

Impact of Swine Manure on Soil Organic Carbon

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WHY SOIL ORGANIC CARBON MATTERS

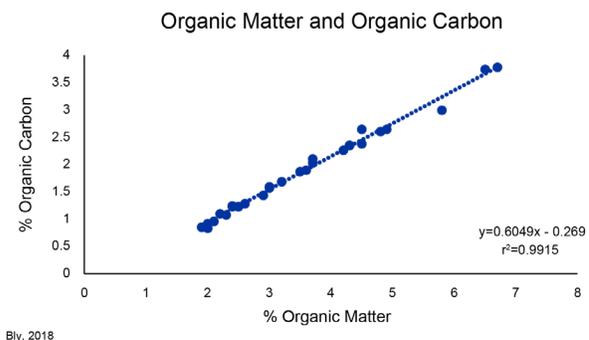
Healthy soil is the foundation of productive farming. Soil organic carbon (SOC) is one of the most important indicators of soil health. Soils with higher organic carbon tend to have better structure, infiltrate and hold more water, resist erosion, and support stronger biological activity. These benefits translate directly into improved nutrient availability, better crop resilience during dry periods, and long-term productivity.

SOC also fuels soil microbes. These microbes drive nutrient cycling, help release nitrogen and phosphorus for crops, and stabilize soil aggregates. In practical terms, higher SOC means soils that work better for the producer, especially under the variable weather conditions common in South Dakota and the Northern Great Plains.

HOW CAN PRODUCERS BUILD SOIL ORGANIC CARBON

Swine manure is more than a nutrient source. It also supplies organic matter, including a readily available organic carbon fraction, that feeds soil biology and supports carbon storage. Unlike commercial fertilizers, which mainly deliver nutrients, manure influences both the biological and physical properties of soil. Graph 1 illustrates the strong linear relationship between soil organic matter and organic carbon, showing that increases in organic matter are closely matched by

increases in organic carbon ($R^2 = 0.99$). The trendline indicates that organic carbon can be reliably predicted from organic matter content, based on data reported by Bly (2018).



Graph 1: Predicting Organic Carbon from Organic Matter.

Swine manure can help increase SOC over time. However, the response is not uniform across all fields or management systems. Soil type, climate, manure form, application rate, and duration of use all matter.

This fact sheet summarizes what research shows about how swine manure affects SOC and what that means for field-level decisions.

Carbon and the Soil System

Carbon is essential for all life as well as for soil function. In soil, carbon helps bind sand, silt, and clay into stable aggregates. Without carbon, soil becomes loose, structure breaks down, and productivity declines. Soil organic carbon refers specifically to carbon derived from living or once-living materials. It is dynamic and sensitive to management. In contrast, inorganic carbon is mineral-based and much more stable.

Figure 1 illustrates the land-based carbon cycle and shows how carbon moves among plants, soil, and the atmosphere. Plants capture carbon dioxide from the air and transfer carbon into the soil through roots and residues. Soil microbes process this material. Some carbon returns to the atmosphere, while some remains stored in the soil for decades or longer.

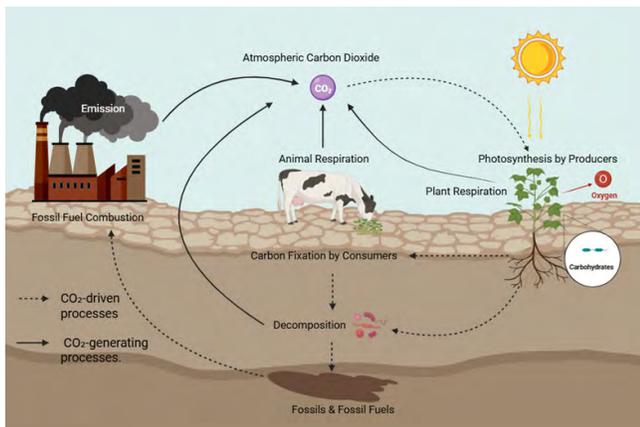


Figure 1: Land-Based Carbon Cycle.

Soil Organic Carbon in Agricultural Systems

Soils contain more organic carbon than vegetation and the atmosphere combined. Because of this, small changes in SOC at the field scale can have large impacts on soil health and carbon balance.

- Predicting SOC changes in the soil are challenging. SOC responds to:
 - Carbon to nitrogen ratio of manure
 - Application rate
 - Application method such as surface application, incorporation, or injection
 - Soil texture
 - Temperature and moisture
 - Cropping system and residue management

Research shows that manure application often increases SOC, but not always. Some studies show little change, and a few show declines. This variability highlights the importance of understanding how and why SOC responds under different conditions.

WHAT RESEARCH SHOWS ABOUT MANURE AND SOC

Per Fronczak & Drobnak, 2023, the general trends between swine manure and SOC

- Solid swine manure tends to increase SOC.
- Liquid swine manure often shows little direct increase in SOC.
- Long-term applications lasting more than five years are more likely to increase SOC than short-term use.
- Medium-textured soils tend to show greater SOC gains than very sandy or very heavy soils.

	Factor	Influence
Type of swine manure	Liquid	No influence
	Solid	Increase
	Solid + inorganic fertilizer	Increase
Application method	Surface applied	No influence
	Incorporated	No influence
Duration of application	Less than 5 years	No influence
	More than 5 years	Increase
Soil texture	Medium-textured soil	Greater increase

Table 1. Comparison of consistency and application of manure as it affects soil organic carbon (Fronczak & Drobnak, 2023).

HOW SWINE MANURE BUILDS SOIL ORGANIC CARBON

Manure influences SOC through two main pathways, shown in Figure 2.

Direct pathway

Manure adds organic carbon directly to the soil. This pathway is strongest with solid manure, which contains higher amounts of organic matter from feces and bedding.

Indirect pathway

Manure supplies nutrients that stimulate plant growth. More plant growth leads to more roots, residues, and root exudates entering the soil, all of which contain Carbon. These plant-derived inputs are often more important for long-term SOC storage than the carbon contained in manure itself.

Liquid swine manure contains relatively little stable organic matter. Most of its carbon is easily decomposed. As a result, liquid manure tends to influence SOC mainly by increasing crop biomass rather than by directly adding long-lasting carbon.

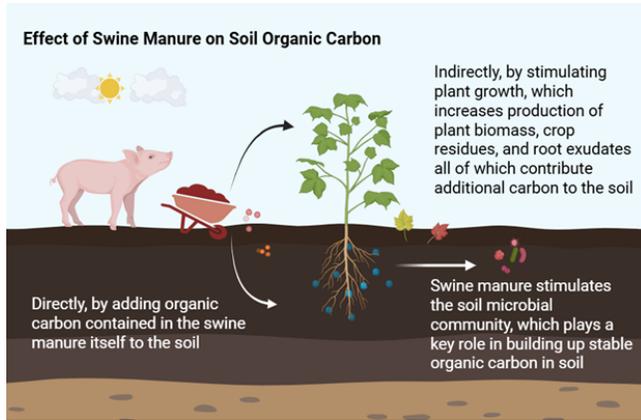


Figure 2: Effects of Swine Manure on Soil Organic Carbon.

LIQUID SWINE MANURE AND THE PRIMING EFFECT

Several long-term studies show that liquid swine manure does not consistently increase SOC and may sometimes reduce it. This occurs through a process known as the priming effect. The priming effect happens when fresh organic inputs stimulate soil microbes to decompose existing soil organic matter more rapidly. In systems receiving liquid swine manure, readily available carbon and nitrogen can accelerate microbial activity. This can offset or even exceed the carbon added by increased plant growth. Figure 3 illustrates results from a long-term grassland study by Angers et al. (2010) where liquid swine manure increased nitrogen and phosphorus but did not increase total SOC. In some cases, SOC declined at moderate application rates.

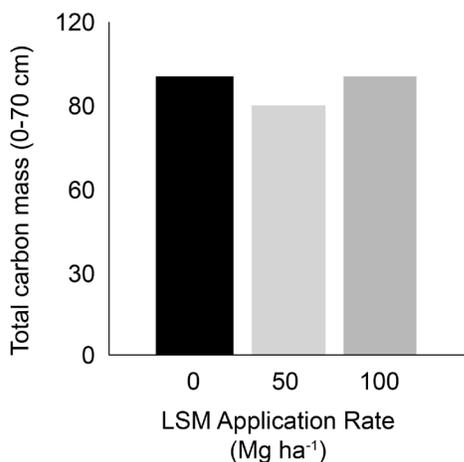


Figure 3: Effect of long-term liquid swine manure (LSM) application on total soil carbon storage (0–70 cm / 11.8 inches) under grassland management.

CLIMATE AND SOIL STRONGLY CONTROL SOC

Even without manure, SOC levels vary widely due to climate and soil properties.

Temperature: Cooler temperatures favor SOC accumulation by slowing microbial decomposition. Warmer conditions increase decomposition and carbon loss. Across many systems, SOC declines as mean annual temperature rise.

Moisture: SOC generally increases with precipitation up to a point. Moderate rainfall supports plant growth and carbon inputs. Excessive moisture can increase decomposition and reduce SOC. The relationship between rainfall and SOC is nonlinear and site-specific.

Table 2 summarizes how temperature, precipitation, nitrogen status, and soil structure influence SOC storage.

Factor	Impact on SOC	Insight
Temperature	Each 1°C (33.8 °F) increase in mean annual temperature reduces SOC by 3.3%	Warmer climates speed up decomposition, less carbon stays in the soil
Precipitation	SOC increases with rainfall up to ~ 60–70 cm/year; declines beyond due to faster decomposition	Moderate rain helps build SOC; too much rain breaks it down faster
Optimal Conditions	Cool temperatures and moderate rainfall (60–70 cm/year) lead to the highest SOC levels	Best SOC found in cooler, moderately wet regions
Soil Nitrogen	A 0.1 % increase in nitrogen concentration led to a 0.99 % increase in SOC concentration.	Fertile soils with good nitrogen hold more carbon
Bulk Density	Moderate bulk density (around 1.4–1.5 Mg m ⁻³) promotes SOC retention, while excessive compaction reduces SOC storage.	Balanced soil structure helps store carbon, avoid over-compaction
Soil pH & Texture	Minimal influence on SOC in this study	pH and texture didn't strongly affect SOC in this dataset

Table 2: How Climate and Soil Characteristics Influence Soil Organic Carbon (SOC).

Soil texture matters

Soil texture plays a major role in carbon stabilization.

- Clay-rich soils protect organic matter from microbial breakdown and store carbon more effectively.
- Sandy soils lose carbon more quickly due to limited protection and faster decomposition.

Manure applications tend to increase SOC more consistently in fine-textured soils than in sandy soils.

Long-Term Case Studies

Long-term field studies show mixed results, reinforcing the need for site-specific management.

- In Mississippi, repeated swine effluent irrigation increased SOC, with responses varying by soil type.
- In Oklahoma, long-term lagoon sludge applications increased SOC at depth but not consistently at the surface.

These results show that soil properties, application rate, and duration all influence outcomes.

SOC Does Not Increase Forever

Adding manure or residues does not always lead to proportional SOC gains. As SOC increases, soils may become less efficient at storing additional carbon.

Recent research shows:

- Initial SOC level is the strongest predictor of future SOC response.
- Soil bulk density and temperature also influence carbon stabilization.
- There is debate about whether soils reach a true saturation point, but responses clearly slow over time.

MANAGEMENT STRATEGIES TO IMPROVE SOC RETENTION

Research consistently supports the following practices for building and stabilizing SOC:

- Use integrated nutrient management that combines organic and mineral inputs.

- Reduce soil disturbance through conservation tillage.
- Retain crop residues whenever possible.
- Use diverse crop rotations.
- Consider practices such as agroforestry or biochar where appropriate.
- Avoid relying solely on mineral fertilizers in cool, moist climates.

KEY TAKEAWAYS FOR PRODUCERS

- Swine manure can support increases of SOC, but results depend on manure type, soil, climate, and time.
- Solid manure has greater potential to build SOC than liquid manure.
- Liquid manure mainly supports SOC indirectly through increased crop growth.
- Climate and soil texture often have a stronger influence on SOC than manure alone.
- Long-term, consistent management matters more than single-year decisions.

Building soil organic carbon is a long-term investment. Manure can be part of that strategy, but it works best when combined with good residue management, reduced disturbance, and realistic expectations based on local soil and climate conditions.

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