# Carbon Sequestration under Different Grazing Systems

Keith Reid

## INTRODUCTION

Grazing has been a key feed source since the beginning of livestock agriculture, but today there are new opportunities for profiting from pasture with the potential for sequestering carbon from the air beneath our grazing lands. Pasture soils play a huge role in storing carbon, with estimates that up to three-quarters of the carbon stored in terrestrial ecosystems is in grasslands (Del Prado et al., 2014).

Carbon stored in the soil as organic matter is highly beneficial for soil functioning. Soils high in organic matter have:

- Greater capacity to hold nutrients in plant-available forms
- Higher moisture-holding capacity
- More stable soil structure, which resists crusting and erosion
- Higher, more stable growth of whatever plants are growing in this soil, particularly in stress years

Managing grazing systems to build soil carbon benefits the whole farming system. In this factsheet, we will summarize the current state of knowledge about how grazing management can impact carbon accumulation and how farmers can harness this to build carbon on their farms

### The Carbon Cycle in Pastures

Figure 1 shows the major steps in carbon cycling in pasture systems. Photosynthesis is the driver of the entire cycle, where the sun's energy is used to combine the carbon from $CO_2$ with hydrogen from $H_2O$ to form sugars which are the basis of all other organic compounds.

Most of this "stored sunshine" is respired back into the atmosphere, first by the plants themselves to support their growth, and then by the animals that graze on the plants. Further respirations occur as part of soil bacteria and fungi growth as they use root exudates and dead plant materials for feedstock. On a daily basis, photosynthesis

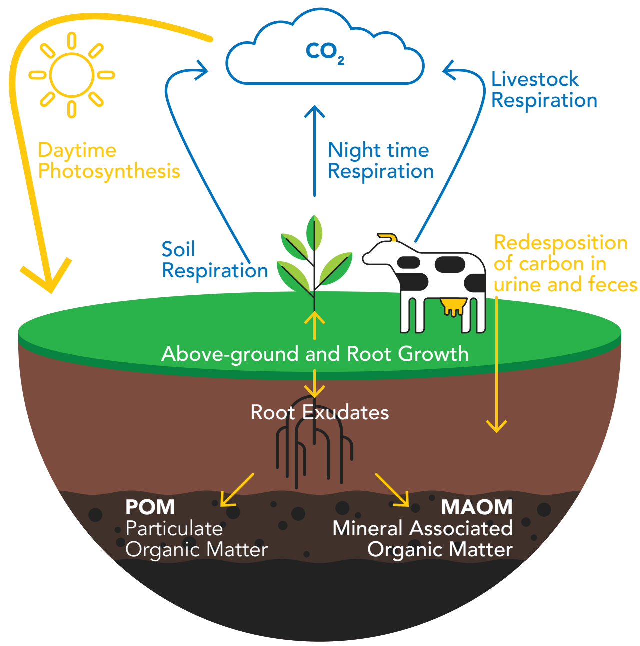


**Figure 1. The carbon cycle in pasture systems.**

only happens during the day when there is adequate light, while respiration goes on twenty-four hours a day, so part of the carbon is constantly cycling back to the atmosphere as $CO_2$. This respiration provides energy to keep plants alive and supports the conversion of simple sugars from photosynthesis into more complex compounds like starch, cellulose, lignin, or proteins. These compounds are incorporated into new growth, both above and below ground. Some of these compounds are also released into the soil around the roots, where they support an active and diverse microbial community. These processes occur in all plants, but in agriculture, we seek to harvest part of this plant material as products useful to humans, either directly or as feed for livestock. In grazing systems, livestock returns between 24-40% of the carbon they consume back to the soil in feces and urine (Whitehead, 2020). Only a small fraction of the total carbon fixed in photosynthesis ends up as stable organic matter in the soil.

The primary goal of a grazing system is to grow forage that can be harvested by livestock to produce milk, meat and fibre, but increasing the sequestration of carbon in the soil is a side benefit. Fortunately, these goals are not mutually exclusive, and improved forage productivity will translate to increased availability of carbon for storage in the soil by increasing photosynthesis and moving more carbon into the soil for root growth and root exudates. As a bonus, perennial pastures almost eliminate soil erosion, which automatically helps to keep any sequestered carbon in place.

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Carbon cycling in grazing systems is tightly linked with the growth of the forages in the pasture, so it is helpful to think about the growth cycle in your pasture. In early spring, as the plants are coming out of winter dormancy, there is little or no leaf tissue to support photosynthesis, so reserves are pulled from the roots, and $CO_2$ is released during respiration to support new leaf growth. As leaf tissue develops, photosynthesis increases so that the plants rapidly switch from a net source of $CO_2$ to a net sink.

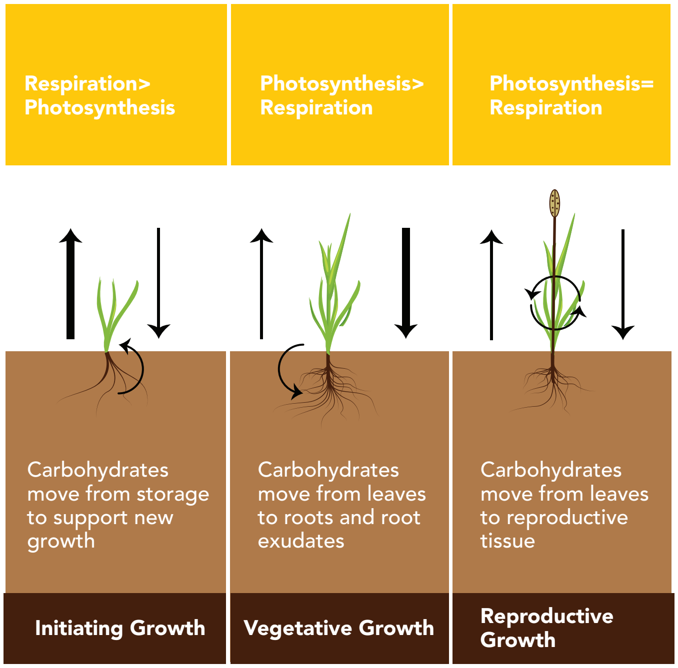


**Figure 2. Carbon dynamics of pasture maturity.**

As the season progresses, the plants grow rapidly through the vegetative phase and then slow significantly as they enter the reproductive phase, and the amount of carbon assimilation follows a similar pattern. The transfer of carbon to the roots, in particular, slows as the plants enter the reproductive phase, reducing both the growth of new root tissue and the exudation of carbohydrates into the rhizosphere (root zone). This slowed growth, combined with limitations of water shortage and high temperatures, contributes to the "summer slump" in many pastures where growth declines significantly, followed by a rebound as the weather cools in the fall.

It might seem logical that ungrazed pastures would sequester the most carbon, but this is not the case because the plants simply take up space without contributing much photosynthesis after they have "gone to seed". In managed grazing systems, the plants are kept in the vegetative growth phase as much as possible, so they are actively growing as long as there is adequate heat and moisture.

Below ground, the carbon that gets fixed in the leaves becomes part of the stable pool of organic matter in the soil through two main pathways. The first is particulate organic matter (POM), made up of small pieces of dead vegetation (roots or tops), manure (either feces deposited directly in the field or spread from storage), or the remains from soil organisms that have died (bacteria, fungi, insects, earthworms, etc.). These particles are a mix of indigestible compounds and materials that would still be a good food source for soil organisms. The key to the stability of POM is being incorporated into soil aggregates, where they are physically protected from being eaten. The persistence of POM has been measured in the range of years to decades (Derrien et al., 2023).

The second pathway is the formation of compounds that are chemically protected from degradation. There is much debate among soil scientists about the exact processes that are happening in the soil, and it is most likely that there are several processes that will vary depending on the climate, soil drainage and mineralogy. It appears that the soluble carbon compounds released from the roots follow this pathway and either bind directly with minerals in the soil or are consumed first by soil microbes, which then excrete compounds that are either too low in food value for other organisms or bind to soil minerals in a way that prevents their consumption. This Mineral Associated Organic Matter (MAOM) is very persistent in the soil, ranging from decades to centuries, but the ability of the soil to absorb MAOM can be saturated. There is currently research looking at whether deep-rooted crops can sequester more carbon by pumping root exudates into the subsoil where the capacity of the soil to absorb MAOM has not been saturated (Derrien et al., 2023).

How pastures are managed for grazing will have a huge impact on how much carbon is added to the soil bank and how much is converted into stable organic matter. The next section will go into more detail about how management can increase both harvestable forage and carbon sequestration.

## Managing Pastures to Sequester More Carbon

There is a lot of variation in the impacts of different grazing systems on carbon sequestration reported in the scientific literature, but one trend is very clear: there is more carbon stored under perennial forage systems than under annual field crops. When pastures are grown in rotation with field crops, this C accumulation increased the longer that the fields were in pasture (Lin et al., 2020).

Improving pasture management may be eligible for funding to cover costs for seed, planting and professional advice by a Certified Crop Adviser, agronomist or agrologist under the On-Farm Climate Action Fund. For more information, please visit: **https://ofcaf.perennia.ca/**

This does not mean that all grazing systems are created equal. Poor pasture management, and in particular over-grazing, will turn the pasture into a source for atmospheric carbon, rather than a sink. When too much of the top growth has been removed, there is not enough leaf tissue to photosynthesize efficiently, so the plants are in an energy deficit. Carbon is pulled from the roots to grow more leaves, shrinking the root system, leaving the pasture vulnerable to any moisture deficits and cutting off the root exudates that build organic matter. Some plants in a stressed pasture will die out, leaving bare patches that are susceptible to erosion.

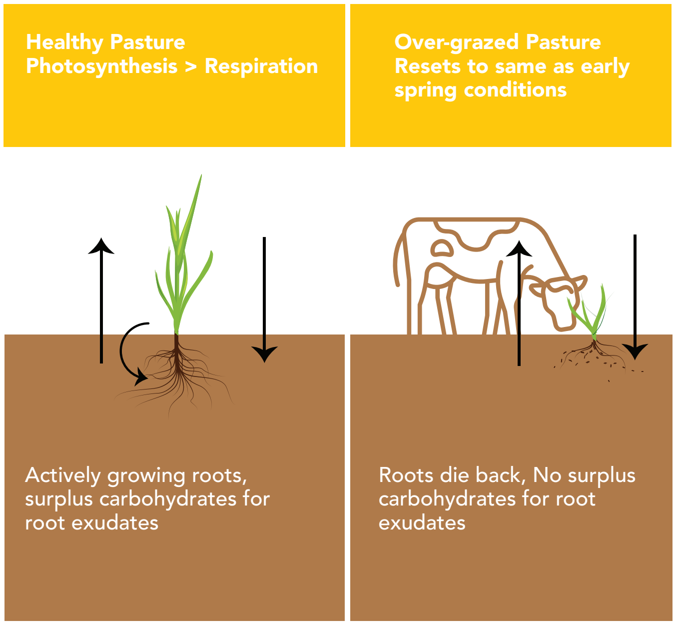


**Figure 3. How over-grazing affects plant pasture dynamics.**

**What about the other GHGs?**

Carbon dioxide receives a lot of attention as a greenhouse gas, so sequestering carbon in the soil is one way to reduce the risk of climate change. From agriculture, however, methane ($CH_4$) and nitrous oxide ($N_2O$) also contribute to our GHG footprint.

Ruminant livestock produce $CH_4$ in their rumens as a byproduct of digestion. This cannot be avoided completely, but the amount of $CH_4$ released is much higher from livestock consuming poor quality feed, so maintaining high quality forage on pastures helps to limit this. Additionally, manure deposited on pastures releases less GHGs than stored manure.

Excessive N fertilizer on pastures can result in $N_2O$ emissions. Using legumes to supplement the N requirements of your pastures will result in much lower $N_2O$ emissions than using fertilizer.

The lack of feed from these pastures, particularly at the end of the growing season, will mean reduced animal performance, including the possibility of mortality if they begin grazing on poisonous plants that they would normally avoid. The carbon content of these soils is often equal to or below that under an annual crop. However, these over-grazed and degraded fields will show more benefit from improved management than pastures that are already well managed (Klumpp and Fornara, 2018).

The differences are less clear when comparing continuously grazed to rotationally grazed pastures, with effects ranging from slight decreases with rotational grazing compared to continuous (Sarkar et al., 2020), to no change (Gourlez De La Motte et al., 2018), to significant increases in soil carbon with rotational grazing (Conant et al., 2017; Whitehead, 2020). These discrepancies may seem confusing, but the common element in the studies showing equal or better soil carbon sequestration in continuously grazed plots were all very closely managed grazing systems, with the grass growth closely monitored so that grazing pressure never exceeded the forage production and supplement feed was provided if required. This is far from a "laissez-faire" approach to grazing where livestock are turned out on pasture in spring and left there until fall. These studies were also in areas where pasture production appeared to be consistent throughout the season without a significant "summer slump." None of these studies included situations where the paddocks had been over-grazed, which would have changed the results since over-grazing has been shown to have a significant negative impact on soil carbon (Zhou et al., 2020). A challenge in comparing two well-managed grazing systems is that the differences between systems will be small and, therefore, harder to measure. On the whole, however, it appears that adopting management-intensive rotational grazing will be beneficial for storing more carbon in the soil, which has been demonstrated in a long-term study in Nova Scotia (Bouman et al., 2018).

One factor in rotational grazing systems that does appear to influence carbon sequestration is the length of the rest period between grazing, with more soil C accumulation with longer rest periods (Jordon et al., 2022). Each grazing cycle should also be managed so that at least 50% of the forage remains when the livestock are removed. This will ensure adequate leaf tissue to support rapid regrowth, which will, in turn, supply enough photosynthesis to move carbohydrates down into the roots.

Nitrogen fertilization is seldom mentioned as a variable in the analyses of pasture management impacts, particularly when they are conducted on a global scale. Nitrogen is one of the major limitations to grass growth, and failure to provide adequate nitrogen will limit both feed supply to livestock and carbon sequestration. However, adding nitrogen fertilizer, particularly at excessive levels, will increase the release of nitrous oxide ($N_2O$), an even more

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potent greenhouse gas than $CO_2$ (see sidebar). Including perennial legumes in the forage mix, like birdsfoot trefoil or white clover, can meet the nitrogen requirements of the pasture without increasing greenhouse gas emissions (Barneze et al., 2020).

Adding more species to the pasture mix might increase both pasture productivity and carbon sequestration. A study in Pennsylvania found that a five-species mix accumulated more carbon in the soil over five years than a single species (Skinner and Dell, 2016). It is unclear how much of the effect was from adding more productive species to the mix or including legumes, which improved the nitrogen status of the sward, rather than simply a response to increased species diversity. There is certainly evidence that plants that use the C4 photosynthetic pathway (i.e., warm season grasses) are more effective at building soil carbon stores than C3 plants (cool season grasses, legumes) and maintain growth during summer even though they may not start growing as quickly in spring. Deeper-rooted plants can move carbon from root exudates into the subsoil, where there is more capacity for soil minerals to bind with those compounds and stabilize them. In long-term pastures on variable soils, a diverse mix of species can allow the best-adapted plants to dominate in different conditions, so the overall productivity of the pasture is increased, including the amount of carbon translocated into the soil. It has been suggested that including non-legume broadleaf plants (forbs) in pasture mixes will increase carbon sequestration through enhanced microbial activity, but there is limited evidence to support or refute this (Jordon et al., 2022). There is a need for further research into the impacts of species diversity, or of including plants with specific functions in the mix, on both forage yield and quality and carbon sequestration.

## Summary

Well-managed pastures can be a highly profitable part of a livestock operation, and the management to support strong forage growth will also increase the storage of carbon in the soil. This could be achieved in a continuously grazed system, but the level of management to match forage supply with grazing pressure, where rates of forage growth vary through the season, is very high. For most farms, matching forage growth to feed requirements is more easily accomplished in a rotational grazing system.

The keys to managing rotational grazing for carbon sequestration are:

1. Maintain adequate soil fertility and pH
2. Plant a mix of grasses and legumes that are adapted to your soil and climate
3. Keep the sward vegetative. This can be done by managing the grazing so that forage is harvested evenly down to approximately half of the total volume at each graze, and leaving a long recovery period between each graze.

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