SOIL AS A CARBON SINK 101

Food & Trees For Africa

African Climate Reality Project

WHAT IS SOIL?

Soil is considered the most fundamental of all of the earth's resources. Most people simply refer to it as 'dirt', which is unfair when you consider that it forms the basis for all life on earth. What's more, it is a medium that provides food, fuel, and fibre, all of which contribute to food security and the quality of the environment (Blanco-Canqui H., 2010).

HOW IS CARBON STORED IN SOIL?

Soils form over hundreds and thousands of years by weathering processes in nature breaking down rocks. Living organisms such as plants and microbes that commonly live in soil then colonise these weathered rocks. These organisms all contribute to the formation of soil organic matter (Schwartz, 2014).

Soil organic matter is a mixture of organic materials at various stages of decomposition, all of which are rich in carbon (Ontl & Schulte, 2012). The carbon stored in soil organic matter is referred to as soil organic carbon, and forms part of the global carbon cycle, which involves cycling of carbon through the ocean, soil, vegetation, and the atmosphere (see figure 1) (FAO, 2017. b).

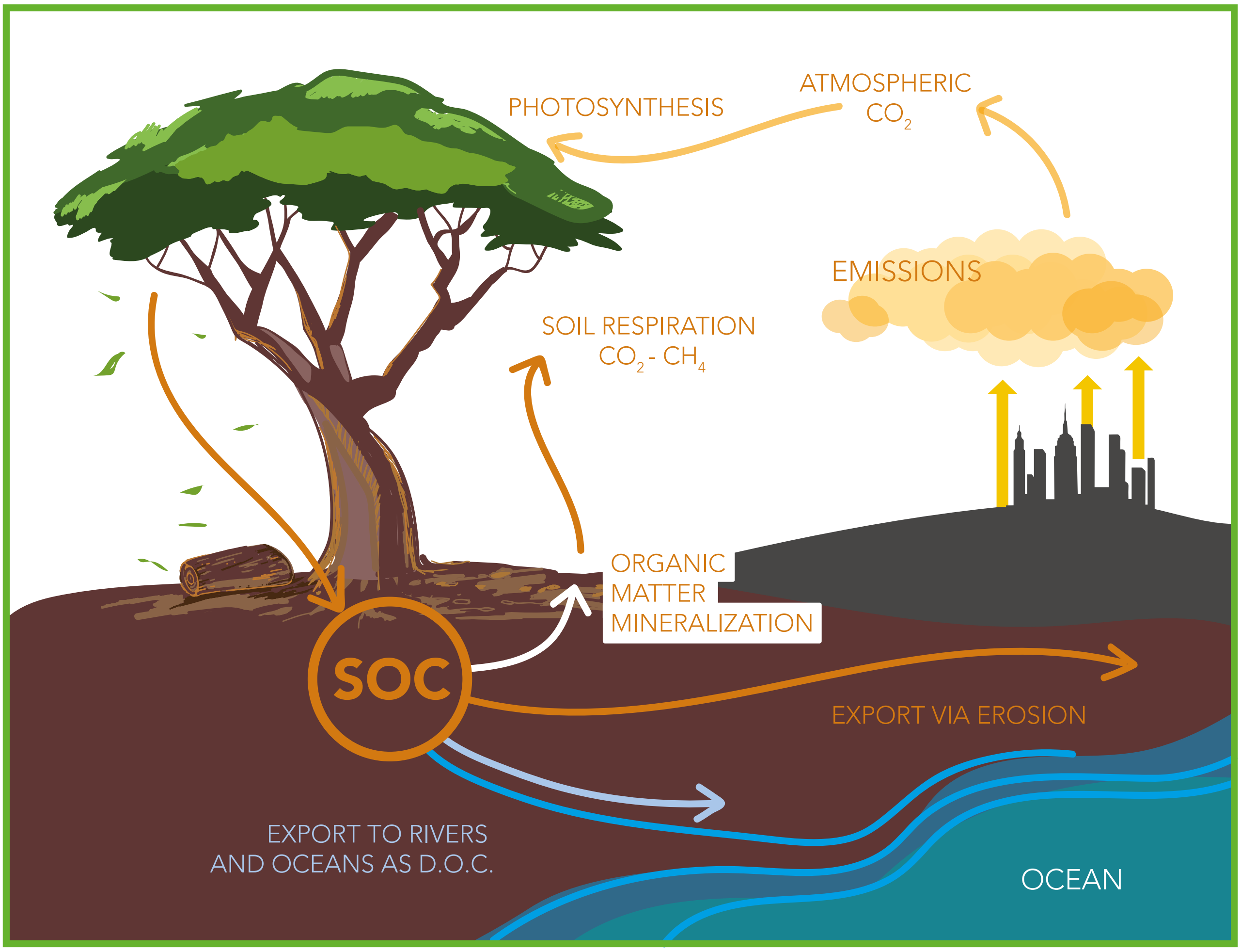


Figure 1: The role of soil organic carbon (SOC) in the global carbon cycle (Adapted from FAO, 2017. b)

WHAT'S THE DIFFERENCE BETWEEN SOIL ORGANIC MATTER AND SOIL ORGANIC CARBON?

- Soil organic matter plays an important role in the physical, chemical, and biological function of soils. It includes all the organic materials in soil regardless of its state of decomposition. This mixture of organic materials is mostly rich in carbon, but also consists of other minerals like nitrogen and potassium.
- Soil organic carbon is the organic carbon that remains in the soil once living organisms decompose. It refers only to the carbon portion within the soil organic matter.

(Ontl & Schulte, 2012; WA Government , 2020)

WHAT IS SOIL ORGANIC MATTER MADE FROM?

Soil organic matter consists of both living and dead organic matter, like field stubble after a harvest and even decayed materials from millions of years ago (FAO, 2017. a). It usually consists of:

- Soil microbes, like bacteria and fungi
- Decaying material from dead organisms, like compost and crop residues
- Faecal matter, like manure
- Products from decomposition, like humus

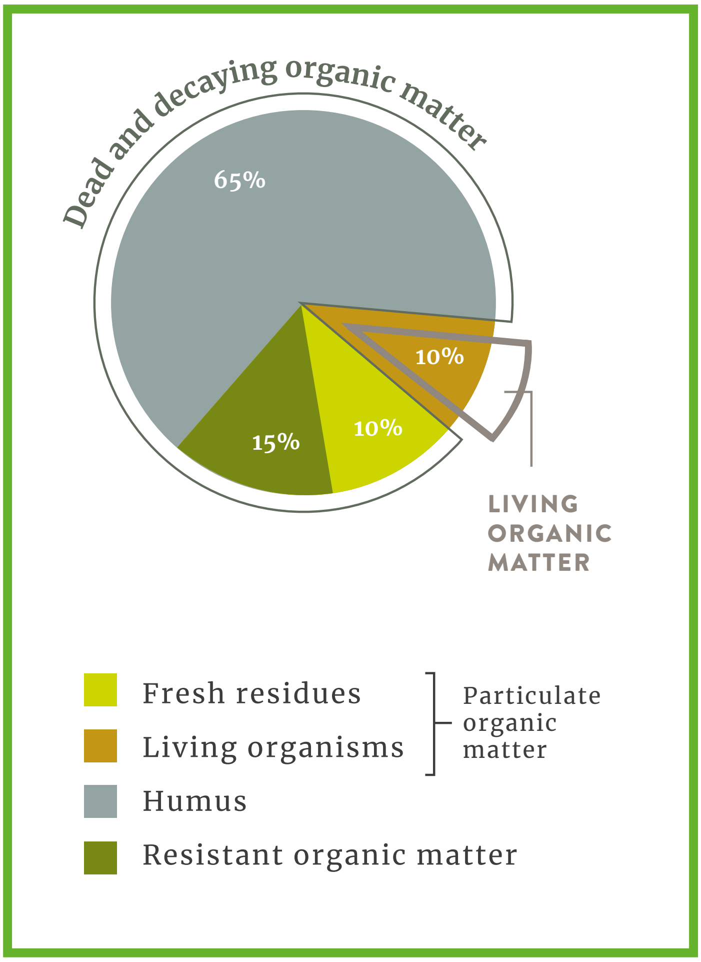


Figure 2: Most Soil organic matter is dead or decaying, with living organisms making up about 10% of the soil organic matter pool (Adapted from WA Government , 2020).

WHAT DETERMINES THE AMOUNT OF CARBON IN SOIL ORGANIC MATTER?

The amount of soil organic carbon in soil organic matter depends on ecosystem processes such as photosynthesis, respiration, and decomposition (see figure 3) (Ontl & Schulte, 2012).

A by-product of photosynthesis

Plant roots grow in response to the process of photosynthesis, where plants absorb CO_2 from the atmosphere. These root systems store an abundance of carbon within the soils.

Mycorrhizae

Carbon is also transferred into the soil from roots to soil microbes. For example, many plants form symbiotic relationships between their roots and specialised fungi in the soil known as mycorrhizae. In this case, the roots supply mycorrhizae with energy in the form of carbon, while the fungi transfers nutrients to the plant.

Decomposition

Finally, decomposition of dead organic matter like plants and animals also incorporates carbon into soils. This process relies on soil microbes to break down the organic matter, which releases CO_2 and CH_4 (methane) into the atmosphere through respiration. A proportion of the original carbon is retained in the soil through the formation of humus.

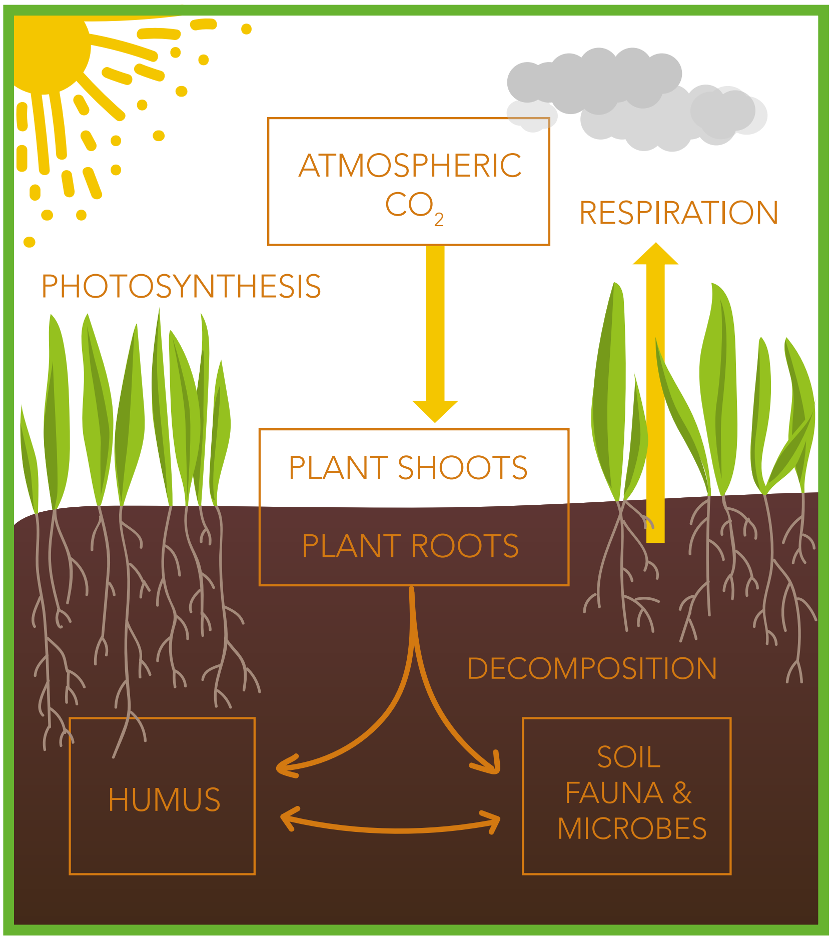


Figure 3: Carbon balance within the soil (brown box) is controlled by carbon inputs from photosynthesis and carbon losses by respiration (Adapted from Ontl & Schulte, 2012).

WHY IS SOIL ORGANIC MATTER IMPORTANT?

Soil organic matter is a key indicator for agricultural productivity as well as environmental resilience. Besides carbon storage, it's important as it:

- Helps stabilise soil structure
- Retains and releases plant nutrients
- Reduces soil erosion
- Improves water quality
- Leads to increased food security

(Ontl & Schulte, 2012; FAO, 2017. b)

SOIL AS A CARBON SINK:

A **carbon sink** is a natural reservoir that absorbs and stores more carbon from the atmosphere than it releases. Plants, the ocean, freshwater bodies, and soil all extract CO_2, which helps lower the concentration of CO_2 in the atmosphere (Global, n.d).

Soil is considered the largest carbon sink on land. The **soil organic carbon pool** stores around **1,500 billion tonnes of carbon** in the **first one metre of soil** and about **2,500 billion tonnes at two metres soil depth**. That's more carbon than is contained in both the atmosphere and vegetation combined (FAO, 2016). The largest stocks of soil organic carbon can be found in wetlands and peatlands, permafrost, and grasslands (FAO, 2017. b; FAO, 2017. c).

Increasing the total organic carbon in soil should be considered a priority as it decreases the amount of carbon in the atmosphere while simultaneously improving soil quality, which is vital for food security (Carson, n.d.).

HOW MUCH CARBON CAN SOIL STORE?

The potential storage of organic carbon

The potential organic carbon storage depends on the properties of the soil type. For example, soils that contain a lot of clay particles protect organic matter from decomposing and retain carbon in their soils for longer. By contrast, microorganisms can easily access organic carbon in sandier soils, which release carbon back into the atmosphere via decomposition, resulting in lower levels of carbon in the soil. (Carson, n.d.)

Figure 4: The basic different types of soil (Adapted from AplusTopper, 2020).

The obtainable storage of organic matter

The amount of carbon that soils can actively access is determined by climate. Rainfall in particular has a large influence on plant productivity (photosynthesis and growth), which in turn influences the amount of organic carbon that is put into the soil. For example, in regions with a high rainfall, the soils tend to have greater access to carbon as opposed to the same soil types in lower rainfall regions.

The actual storage of organic carbon

Land management has a larger influence over the amount of carbon stored in soil. This is because different land management techniques influence how much carbon is put into and removed from soil.

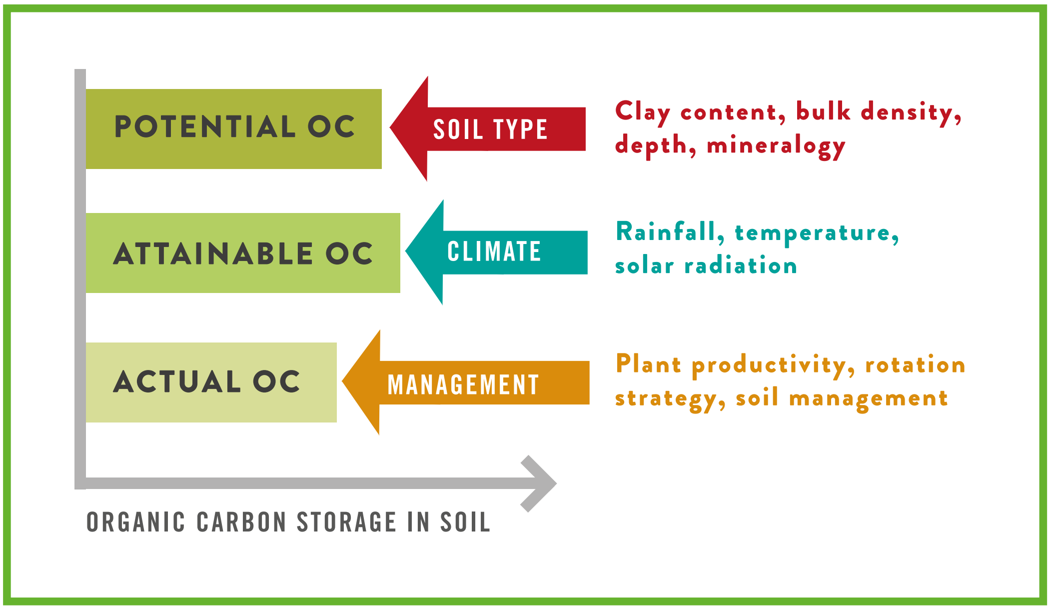


Figure 5: The influence of soil type, climate and management factors on the storage of organic carbon that can be achieved in a given soil (Adapted from Carson, n.d.)

HOW IS CARBON RELEASED FROM SOIL?

The world's cultivated soils have **lost between 50 and 70 percent of their original carbon stock**, much of which has returned to the atmosphere in the form of CO_2 (Schwartz, 2014).

Organic carbon is lost from the soil through (Carson, n.d.):

- **Decomposition by microorganisms** – microorganisms convert organic carbon into CO_2 through respiration
- **Erosion of surface soil** – organic carbon is stored in the surface of the soil layer, which can be easily eroded through both natural and human-induced processes
- **Agricultural practices** – harvesting materials like grain, hay, and animal grazing all contribute towards the removal of organic carbon from soil

FROM A CARBON SINK TO A CARBON SOURCE:

Despite being the planet's second largest carbon sink after the oceans, soil's ability to retain huge amounts of carbon has been weakened in recent decades due to unsustainable land-management practices and land use change (Euorpean Commission, 2011). The Food and Agriculture Organisation (2017c) stated that by 2017, the degradation of the world's soils had released up to **79 billion metric tonnes of carbon** into the atmosphere, while other sources suggest that the world had lost even more than that – **133 billion tonnes of carbon** since the 'dawn of agriculture' (Dunne, 2017).

Today, soils around the world face a suite of challenges. Some examples of how soils face degradation and a loss of Soil Organic Carbon include (Navarro-Pedreño, et al., 2021; Euorpean Commission, 2011):

- Erosion from wind and water
- Conversion of natural ecosystems to arable land
- Deep ploughing of arable soils
- Overgrazing
- Soil leaching
- Compaction from heavy machinery
- Sealing from building and urbanisation
- Acidification from inappropriate fertiliser use
- Contamination from industrial or agricultural operations

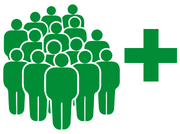
THE IMPACT OF LAND DEGRADATION ON CARBON SEQUESTRATION

Land degradation can be defined as the deterioration of land's condition in response to direct or indirect human-induced processes (including climate change). The impact of land degradation often leads to the long-term reduction of organic productivity, ecological integrity, or the value of the land to humans (Navarro-Pedreño, et al., 2021). Any process of land degradation will inevitably reduce soil organic carbon stocks and contribute towards the greenhouse effect (Ai, et al., 2018).

DESERTIFICATION:

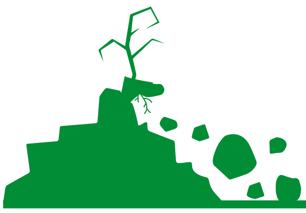
Desertification is the gradual process of land turning into desert as the quality of soil declines over time. Due to the intensity of human disturbance, land desertification is one of the main driving factors causing the accelerated release of soil organic carbon into the atmosphere. In particular, the soils of fragile ecosystems in arid (dry) and semi-arid areas are vulnerable to non-sustainable land use practices, and release large amounts of carbon into the atmosphere when disturbed (Ai, et al., 2018).

Some of the main causes of desertification include:

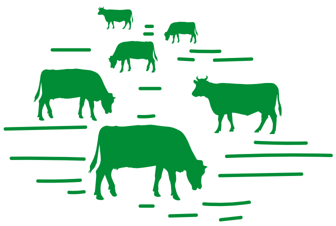


Population growth: Larger populations put pressure on the environment for resources like wood, water, and food.

Removal of wood: When land is cleared for resources like wood, plant roots are no longer able to hold the soil together, making it vulnerable to soil erosion.



Soil erosion: Soil erosion can be defined as the removal of the top layers of soil when exposed to water and wind, as well as human practices like tillage. This results in the deterioration of the soil quality through the loss of soil organic matter (BBC, n.d.).



Overgrazing: When livestock trample grasslands excessively, they can completely destroy the soil's surface layer, which impacts the soil's ability to regulate nutrient cycling, stabilise soil, and filter water. High levels of grazing also reduce grass and plant cover, which exposes soil and makes it vulnerable to soil erosion.

SOIL EROSION:

When soil erosion occurs naturally, such as wind erosion and rain erosion, the process can promote the renewal of nutrients in the soil. However, when these forms of erosion are accelerated by human disturbance, they can become destructive and destroy soil structure, reduce soil fertility, and impact the soil carbon cycle. In 2018, it was recorded that **1 billion hectares of land area** in the world had been subjected to **water erosion**, and around **550 million hectares** were affected by **wind erosion** (Ai, et al., 2018).

Types of soil erosion by natural and human-induced processes

TYPES OF NATURAL SOIL EROSION	HUMAN-INDUCED SOIL EROSION
Sheet erosion by water	Deforestation for agriculture like coffee, soybean, palm oil and wheat.
Wind erosion	Poor management of livestock, which can lead to overgrazing.
Rill erosion, which occurs when heavy rain removes soil and creates small channels on hillsides.	Excessive use of certain phosphoric (rich in phosphorous) chemicals, particularly in monocultures (one type of crop), which causes an imbalance of soil microorganisms.
Gully erosion when water runoff removes soil along drainage lines.	Construction of buildings and roads prevents the normal circulation of water, as the hard surfaces do not allow water to penetrate into the ground effectively. This leads to runoff as the water moves across the hard surface instead of into it. This can result in erosion and flooding of land nearby.
Temporary erosion that occurs in natural depressions.	Tillage, which is a common farming practice that helps loosen topsoil, exposes carbon buried in the soil to oxygen in the air, and increases the rate at which microbes convert soil organic carbon to CO_2 via respiration (Mooney, et al., 2021). The lowered organic carbon levels make the soil susceptible to soil erosion.

(Youmatter, 2020)

NUTRIENT LOSS AND SOIL DEGRADATION:

Soil health and soil carbon content are thought to positively relate with one another. What this means is that the process of applying nutrients to the soil will increase the soil organic carbon, while depleting nutrients in the soil will cause a reduction of soil organic carbon (Ai, et al., 2018).

Different types of soil and land degradation all cause an increase in the rate at which carbon is released from soil in the form of CO_2. As a result, the function of soil carbon sources increase while the function of carbon sink processes weaken (Ai, et al., 2018).

WHAT ABOUT THE IMPACT OF CLIMATE CHANGE?

Climate change is severely impacting soil systems, although it is difficult to determine and monitor the extent of these effects due to the complexity of soil systems (Navarro-Pedreño, et al., 2021). However, some studies focus on certain scenarios, which highlight a number of the main impacts of climate change on soil organic matter (Euorpean Commission, 2011).

1. Higher temperatures promote accelerated breakdown of organic matter due to increased microbial activity in the soil. While this process stimulates plant growth, it also releases large amounts of CO_2 and CH_4 into the atmosphere (Navarro-Pedreño, et al., 2021; European Commission, 2011).
2. Changes in rainfall patterns can result in either flooding, heavier snowfall, or prolonged droughts, depending on the area. Combined with fluctuations in temperature, these shifts in rainfall will affect soil structure and acidity, which impacts the soil's ability to store water and sustain soil organisms. These factors all contribute towards the release of extra carbon into the atmosphere (Navarro-Pedreño, et al., 2021; Euorpean Commission, 2011).

THE PROBLEM WITH PERMAFROST

The rising global average temperatures due to climate change have the ability to reduce soil organic carbon by accelerating microbial decomposition. This phenomenon is particularly prevalent in thawing permafrost soils, which is estimated to store around **1,400 gigatonnes of carbon** (National Snow and Ice Data Centre, n.d.).

Permafrost occurs when ground—from soil to sediment to rock—that contains water freezes for a minimum of two years and as many as hundreds of thousands of years (Denchak, 2018). If permafrost continues to heat up, the organic matter stored in the frozen soil will continue to thaw and decay, releasing CO_2 and methane into the atmosphere. This will set off a feedback loop that is potentially irreversible within our lifetime. It is estimated that warming **permafrost stored in the earth could emit as much as 240 gigatonnes of CO_2** and methane by the year 2100, ultimately accelerating climate change (IPCC, 2019).

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