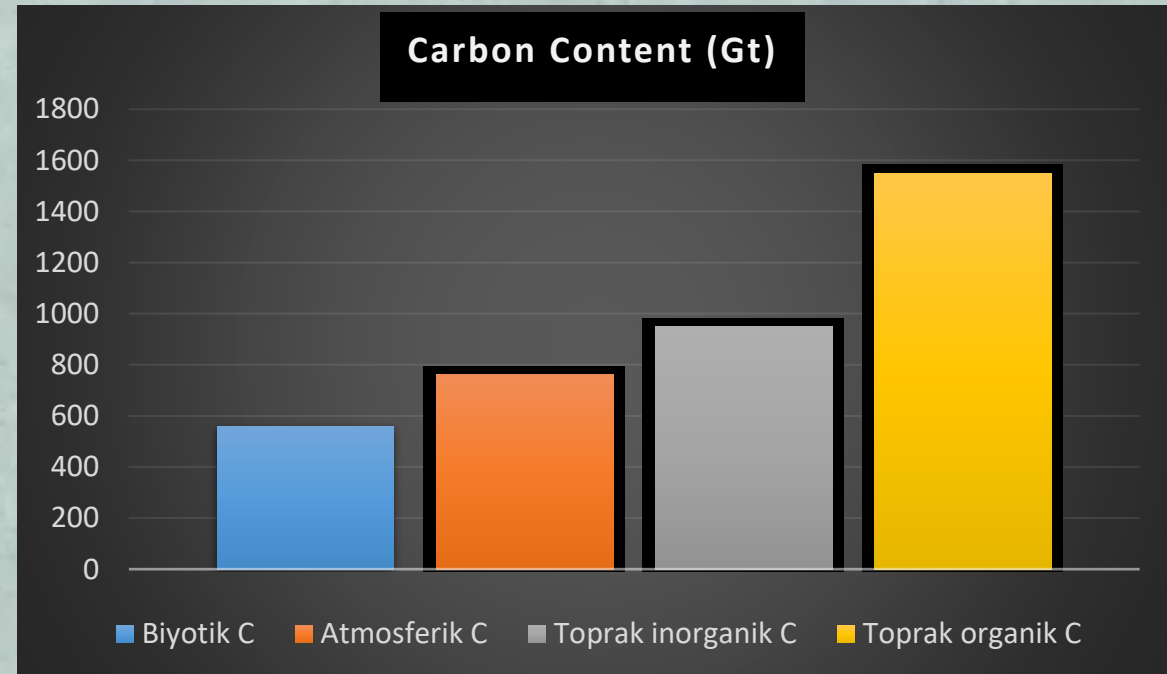
For this reason, it is important to know the expected effect of organic material added to the soil, to know the carbon retention capacity of the soil, and to know the soil carbon balance status that will occur in the short and long term after the application. Therefore, the goal should be to increase the biologically stabilized soil organic matter in the long term in a way that is compatible with environmental conditions.



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Soil organic carbon is an important component of the global carbon cycle, and its presence in soils will have a significant impact on the global climate with which it interacts in the future.



Carbon content of soil, atmosphere and biota (adapted from Lal, 2004)



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The impact of soil organic carbon on climate is complex and may vary depending on soil properties.

For example, as microbial activity will be higher in soils with high temperatures, the decomposition of organic matter will accelerate, resulting in an increase in the release of CO_2 and CH_4 into the atmosphere.

On the other hand, increased carbon sequestration may encourage more plant vegetation.



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There are two basic approaches that are widely used to reduce the amount of CO₂ in the atmosphere. The first of these is reducing emissions and the other is carbon sequestration.

Soil plays an important role in both cases. Carbon sequestration means that CO₂ in the atmosphere is taken by plants through photosynthesis and transferred to the soil.

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 are the largest terrestrial carbon pool, will undoubtedly be an important strategy.



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The carbon storage capacity of soils is not unlimited and may vary depending on soil type. In mineral soils, although the presence of clay and silt particles increases the stability of soil organic carbon through adsorption but the amount is limited.



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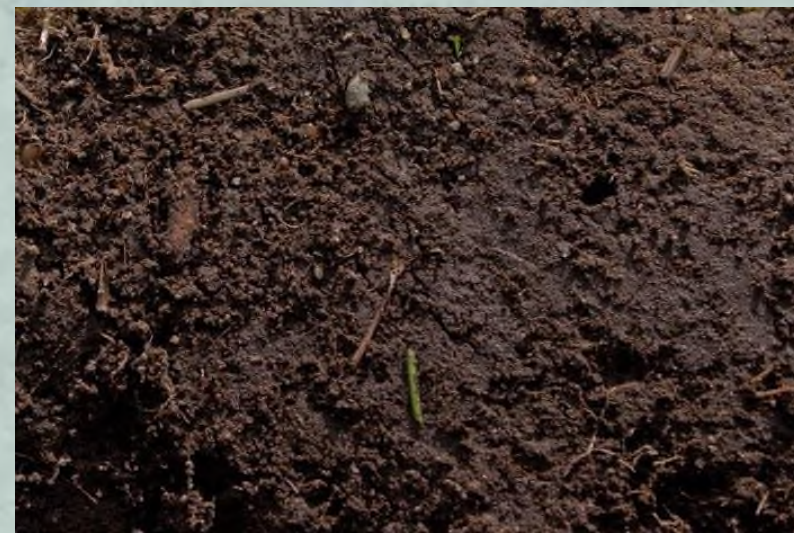
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Soil Aggregate Size on Greenhouse Gas Emissions

Differences can be seen in gas transport and emissions depending on the aggregate size in soils.

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 clay loam texture.



According to the results obtained, while pore sizes significantly affected the release of CO_2 and CH_4 from the soil, they did not have any effect on the release of N_2O .



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The highest CO_2 emission occurred in clay loam soil with the smallest aggregate size.

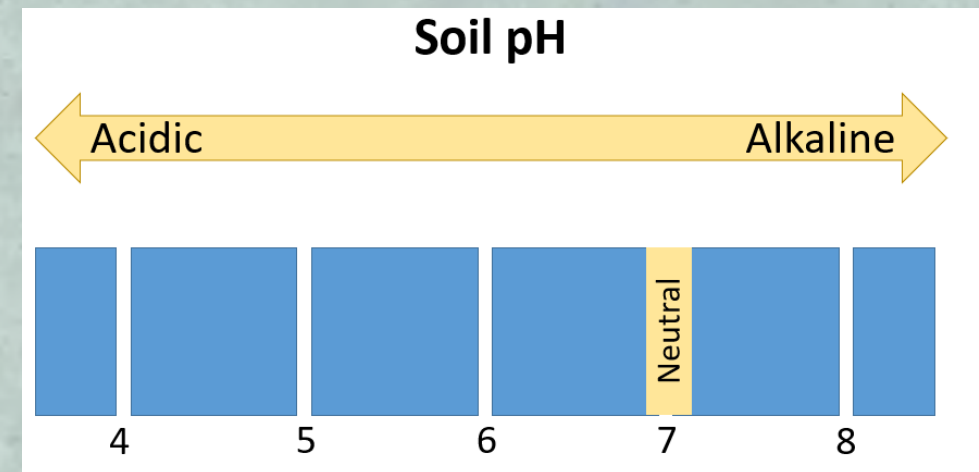
In soil with a sandy loam structure, the highest CO_2 emissions occurred in soils with the largest aggregate size. The study reported increased CH_4 fluxes in soils with small-sized aggregates.

As a result of their study, researchers stated that tillage practices that greatly affect the pore properties of soils may have a direct effect on greenhouse gas emissions.

Effects of Soil pH on Greenhouse Gas Emissions

Soil pH is an expression that represents the amount of H^+ ions in the soil solution that are in dynamic equilibrium with a negatively charged solid phase.

H^+ ions, which are strongly attracted to negatively charged solid surfaces, can replace other cations present there.





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There are different opinions about the effects of soil pH on greenhouse gas emissions.

pH, which has a significant impact on the physical, chemical and biological properties of the soil, inevitably affects the carbon flow in the soil.

Alkaline soils have significantly higher CO_2 content and the organic carbon in these soils is not very chemically stable to mineralization.

Addition of calcium agents to soil can alter soluble organic carbon concentrations and stimulate, albeit limited, soil organic carbon mineralization.



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In a study examining the effects of soil pH on long-term CO₂ emissions, emission measurements were made in soils with pH values of 3.65, 5.00, 6.90 and 8.55.

According to the results obtained, it was seen that ammonium and nitrate fertilization did not affect CO₂ emissions at different soil pH values.

As the researchers reported, pH increase and nitrogen fertilization significantly increased CO₂ emissions, and heterotrophic microbial respiration in the soil played a dominant role in CO₂ emissions.



Soil Moisture and Greenhouse Gas Emission from Soil

While plant development in unirrigated areas is limited by the available soil moisture, with irrigation, there is an increase in the above-ground parts and root development of plants. This situation also increases carbon input into the soil.

Carbon input into the soil is increased by fertilizing and irrigation in arable areas and pasture areas. With the increase in soil moisture, microbial activity also increases.

As a result of both the increase in biomass and the resulting increase in carbon input and the acceleration of the breakdown of organic carbon as a result of the increase in microbial activity, CO₂ release from the soil also increases.





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In a study examining the effects of limited irrigation practices on greenhouse gas emissions in drip irrigation, the highest CO₂ emission values over the years were obtained in the area where the most irrigation was done, and it was stated that the emission values measured after irrigation were higher than the values measured before irrigation.

Similar results were obtained in terms of N₂O emission values measured in the study, and the highest emission values were reached in the area with the most irrigation.

As a result of the study, researchers **stated that irrigation practices significantly increase greenhouse gas emissions.**

However, it has been stated that the lower CO₂ emissions in restricted irrigation practices are due to the slowdown in microorganism activities.



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Soil Temperature and Greenhouse Gas Emission from Soil

Soil moisture, soil temperature, and soil humidity, can be effective in the release of greenhouse gases due to its effects on microbial activity. Under appropriate soil temperature conditions, CO₂ emissions increase due to oxidation of organic matter.

The increase in soil temperature accelerates organic matter decomposition, causes increased microbial activity and root development, and as a result, accelerates the carbon mineralization process and increases CO₂ emissions.





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According to the results obtained in a study examining the effects of soil temperature and moisture on N_2O and CO_2 concentrations, N_2O concentration increased in parallel with the increase in soil moisture at a depth of 10-30 cm. The CO_2 concentration in the soil also increased with the increase in soil temperature.

In another study, it was similarly noted that CO_2 emissions increased with the increase in soil temperature and the increase rate reached 59%.

However, since microbial activity in soil may be active between certain temperature values, a linear relationship between soil temperature and CO_2 emission may not always be obtained.



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Changes in Greenhouse Gas Emissions Depending on Soil Tillage Practices

As a result of tillage practices, there may be significant changes in greenhouse gas transfers between the atmosphere and the soil.



Greenhouse gas emissions resulting from soil cultivation may arise directly from the use of fossil fuels consumed by the vehicles used, or may occur due to the effects it has on soil properties.



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Tillage can affect the distribution and transformation 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 retention capacity and temperature as a result of tillage may change the decomposition dynamics of organic matter.



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In a study aimed at determining the possible effects of reduced tillage practices on CO₂ emissions from soils, four different practices were compared.

These applications are 12 cm tillage with a chisel, 5 cm tillage with a chisel, mulching straw on the surface and uncultivated soil covered with stubble.

Tillage at a depth of 10-12 cm in the summer increased CO₂ emissions approximately 2 times compared to other practices. This was followed by shallow tillage, mulching and no-till.



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In a study comparing the effects of traditional tillage and direct sowing on CO₂ emissions, soybeans were grown while the soil was cultivated with a chisel, disc harrow and cultivator, and in the other application by direct sowing. CO₂ emissions from the soil were measured for 55 days.

As a result of the study, it was determined that the lowest emission occurred in the direct sowing application.



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Mulching is one of the effective practices on carbon sequestration, and this effect may vary depending on soil properties and application time to the mulch material.

Mulching helps reduce the negative effects of climate change by offsetting greenhouse gas emissions and increasing organic carbon sequestration in the soil.

However, long-term residue addition can bring soils to a carbon saturation level, creating a situation where greenhouse gas emissions from soils exceed the amount of carbon sequestration.



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GREENHOUSE GAS EMISSIONS FROM FERTILIZER USE



Greenhouse gas emissions from agriculture largely consist of methane (CH_4) and nitrous oxide (N_2O) gas. The highest greenhouse gas emissions among agricultural activities are enteric It occurs by fermentation and its rate is close to 48%.

Emission source	amount of release (Kilotons of CO_2 equivalent)	%
Enteric fermentation	2849716	47.60
Animal manure remaining in pastures	772541	12.91
Paddy farming	686111	11.46
Synthetic fertilizers	625107	10.44
Animal manure use and management	399815	6.68
Burning savannas	211921	3.54
Product residues	191540	3.20
Animal manure applied to the soil	165093	2.76
Treated organic soils	46996	0.79
Burnt product residues	37387	0.62
TOTAL	5986227	100

One of the most important agricultural inputs in plant production is fertilizers, and due to fertilizers, significant greenhouse gas emissions are released into the atmosphere. 10% of the gases released into the atmosphere due to agricultural activities were realized through synthetic fertilizers in 2020.



Apart from chemical fertilizers used in agriculture, animal manure also have an important share as a source of emissions.

There is a general increase in greenhouse gas emissions into the atmosphere over the years. This is also valid for greenhouse gas emission from agriculture and the increase in emissions from agriculture due to the use of chemical fertilizers has reached much higher rates.

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
Animal manure	109013	122615	144580	156499	145270	156386	165093	51
Synthetic fertilizers	63209	174069	334374	425288	446178	559822	625107	889



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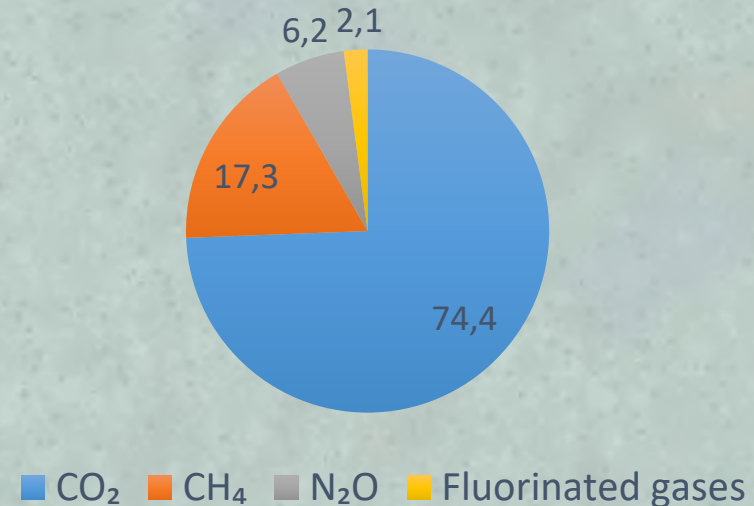


Greenhouse Gas Release Mechanism to the Atmosphere through Fertilizers

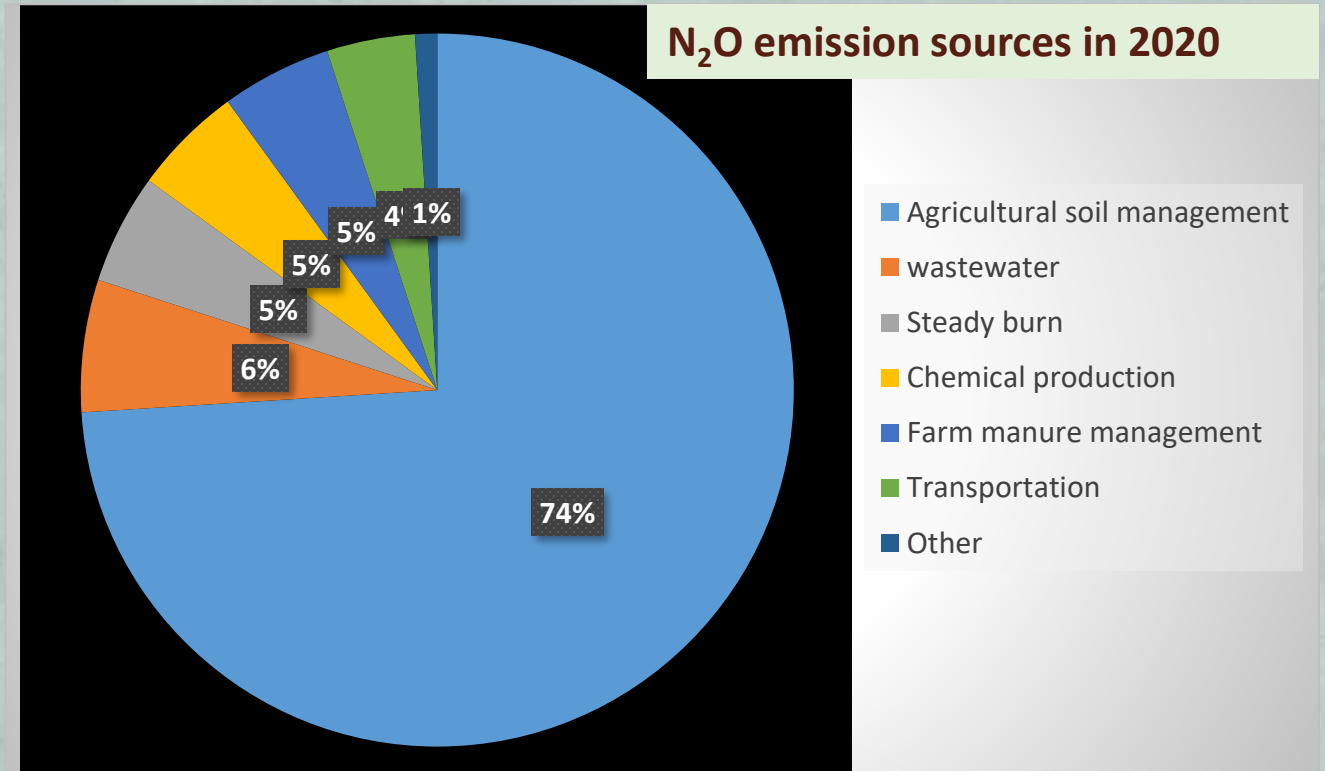
Greenhouse gas emissions from agriculture largely consist of nitrous oxide (N_2O) resulting from fertilization and methane (CH_4) gas resulting from cattle breeding. N_2O and CH_4 gases are gases with higher global warming potential than CO_2 gas. In the Global Climate Change Panel, it was stated that the unit masses of CH_4 and N_2O gases have 25 and 298 times more global warming potential than CO_2 gas, respectively.

If no precautions are taken, it is predicted that the amount of N_2O in the atmosphere will increase by 35-60% and the amount of CH_4 in the atmosphere will increase by 60% by 2030.

Gas emissions



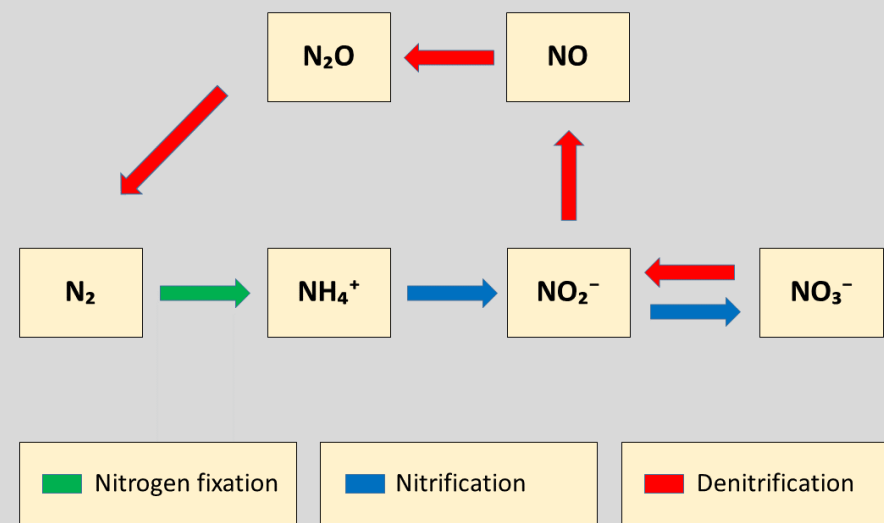
Nitrous oxide molecules can remain in the atmosphere for an average of 114 years. Globally, although the majority of N_2O emissions enter the atmosphere naturally, approximately 40% are caused by human activities.



Human-induced N_2O emissions are released into the atmosphere largely through agricultural activities. The use of nitrogenous fertilizer in agricultural activities has a great impact on N_2O emissions.

The two main ways N_2O is produced in agricultural soils are nitrification and denitrification. The conversion of ammonium into nitrate ions by some microorganisms in soil is defined as nitrification.

Schematic representation of the nitrogen cycle



Nitrification occurs in the presence of oxygen. Denitrification is the process of reducing nitrate to free nitrogen gas (N_2) after various processes. During this process, although the conversion of nitrate to N_2 gas is generally completed, a small and variable amount of nitrogen form is released into the atmosphere in the form of N_2O gas.



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Unlike other nitrogenous fertilizers, when urea fertilizer is applied to the soil, CO_2 added during the industrial production process is released.

Urea ($\text{CH}_4\text{N}_2\text{O}$) turns into ammonium (NH_4^+), hydroxyl (OH^-) and bicarbonate (HCO_3^-) ions in the presence of water and urease enzymes. HCO_3^- , formed as a result of the reaction, is separated into its constituent CO_2 and H_2O after lime is added.

In this way, CO_2 release from soils occurs at lower levels compared to N_2O release from nitrogen fertilizer applications.





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Greenhouse Gas Emissions from Nitrogenous Synthetic Fertilizers

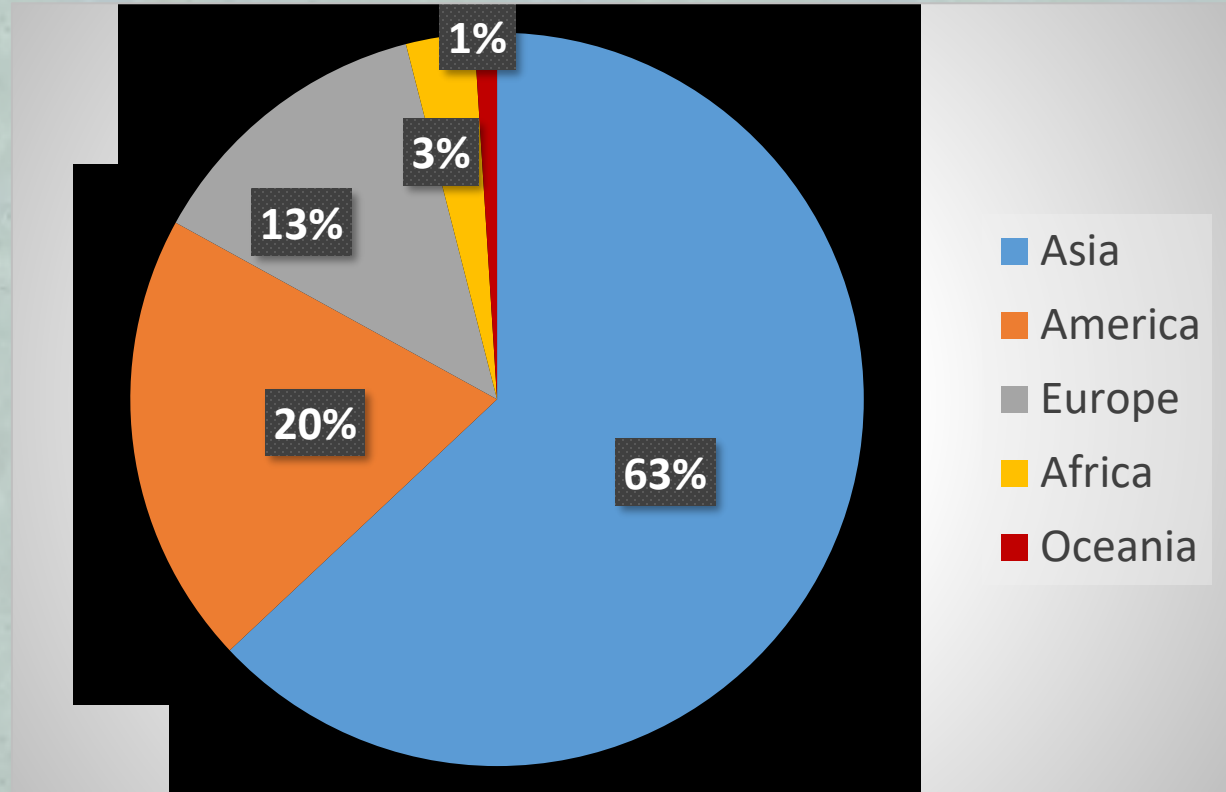
...tion is fertilization.

Nitrogenous fertilizers are among the most used fertilizers in the world. Annual nitrogen fertilizer production is estimated to be approximately 100 Tg N on a global scale.

However, nitrogenous 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 that it turns into N₂O gas and is released into the atmosphere after application.

Although it is a very small amount of emissions, its effect is very strong due to its high global warming potential and the fact that it can remain in the atmosphere for a long time. When evaluated in terms of global warming potential, each 1 kg N input applied to soil is considered to be an average of 4.65 kg CO₂.

Since 1961, for which we have access to global data, greenhouse gas emissions due to the use of synthetic fertilizers have increased approximately 10 times.



N₂O Rates From Synthetic Fertilizers In The Period 2001-2011 By Continents

Greenhouse gas emissions from synthetic fertilizers account for approximately 11% of total emissions from agriculture. A significant amount of these emissions come from the Asian continent.



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Some Environmental Factors Affecting Greenhouse Gas Emission from Fertilizers

Nitrous oxide formation 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 direction of the reaction depends on the temperature. While the conversion of nitrogen components slows down under low temperature conditions, the conversion rate increases with increasing temperature.

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 in the environment.



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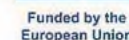


Effects of Fertilizers with Increased Efficiency on Emission Reduction

Increasing the effectiveness of fertilizers, minimizing possible losses in the soil and ensuring that plants benefit more from the nutrients they contain, has become a widely preferred method in recent years. These fertilizers, generally called efficiency-increased fertilizers, are defined as **"fertilizer products with properties that increase plant uptake and reduce nutrient loss."**



Different methods such as **coating, encapsulation and inhibitor** addition are used in such products, which aim to increase the efficiency of nitrogenous fertilizers. In this way, it is possible to spread nitrogen emissions over a wide period and losses are minimized.



Slow and controlled release fertilizers and fertilizers with inhibitor not only have higher nitrogen use efficiency, but also have the potential to reduce N_2O emissions resulting from fertilization.

According to the results of a study conducted under irrigated farming conditions and corn plant cultivation at different times:

A controlled-release polymer-coated urea reduced N_2O emissions by 42% compared to urea and 14% compared to urea ammonium nitrate fertilizer (UAN) in no-till and minimum tillage environments.

Application of inhibitory urea fertilizer reduced the N_2O emission value by 46% compared to normal urea and by 21% compared to urea ammonium nitrate.



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Greenhouse Gas Emissions During Fertilizer Production

The technique for obtaining ammonia (NH_3) from nitrogen (N) and hydrogen (H) is the primary method of nitrogenous fertilizer production in the world, and this method requires high temperatures and high energy.

It is estimated that approximately 1.2% of the world's energy is consumed during fertilizer production and the same amount of greenhouse gas emissions are emitted.





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The main greenhouse gases released during nitrogen fertilizer production are CO_2 , which is produced by burning natural gas used in ammonia synthesis, and N_2O , which is released during the production of nitric acid.

During ammonia production, approximately 1250 m^3 of natural gas is required for 1 metric ton of anhydrous ammonia.

The amount of greenhouse gas released into the atmosphere during global fertilizer production in 2020 was reported as 389142 Kilotons of CO_2 equivalent.

CO_2 released due to the use of fossil fuels during the production of phosphorus fertilizers and CO_2 released during the transportation of raw materials have become the main greenhouse gases in production.



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Organic fertilizers produce high amounts of emissions, especially during long-term storage.

It has been stated that while CH_4 emissions decrease during the storage of liquid organic wastes or fertilizers, N_2O emissions increase.

It is reported that emissions resulting from the storage of synthetic fertilizers are almost non-existent.



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Greenhouse Gas Emissions from Animal Manures

Animal manures have a significant share in agricultural greenhouse gas emissions. Animal manure management, animal manure left on pastures and animal manure applied to the soil cause approximately 22% of greenhouse gas emissions from agriculture in total. Emissions from animal manure resulting from livestock activities are methane (CH_4) and nitrous oxide (N_2O) gases.





Greenhouse gases released through animal manures vary greatly depending on many factors.

Based on IPCC's "National Greenhouse Gas Emission Inventory Report" and based on the average annual temperature of 20°C for different animals, CH₄ gas emission factors are given in the Table below.

Farm Animal	Emission Factor (kg CH ₄ Animal Head ⁻¹ Year ⁻¹)
Dairy cattle	27
Other cattle	13
Pig	5
Pig Breeding	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



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EFFECTS OF LIME APPLICATIONS IN AGRICULTURAL SOILS ON GHG EMISSIONS



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Soil amendment materials are widely used in the world to increase the efficiency of agricultural production in acidic soils. The main aim of using these materials is to increase the availability of plant nutrients by reducing soil acidity.



<https://thatsfarming.com/>

In this way, soil fertility is increased and as a result, product yield and quality are improved. The most preferred method for this purpose throughout the world is liming agricultural soils.



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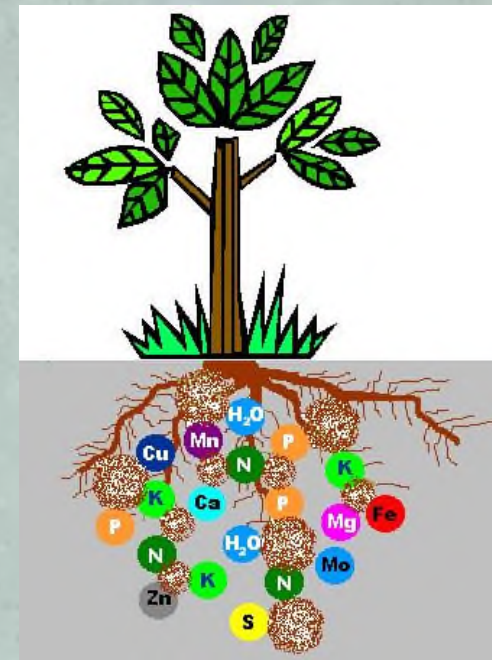


Effect of Soil Reaction on Plant Development

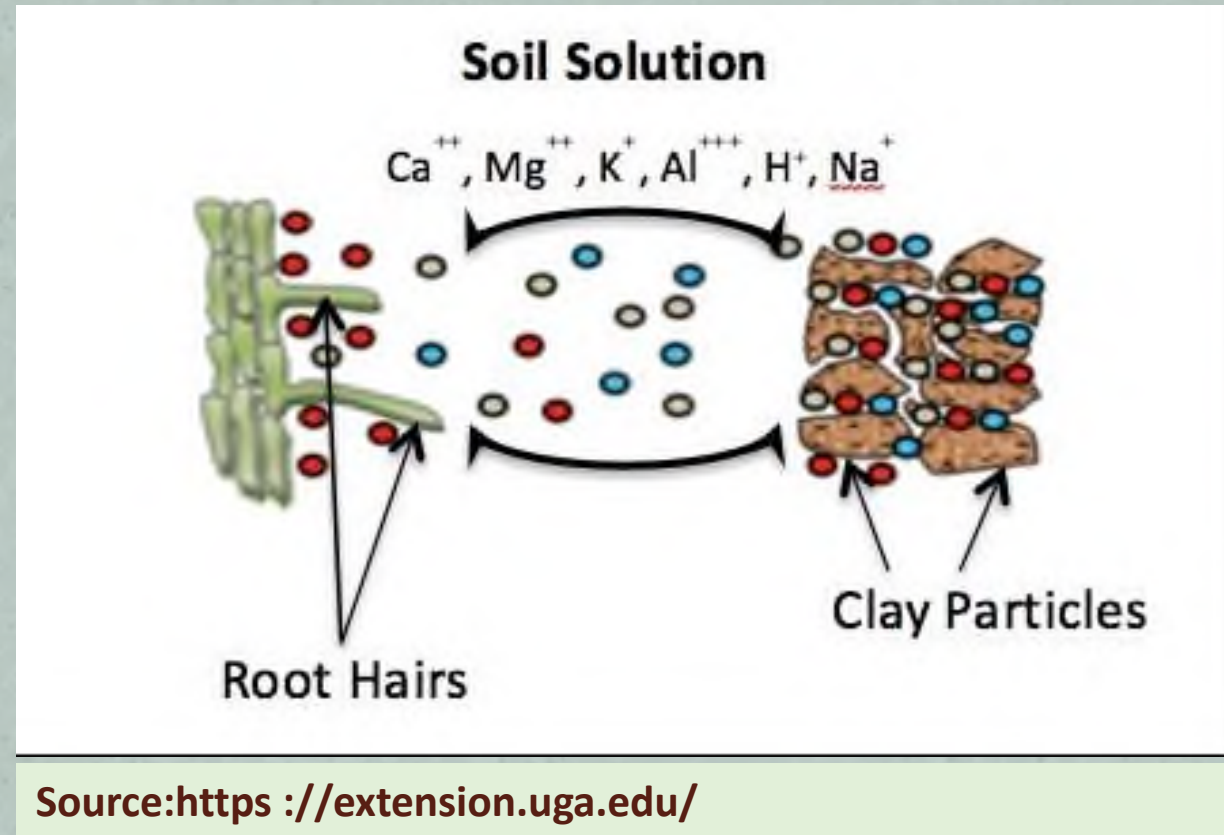
There are many factors that affect the uptake of plant nutrients in the soil by plants. Among these factors, soil reaction is one of the most important.

Plants can generally benefit from plant nutrients at an optimum level if the soil pH is close to neutral reaction.

However, increases in acidic or alkaline pH in the soil solution significantly reduce the solubility of some plant nutrients.

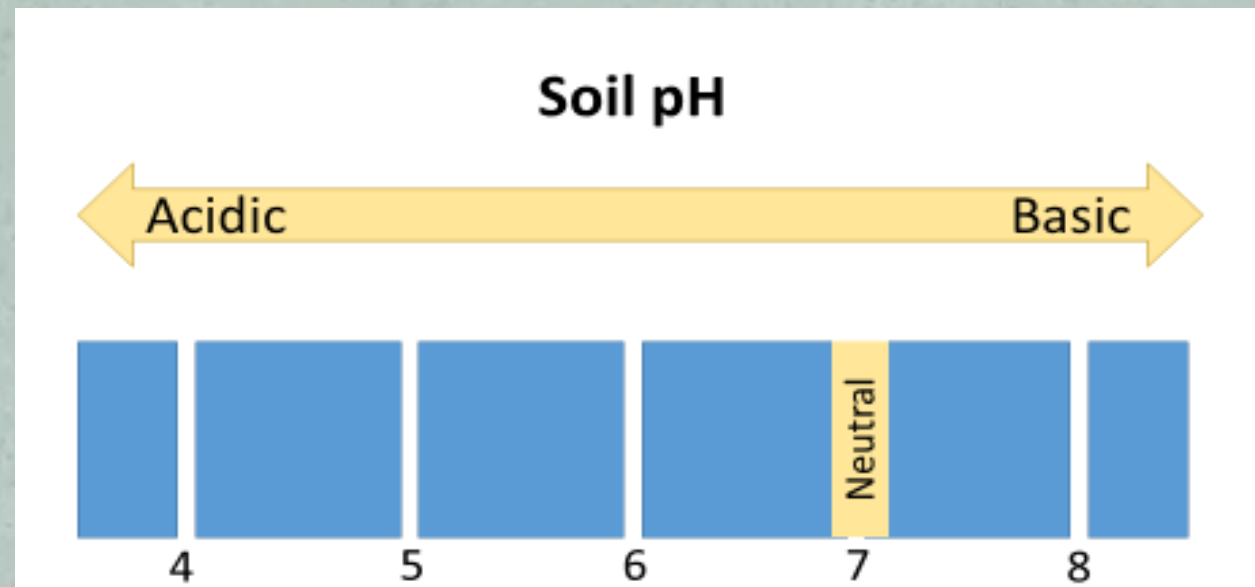


Soil acidity is a term used to express the amount of hydrogen (H) and aluminum (Al) ions in soil. An increase in the amount of hydrogen or aluminum ions means acidification of the soil and the negatively charged cation exchange capacity (CEC) of the soil is restricted.



This is a detrimental situation for the root growth and normal development of plants.

Soil pH is an indicator of "soil acidity". While a pH value of 7.0 is defined as neutral, below this value is defined as acidic, and above this value is defined as basic or alkaline.



pH classification in soils in general

Small changes in pH numbers 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.



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Soil acidity can have negative effects on plant development in different ways.

Decreases in the uptake of some plant nutrients due to the increase in acidity or toxic ion effects can be considered as the most important problem.

In acidic soils, deficiencies of some nutrients such as **phosphorus, molybdenum and calcium** are observed due to the decrease in their solubility, while ions such as **aluminum, manganese and hydrogen** can increase to levels that may cause toxicity.

Acidity is an important factor limiting crop yield in soils, and approximately **four billion hectares** of land in the world are acidic.



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Liming Applications in Agricultural Soils

In acidic soils, liming applications are the most frequently used method to neutralize the soil. Liming materials commonly used to eliminate acidity are calcium compounds such as limestone, slaked and quicklime, and dolomite.

While calcium cannot increase soil pH when used alone, basic cations in liming materials can be neutralized by hydrogen ions in acid soils.





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Liming, if done correctly, provides significant benefits in crop production, some of these benefits are as follows:

*With liming in acidic soils, plants 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 increases due to the increase in soil pH, nutrient uptake through plant roots increases.



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*With liming, the cation exchange capacity (CCC) of the soil increases, and this prevents loss of essential cations, especially potassium, by leaching.

*Since nodule formation will be supported in legumes, there will be an increase in biological nitrogen fixation.

*As some herbicides will be easier to break down in optimal soil pH, damage to plants is prevented during crop rotation. Some nematicides work more effectively in areas where liming has been done.



When liming, in addition to soil characteristics, the optimum pH requirement of the grown plant should also be known. It is always possible to experience different nutritional problems if too much lime is applied.

The optimum pH requirements of some plants are shown on the side.

Plant	pH
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



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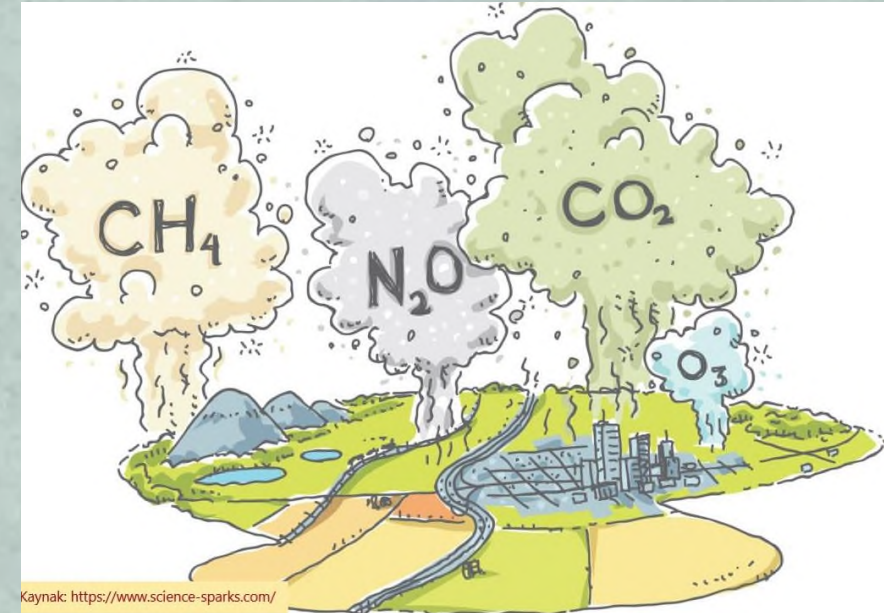
Generally, liming materials come in two different types:

The first group, called calcitic limestone, includes calcium carbonate (CaCO_3), calcium hydroxide [$\text{Ca}(\text{OH})_2$] or calcium oxide (CaO).

Dolomitic limestone [$\text{CaMg}(\text{CO}_3)_2$], which contains a significant amount of magnesium along with calcium, is classified as the second type.

Effect of Lime Applications in Soils on Greenhouse Gas Emissions

Applying liming materials to the soil to ensure neutralization in acidic soils also has some environmental effects. These effects may vary 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 gas.



Kaynak: <https://www.science-sparks.com/>



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Effects of Liming on Carbon Dioxide Release in Soils

Increases in the amount of atmospheric CO₂ can be observed due to the application of lime to acid soils. This situation is tried to be explained with the equation shown below:





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- After the lime dissolves in soil moisture, 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 the soil pH increases due to the decrease in the acid hydrolysis of aluminum.
- When the bicarbonate (HCO_3^-) ions formed during this reaction react with the H^+ ions present in the soil, carbon dioxide (CO_2) and water (H_2O) are released.
- As a result of these processes, the H^+ concentration that causes acidity in the soil decreases, while conditions that hinder plant development, such as toxicity caused by Al^{3+} ions and Ca^{2+} deficiency, are partially eliminated.



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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.

In a study conducted to calculate CO_2 emissions due to liming of agricultural soils in Brazil, it was reported that the average amount of emissions was 7.2 Tg per year in the period between 1990 and 2000.



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Effects of Liming on Nitrous Oxide Release in Acid Soils

Liming increases the pH of the soil and thus increases the fertility of the soil. In addition, it also affects greenhouse gas emissions depending on soil carbon content and the cycle of elements.

Contrary to the increase in CO₂ emissions to the atmosphere due to liming, many studies have emphasized the decrease in N₂O emissions due to nitrogen fertilization.



- In a study examining nitrogen losses due to liming of soils, it was stated that nitrogen loss by washing with liming and N_2O emissions to the atmosphere decreased, but direct CO_2 emissions due to liming increased. In the study, greenhouse gas emissions resulting from liming were approximately four times higher than the amount saved by reducing N_2O emissions. It has been stated that .

- In a study investigating the effects of liming, the possible effects of four different liming materials on N_2O release in a soil with a pH of 5.35 were examined. In the study, dolomit- $CaMg(CO_3)_2$, kalsit- $CaCO_3$, calcium hydroxide- $Ca(OH)_2$ and calcium oxide- CaO were used as liming materials, and a decrease in N_2O release from the soil was observed as a result of all applications. Compared to other applications, the highest reduction in N_2O release was achieved in the $Ca(OH)_2$ application, and this was associated with a further increase in pH.



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- In a study conducted to reveal the effects of greenhouse gas emissions in areas where no-tillage agriculture is practiced and lime is applied, N_2O and CH_4 emissions were observed from an acidic soil with inadequate drainage.
- According to the results of the study, N_2O emissions were reduced by 61% with liming in areas where conventional agricultural practices were applied, while no effect was observed in areas where agriculture was carried out without tillage.
- According to their results, researchers emphasized that no-till agriculture is an important tool to improve the physical properties of the soil and at the same time reduce N_2O and CH_4 emissions.



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Effects of 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.



The fact that the produced biochars are largely **alkaline** has caused most of the work done to date to be in acidic soils. It has been the subject of many studies because it increases the availability of nutrients by increasing the pH of the soil when applied as in liming.



It is possible to find many studies examining the effects of biochar applications on soil greenhouse gas fluxes.

In a study conducted for this purpose, the effects of biochar applications on CO_2 , CH_4 and N_2O fluxes were tried to be evaluated.

According to the study results, it was reported that soil CO_2 fluxes increased by 22% due to biochar applications, while N_2O fluxes decreased by 31%. However, biochar applications did not show any effect on CH_4 flux in the soil.



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MAKING FERTILIZATION MORE SUSTAINABLE IN THE CONTEXT OF CLIMATE CHANGE



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The main goal of those who produce herbal 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. The amounts of basic fertilizer used in agricultural production around the world in recent years are shown in tons.

Years	Nitrogen fertilizer (N)	Phosphorus fertilizer (P ₂ O ₅)	Potassium fertilizer (K ₂ O)
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.



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- 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.
- 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.



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- 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 (CH₄)** and **nitrous oxide (N₂O)** gas.
- 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.

The chart below shows the change in greenhouse gas emissions from synthetic fertilizers over the years.

In the last 60 years, the increase in the amount of emissions caused by synthetic fertilizers has approached 10 times.

Changes in Fertilizer - Related Greenhouse Gas Emissions Over the Years

Emission Source	Emission amount (Kiloton CO ₂ equivalent)							Rate of Change (%)
	1961	1970	1980	1990	2000	2010	2020	
Synthetic fertilizers	63209	174069	334374	425288	446178	559822	625107	889



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Environmental Effects of Fertilizer Use

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 will be mentioned here.



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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. 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.

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.

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.

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.

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.



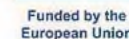
Eutrophication

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, 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 also be seen in rivers and seas.





Increasing Fertilizer Use Efficiency and Preventing Unnecessary Fertilizer Use

Fertilizers, one of the most important inputs of agriculture, have limited effectiveness due to misuse.

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

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.

Some factors that reduce the effectiveness of fertilizer use

Although nitrogen use efficiency varies depending on the applications and environmental factors, it is approximately 25-40% worldwide.

Some factors that reduce the efficiency of fertilizer use and their reduction rates are shown in the Table.

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
Unconscious fertilizer application	20-50



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Applying correct fertilization programs

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.

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 benefit from soil and leaf analysis.





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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.



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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 CO₂ and store it in the soil.





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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.

Increasing soil organic matter content

Fertilizers with increased efficiency are defined as "fertilizer products with properties that increase plant uptake and reduce nutrient loss."

Different methods such as coating, encapsulation, and inhibitor addition are used in these products.

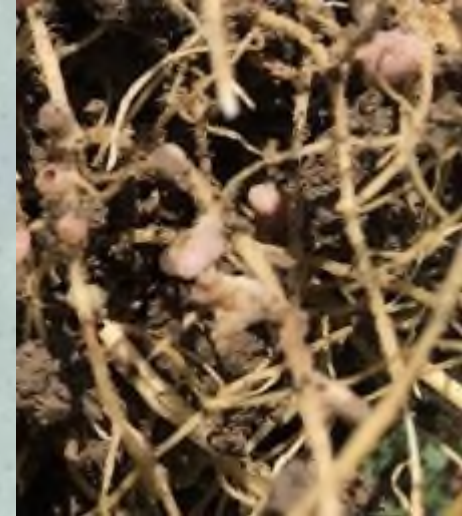
Slow and controlled release fertilizers and inhibitor fertilizers not only have higher nitrogen use efficiency, but also have the potential to reduce N₂O emissions resulting from fertilization.

Including such fertilizers in plant nutrition programs is important to reduce greenhouse gas emissions.



Using microbial fertilizers

When applied to seeds or soil, it fixes atmospheric nitrogen, increases the availability of plant nutrients or promotes vegetative growth by producing secondary metabolites; Material consisting of living microorganisms that can colonize the rhizosphere or enter plant tissues is called biological fertilizer.



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 Rhizobacteria (PGPR).



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Studies conducted to date have shown that species belonging to the *Azotobacter*, *Azospirillum*, *Burkholderia*, *Pseudomonas*, *Bacillus* and *Paenibacillus* genera stand out as PGPR.

Although they are often not sufficient on their own, it may be possible to reduce the use of intensive synthetic fertilizers 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.



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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. Precision agriculture, which emerged as a result of the integration of innovations in technology with 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 which cultivation is carried out.



Source: <https://kayseri.tarimorman.gov.tr/>



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 variable rate fertilizer applications:

- One of these is a **map-based variable rate application** and uses maps obtained from parameters measured in the field.
- The other method is **sensor based variable rate application**. In the sensor-based application, there is no mapping, but measurements are taken on the move via real-time sensors based on soil or plant characteristics.

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



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Deforestation, desertification and erosion are among the most important environmental problems we face today. These have qualities that interact with climate change and trigger each other. Although the dimensions of these problems increase due to the effects of climate change, it is vitally important to prevent deforestation, desertification and erosion in order to prevent climate change.



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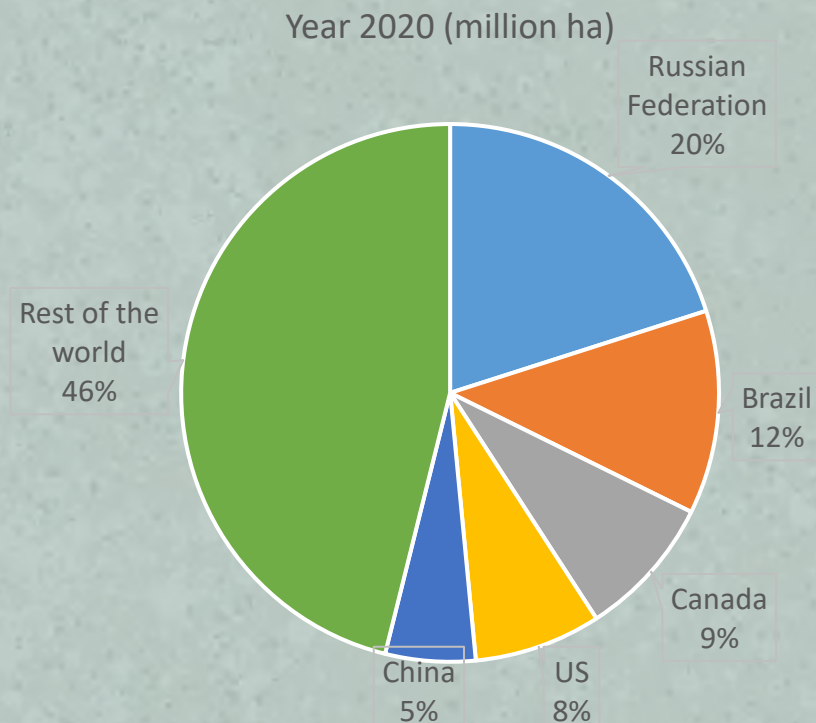


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deforestation

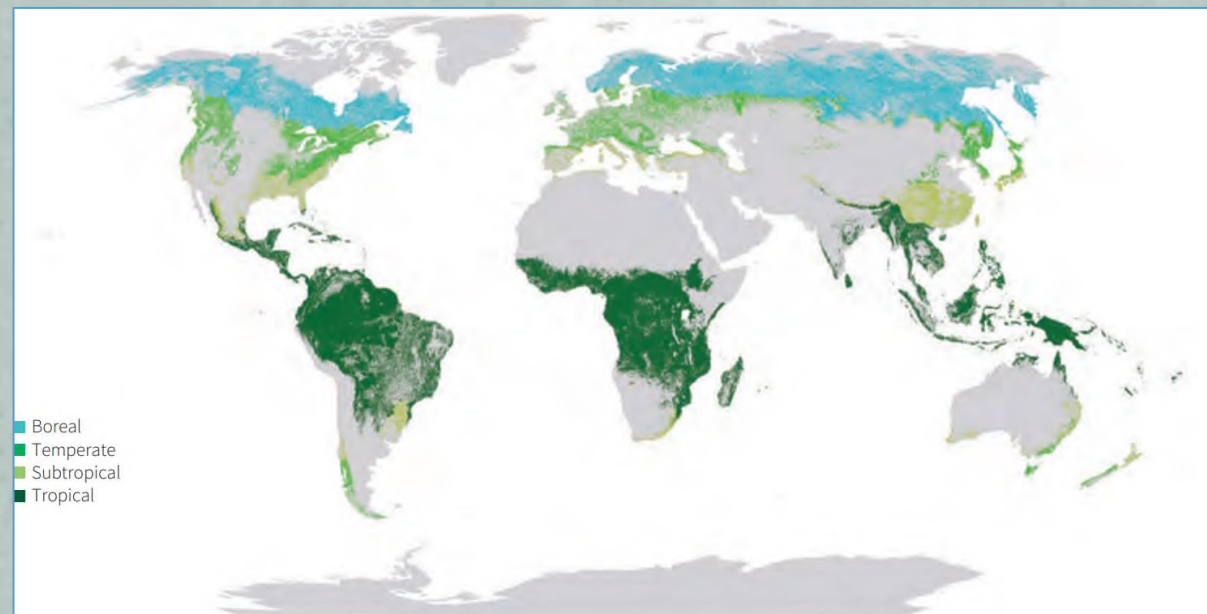
According to the report prepared and published by FAO in 2020, the total of forest areas around the world is 4.06 billion hectares. This corresponds to one third of the total land area. 20% of the world's forests are located in the Russian Federation, followed by Brazil, Canada, the United States and China.



Forest areas by country

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%.



Distribution of forests according to climate zones (adapted from FAO)

This is followed by boreal forests with 27%, forests in temperate regions with 17% and subtropical forests with 11%.



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After humans settled down, there has been a continuous decrease in forest areas around the world. It is estimated that 10 thousand years ago there was 6 billion hectares of forest area worldwide.

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 today.

According to FAO, **deforestation** is considered as the conversion of forest to other land uses (agricultural land, pasture, settlement, etc.).



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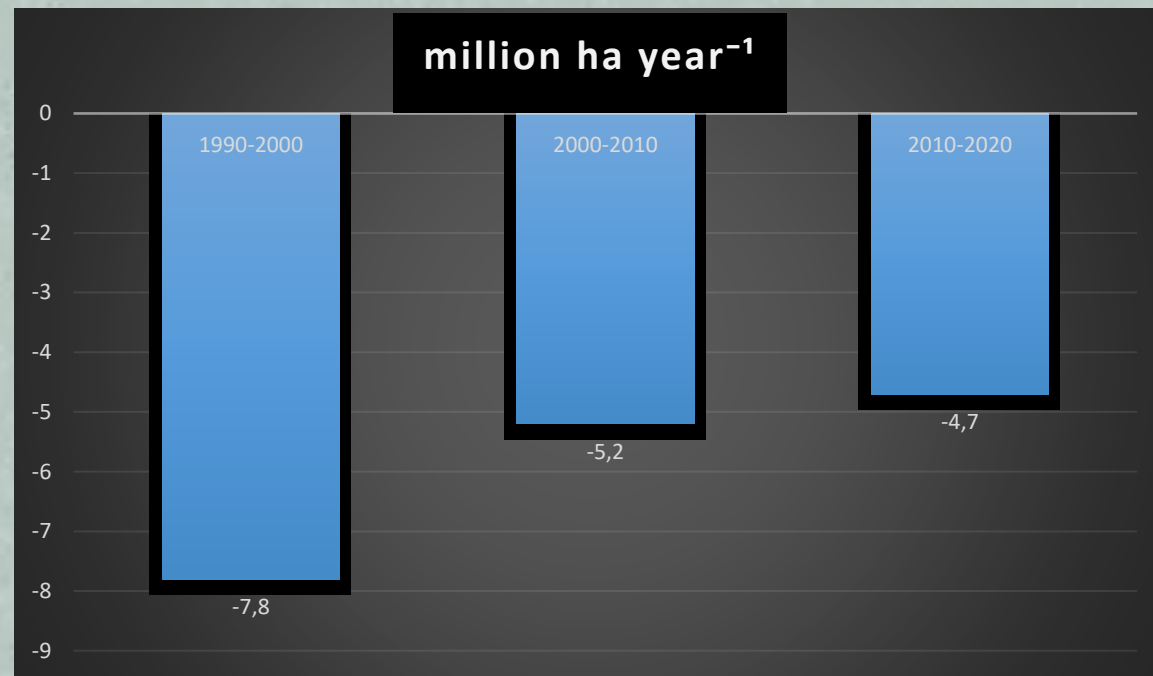


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The net amount of forest lost worldwide in the last thirty years was 178 million hectares.

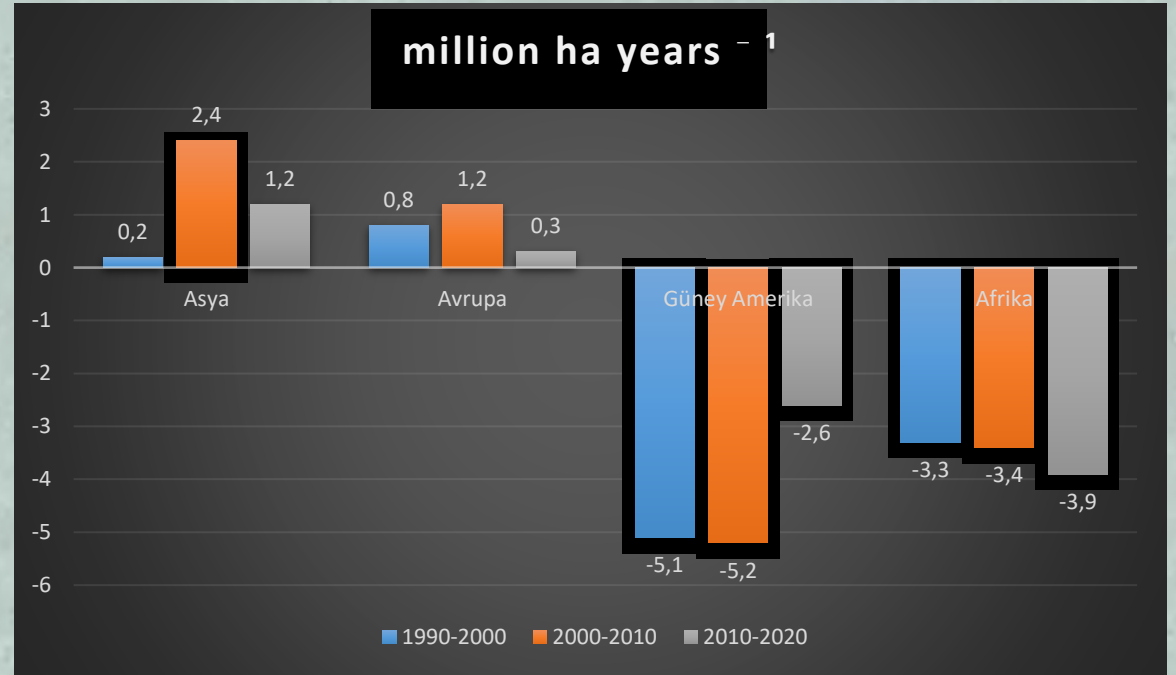
While this loss rate was 7.8 million hectares annually between 1990 and 2000, it decreased to 5.2 million and 4.7 million hectares, respectively, in the other ten-year periods.



Annual average net change in forest areas over the ten-year period between 1990 and 2020

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 Asia and Europe.



Annual average net change in forest areas according to regions and periods



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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.

Forest carbon stocks by continents

COUNTRIES	Forest carbon stock (million tons)			
	1990	2000	2010	2020
Africa	94274	90137	85913	80886
Asia	77093	78564	81938	84733
Europe	158744	162457	168069	172442
America	304949	299048	293489	290964
Oceania	33338	33111	33077	33063
TOTAL	668399	663316	662485	662088

The total forest carbon stock on a global scale is estimated to be 662 million tons.



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It is obvious that climate change, which occurs due to the increase in greenhouse gases in the atmosphere, is one of the biggest threats facing the world.

Forest ecosystems are one of the most important tools for reducing CO₂ in the atmosphere, with their high carbon storage potential in both soil and biomass.



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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 shaving cuts,
- 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.



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Desertification

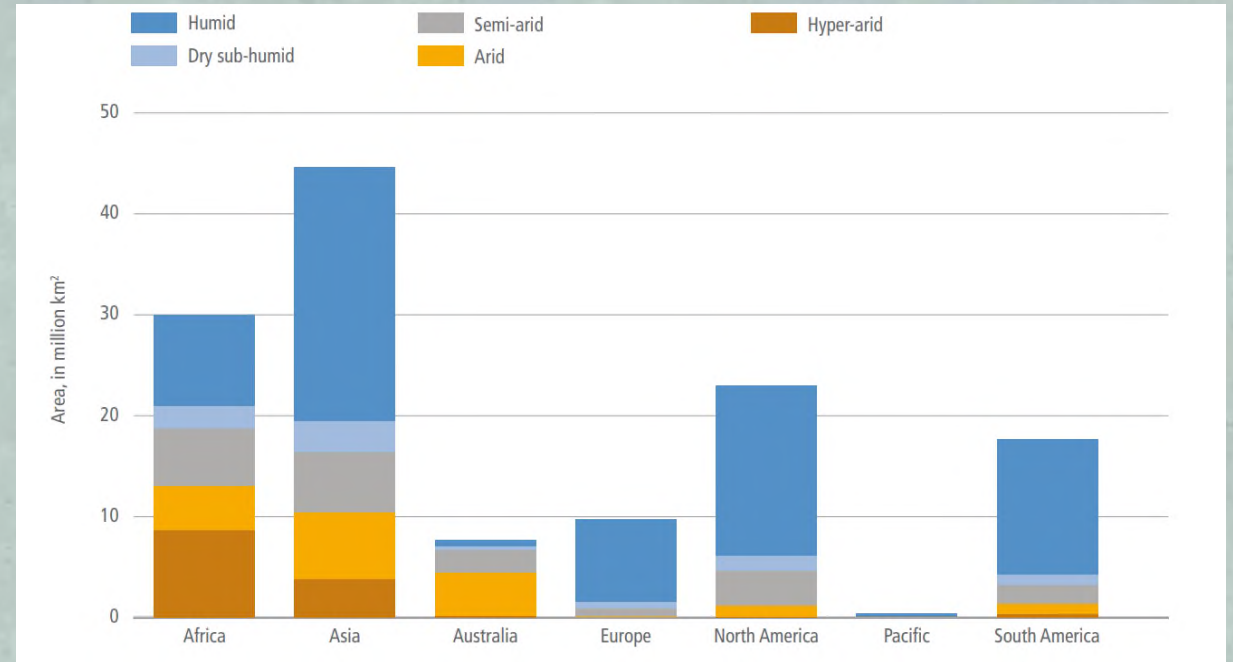
Drought and desertification are among the most important environmental problems we face today, along with climate change.

Desertification is defined as 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 the United Nations Convention to Combat Desertification, arid, semi-arid and dry-semi-humid. It is defined as the **land degradation** it creates in areas.

Accordingly, land degradation that can be seen everywhere is considered desertification if it occurs in **arid, semi-arid and dry-semi-humid** lands.

According to estimates, the proportion of dry areas on a global scale is estimated to be around 46%.

Today, many countries in the world face the danger of desertification.



Dryland categories by geographical regions (1980-2015)

The United Nations Environment Program (UNEP) estimates the global cost of desertification at 42 billion dollars annually. About 70% of the world's dry lands are located in Africa and Asia.



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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.



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The most important environmental and sociological effects of drought and desertification, which have many negative effects, can be listed as follows:

- Loss of biological productivity in ecosystems and decrease in agricultural production;
- The weakening and disappearance of natural vegetation;
- Decrease in biodiversity;
- Creation of suitable conditions for the spread of foreign and invasive plant species;



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- Strengthening of wind erosion;
- Water scarcity, lowering of groundwater levels;
- Poverty and hunger among the people of the affected area;
- Increase in climate or desertification nomads:
- Direct or indirect deterioration in the quality of life in the affected areas.



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Although they vary greatly depending on geography, some important direct and indirect causes of desertification are as follows:

- 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,
- Unconscious use of water resources and mistakes made in irrigation management,



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- 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, floods and floods,
- Problems created by fierce competition and widespread international trade regime due to the spread of globalization and market economy rules, etc.



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Erosion

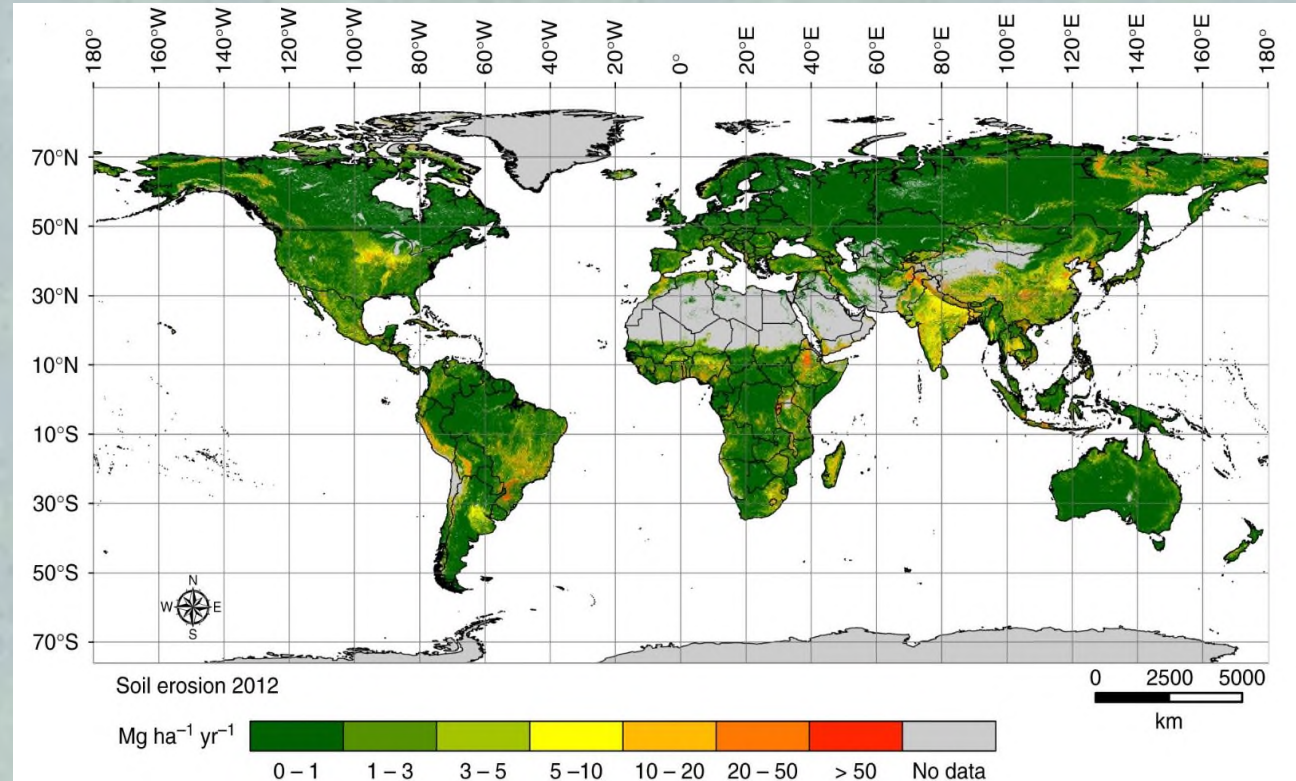
Erosion can be defined as the loss of soil as a result of being carried by different forces such as water, wind and mass movements.

The main factors affecting soil erosion are the amount and intensity of rainfall, wind speed, direction and strength, changes in land use, topography and soil properties.

Various climate models created due to climate change show that generally increasing rainfall intensity and increases in strong wind events may cause an increase in soil erosion, especially with increased drought events.

The degree to which soils are affected by erosion around the world may vary.

Accelerated erosion poses a major threat to soil around the world.



Soil displacement rates due to water erosion, 2012

It is stated that 75 billion tons (Pg) of soil is eroded through erosion every year from arable agricultural areas globally.



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Soil is one of the world's most important natural assets that requires many years to form. The continued existence of life on Earth depends on its existence.

Protecting soil assets and continuing their use in production will be possible by implementing environmentally based approaches in human-soil relations without wasting time.



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Some precautions that can be taken regarding erosion are mentioned 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 stubble planting or use of cover crops.



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Some precautions that can be taken regarding erosion are mentioned below

- ❑ 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.
- ❑ To make drainage arrangements to prevent water accumulation in the soil in problem areas.