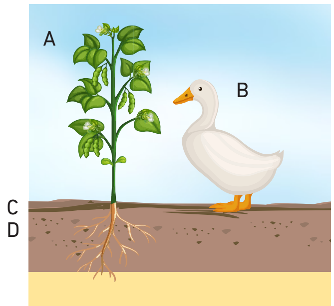
Soil functioning and the carbon cycle: carbon inputs, outputs and stocks

Soil functioning in any ecosystem depends directly on its characteristic carbon cycle. The cycle has dynamic stocks between the different components of the system: **plants, other organisms that intervene in the cycle, organic materials and organic matter in the soil**. This carbon cycle **is modified** by a series of factors: **the mineralisation/humification balance, the export and import of organic materials, and disturbances**. The applied agricultural, livestock or forestry management model can intervene on the carbon cycle by modifying these factors in one direction or another.

System components and their relationship with carbon stocks

Soil is the main element of terrestrial biological systems. **The soil requires carbon (organic materials) to maintain all the biological processes that characterise it**. Thus, managing a terrestrial biological system can be understood as managing the carbon cycle**, which starts from the CO_2 fixed by the photosynthesis of plants until it reaches the ground**. Each terrestrial biological system presents a characteristic **carbon cycle**, in which dynamic stocks of carbon are established that are temporarily retained in the **different components of the system** (**Figure 1**). The quantity and stability of these carbon stocks determines the functioning of the system and its capacity **to sequester carbon from the atmosphere**.



A. Plants
B. Other organisms
C. Organic materials
D. Soil organic matter

Figure 1. Diagram of the different components of the system and their relationship in the carbon cycle.

a) Plants. The carbohydrates that the plant produces and that are not used in respiration are the basis of the carbon cycle. Part of these carbohydrates is released directly by the roots in the form of exudates to feed the soil food web. Another part becomes part of different structures of the plant (reserve, support, reproductive) and finally, they also end up joining the carbon cycle of the system. In some cases these structures represent small and not very stable carbon stocks (such as the aerial part of annual grasses), but in other cases these structures can represent very important carbon stocks with great stability, as is the case of the wood of the forests.

b) Organisms involved in the cycle. Before reaching the soil, the organic matter produced by the plant can pass through different organisms (herbivores, carnivores, decomposers). Every time a new organism intervenes in the cycle, part of the carbon is used to obtain energy for respiration and released into the atmosphere in the form of CO_2. Another part of the carbon is eliminated in the form of excrement and the rest becomes part of the different structural elements of the body of organisms until they die.

c) Organic materials. These materials are provided mainly by the roots and remains of the aerial part of the plants, as well as by the excrement and dead bodies of the different organisms that intervene in the cycle. They are not very stable materials, they are rapidly degraded by microorganisms, thereby losing about 90% of their composition. The fact that they degrade rapidly means that these organic materials represent an insignificant stock within the system.

d) Soil organic matter (SOM). This corresponds to humified organic materials. SOM presents greater stability than the organic matter it comes from and represents a very important stock within the system. In fact, it is the main terrestrial reservoir of organic carbon. Thus, at least 10 kg of organic materials are needed to form 1 kg of SOM, which in turn fixes 3.7 kg of CO_2. 1% of SOM in the soil represents 27 t SOM/ha, which is more than 90 t/ha of CO_2 sequestered.

Factors that modify the system's carbon stocks

There are a series of factors that modify the carbon cycle, and especially the dynamics of carbon in the soil, and that, therefore, affect the system's function and carbon storage capacity.

- **Mineralisation/humification balance of organic materials in the soil.** The soil is the component with the highest carbon retention capacity in the system. Therefore, all the factors that favour greater mineralisation and loss of soil organic matter reduce the total carbon stock of the system. These include the factors that regulate the balance between mineralisation and humification of plant matter and, in general, the different interventions that reduce soil organic matter.

- **Export of organic materials outside the system** (**Figure 2**). If part of the carbohydrates produced by the plant are removed from the system (for example, by agricultural,

Figure 2. Wood extraction is a way of exporting organic matter out of the system. Photo: MJ Broncano.

livestock or forestry use), this produces an overall loss of the carbon stock. When this export is small, the system can recover naturally. But if the export is significant, an overall loss of carbon from the system occurs, especially in the soil, which affects the stock and the biological activity of the soil and causes a gradual impoverishment of the system.

Figure 3. Tractor spreading manure. Photo: José Cárceles, CC-BYNC. (Source: Flickr).

• **Import of organic materials external to the system.** The current agricultural system depends on the external carbon input linked to the use of oil (**fuel and agrochemicals**), without which the system would not function (**Figure 3**). There are also important external inputs based on **slurry**. In both cases, these are costly external inputs and they do not represent any improvement in the productive capacity of the system itself (it does not feed the soil food web or create soil habitat) or the carbon stock. In other cases, external organic materials are imported with the aim of **incorporating organic matter to improve the habitat and feed** the soil food web, increasing the soil's carbon stock. This is the situation that occurs, for example, when there is a transition from conventional to regenerative agriculture.

• **Disturbances.** Disturbances typically represent an abrupt loss of carbon from the system. The clearest case is fires (**Figure 4**). Gross carbon emissions from **fires are huge**, equal to 25% of global annual emissions from fossil fuels. The **impacts of other disturbances** such as extreme droughts or floods on the carbon stocks of the system are less, since the direct release of CO_2 is less or lasts longer over time.

The regenerative model: carbon stocks and climate change

All plants sequester carbon in photosynthesis, whether this sequestered carbon influences reducing atmospheric CO_2 will depend on the cycle that this carbon follows and on whether it becomes part of stable stocks. **The most important potential carbon stock in regenerative systems is soil**. The conventional system destroys the soil structure and favours the mineralisation of soil organic matter, releases the carbon that was retained in the soil into the atmosphere (i.e. it increases the effect of climate change) and eliminates the role of carbon reservoir that the soil has in natural conditions. In addition, this model consumes a large amount of oil linked to the use of machinery and agrochemicals. **The regenerative system preserves the structure of the soil and feeds the soil food web reduces carbon from the atmosphere and introduces it into the soil**, turning the soil back into a large carbon reservoir. In fact, according to the Rodale Institute, if we managed all the world's croplands and pastures according to the regenerative organic model, we could sequester more than 100% of current annual CO_2 emissions.

Figure 4. State of the forest after the 1994 fire in Bages and Berguedà (Barcelona).

Carbon cycle and management model

The agro-silvo-pastoral management model intervenes on a natural system modifying the carbon cycle in its different phases: producing **carbon extraction** (outcomes), modifying the **conditions of return to the soil and the capacity to store carbon** in the soil, and making a contribution of external carbon to the system (oil and agrochemicals). In general, the **conventional model** creates long cycles, with carbon outputs and inputs that are not connected, and **eliminates the most important stocks: soil and large trees. A regenerative management model** must ensure that the outcomes do not significantly affect the biological processes of the soil and, therefore, its productive potential, while minimising external contributions and maintaining the main carbon stocks.