Farmed soils managed with diverse crop rotations in combination with legume cover-cropping will increase soil organic matter and retain a greater portion of soil nitrogen

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Summary: Soils managed through reduced tillage and utilization of diverse cover-crop strategies, such as those that include legumes incorporated with a small grain (i.e., winter wheat), have greater potential to increase both soil organic matter and plant available nitrogen pools (Figure 1).

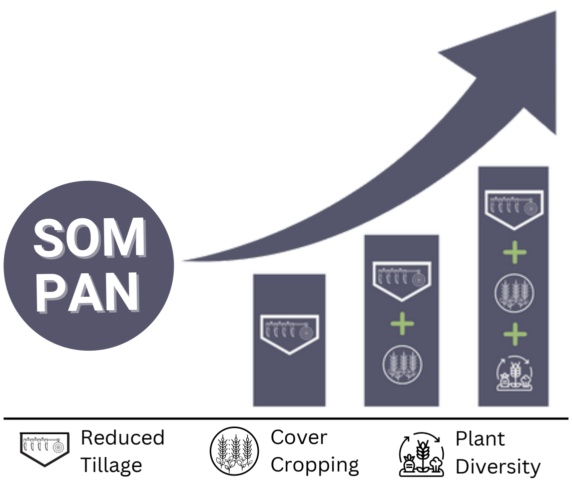

Figure 1. Visualization of Impacts from Farm Management Practices on Soil Organic Matter (SOM) and Plant Available Nitrogen (PAN)

Introduction

At Basil's Harvest, a more sustainable, equitable and resilient food system betters the health of people, farms and soil. Our work connects farmers, institutions, health systems and businesses to collaboratively build innovative and regenerative supply chains. In 2019, we connected with partners across the food supply chain to conceptualize and implement the Regenerative Agriculture in the Heartland (RAH) pilot — a successful initiative providing a real world example of a farm-to-hospital model implemented in the upper Midwest region of the United States. This pilot has paved the way for annual regional procurement of over 4,000 pounds of regenerative organic oats from Minnesota to a hospital system in central Illinois. This illustrates the valuable role of hospitals in regenerative food systems: by purchasing regional and regeneratively grown food, hospitals support farmers and promote diversity on farmland at regional and local levels. The knowledge gained from this initiative was manyfold: we acquired a valuable understanding regarding institutional food procurement and our region's capacity for local food systems. Additionally, through this initiative Basil's Harvest began to explore the connections between soil health, regenerative agriculture and human health.

To examine the connections between farm, food and health systems further, we began with the soil and partnered with Agroecology Solutions, Rodale Institute Midwest Organic Center, and the Bionutrient Institute to measure ecological impacts of regenerative agriculture. Our initial effort assessed soil organic matter and plant-available nitrogen dynamics at Janie's Farm-Forrester Field (25 year organic), Janie's Farm-Brockman Field (15 year organic), Cow Creek Organics Farm (2 year organic), and Janie's Farm-Cullum Field (in its first year of transitioning to organic - 1 year Trans). Our initial effort was to gain a greater understanding of the linkages between farm management practices and critical soil characteristics essential to crop productivity. Future studies will evaluate changes in soil biology, specifically microbial diversity and assessing the influence of soil health on crop nutrient quality.

THE FARMS

Janie's Farm Organics
Danforth, Illinois
janiesfarm.com

Cow Creek Organic Farm
Paxton, Illinois
cowcreekorganics.com

Soil Organic Matter

Soil organic matter (SOM) is a combination of both plant and animal matter incorporated into the soil environment. SOM concentrations will increase when stabilization forces such as entombment within soil aggregates and/or association with clay/silt surfaces outpace microbial decomposition (i.e., mineralization) and/or leaching events. Farm management practices can significantly alter SOM stabilization potential. For example, increases in SOM have been observed in farming systems where management practices such as crop residue retention/incorporation, field application of organic matter inputs and adoption of no till or reduced tillage are actively employed. SOM provides a multitude of benefits including increases in biodiversity, erosion reduction, enhanced soil fertility, and greater water holding capacity–all characteristics that are essential to meeting crop productivity demands. Furthermore, the Soil Health Institute recently suggested that increases in SOM are a critical soil component essential to improving overall soil health (Soil Health Institute 2022).

Specific to organic management, it is understood that the longer a farm is organic, the greater the accumulation of SOM concentrations. Results from our study suggest that the 25-year farm soil managed organically maintains a greater concentration of SOM (> 5.0%,) when compared to other farm soils in our study (Figure 2). Our observation further suggests that the combination of length of time that a farm is managed organic, coupled with particular management practices, including reduced tillage, incorporation of animal and green manure and use of diverse cover-cropping (Table 1), result in a greater potential to elevate SOM concentrations above 5.0%. The remaining farms in our study maintained statistically similar concentrations of SOM, (3.8% -4.2%) demonstrating the importance of no-till or reduced tillage influence on SOM accumulation (Figure 2). Resampling the 2.0-year organic farm within the next several seasons could provide some additional insights of the effects of diverse cropping management (i.e., Sudan-grass and Sunflower rotation), as well as cover-crop usage on SOM stabilization/accumulation (Table 1). Finally, as severe weather events (i.e., significant fluctuations in rainfall intensity) are expected to increase over the next several years, soils maintaining greater concentrations of SOM will offer an added layer of protection against possible crop/soil losses, while at the same time providing a much-needed ally to withstand challenges as the climate continues to change.

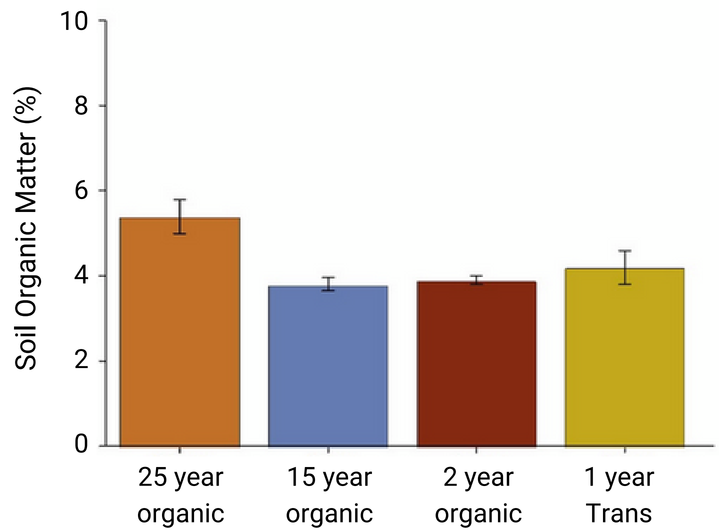

Figure 2. Distribution of Soil Organic Matter across Surveyed Farms

Nitrogen

Nitrogen is a critical component of numerous compounds required for healthy plant development including, but not limited to, amino acids (proteins/enzymes) and genetic material (i.e., DNA). Due to its physiological importance, nitrogen is often a limiting factor in plant growth and as a result, soils within farming systems are regularly amended with either commercial nitrogen fertilizers (anhydrous ammonia, urea, and urea ammonium nitrate to name a few), or nitrogen sources from animal and/or green manures allowed in organic production. Plant roots acquire nitrogen from the soil environment, mostly as dissolved nitrate (NO3-) and ammonium (NH4+); the combination of these compounds is known as the Plant Available Nitrogen pool (PAN). As we consider ways to improve soils through organic management, this study measured PAN and explored, "How can PAN be maintained when eliminating commercial nitrogen fertilizer in organic production, while also improving SOM?"

To begin, SOM plays a critical and often overlooked role in PAN. In this process, microbial activity liberates a fraction of SOM via decomposition (i.e., mineralization), which converts SOM to ammonium ions, which are then transformed to nitrate. In the case of the 25-year organic farm, SOM concentration of 5.4% (Figure 2) will generate ~55.0 lbs. of PAN per acre per year, while the 15-year organic farm would expect to receive ~40 lbs. of PAN per acre per year through microbial mediated mineralization (see calculation: Brady & Weil (2008) chapter 13). This suggests that even small gains in SOM can an effective provide benefit in return of PAN to the soil environment. This observation is supported by results from our study, as the 25-year organic farm maintained significantly greater concentrations of ammonium when compared to other farms, except for the T1-transition farm (Figure 3A). It is possible the greater ammonium concentrations measured in T1 farm soils was the effect of SOM mineralization, (> 4.0%[Figure 2]) coupled with lingering legacy effects from commercial nitrogen fertilizer application applied one year prior when T1 farm soils were managed conventionally.

In addition to SOM, the effective utilization of legume cover-cropping can provide PAN to farm soils. In our study, we observed significantly greater nitrate concentrations in both the 25 and 15-year organic farm soils (Figure 3B). Several studies suggest that the combination of legume cover-crops intercropped with a small grain, usage of animal manures, and reduced tillage increases soil nitrate concentrations. Similar management tactics were employed at both the 25 and 15-year organic farms (Table 1). Crops require nitrogen to maximize productivity and yield. Price increases of commercial nitrogen fertilizers are currently occurring at the time of this publication (September 2022) and are expected to continue in both the immediate and distant future, due to growing instability of materials needed to produce nitrogen-based fertilizers (i.e., natural gas), along with disruption of global supply chains. A reasonable safety net that offsets the expense of commercial nitrogen fertilizers could be the investment in a quality cover-cropping strategy.

Figure 3. Ammoniacal and Nitrate Distribution across Surveyed Farms

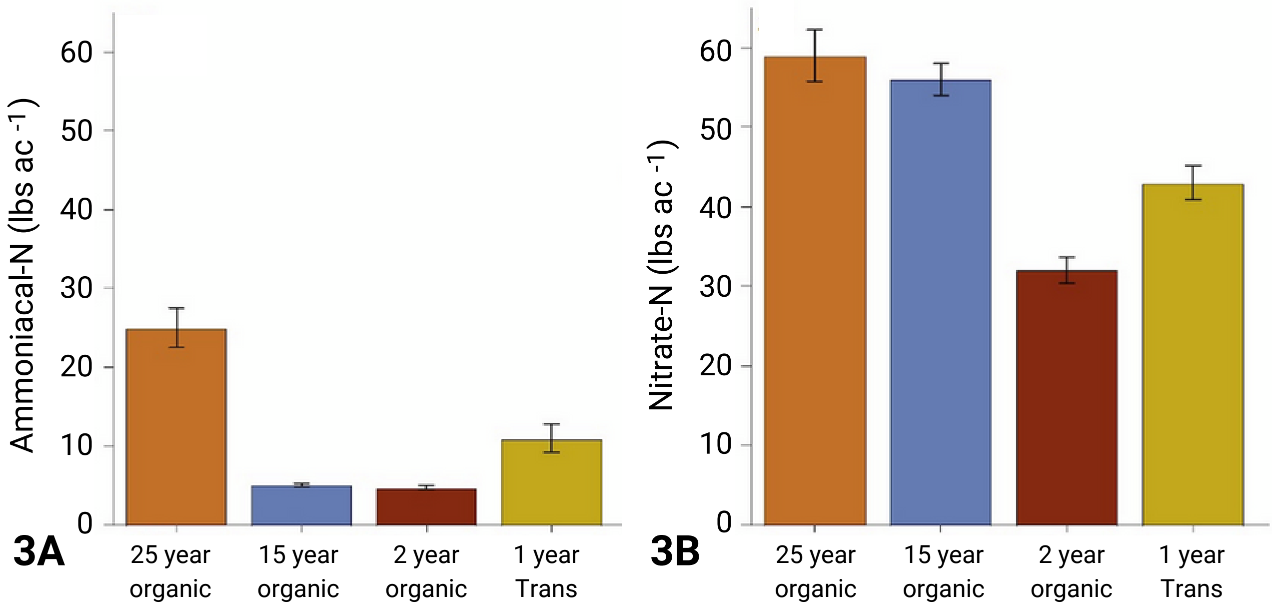

Table 1. Surveyed farm management practices

Management practice	Number of years organic			
	25 year organic	**15 year organic**	**2 year organic**	**1 year Trans**
Crop rotation*	C-cc^1-S-cc^2-C-cc^1-S-cc^2	C-cc^1-S-cc^2-C-cc^1-S-cc^2	C-cc^3-SG-cc^1-S-cc^3-SG-cc^3-SF-cc^3-SG-cc^4	C-cc^1-S-cc^2-W
Primary tillage^	Term-cc	None	ND	None
Weed control	FW,RC,RH,Z	FW,RC,RH,Z	FW,RC,RH,Z	FW,RC,RH,Z
Fertility^y	GM	AM,GM,Org-S	GM	AM,GM,Org-S

*C corn, S soybean, SF Sunflower, GG – Sudan-grass, W/R (Wheat, Rye), W Wheat, cc^1 Rye, cc^{2}Red-clover interseeded into Wheat, cc^{3}Rye and yellow Pea, cc^{4}Red-clover and Alfalfa
^ND Notched Disk
ǂFW, Flame Weeder, RC Row Cultivator, RH Rotary Hoe, RT roto-tiller, Z Zapper
^{y}AM animal manure, CP compost, GM - Green Manure, Org-S – Organic-Sulfur

Conclusion and Future Directions

Farm management practices that actively work to increase SOM provide added soil resilience to both fluctuations in extreme weather events and reduce the need to amend soils with potentially costly or unavailable fertilizers.

- The 25-year farm maintained the highest concentrations of both SOM (Figure 2) and PAN (Figure 3) likely due to reduction of tillage, diverse crop rotations and use of legume cover-crops (Table 1).

- SOM provides several soil ecosystem services essential to crop production including, but not limited to, improved soil structure, greater water holding capacity, and improved soil drainage. Additionally, SOM concentrations greater than 5.0% can provide more than 50 pounds of PAN via microbial mediated mineralization.
- Cover-crop mixtures that incorporate legumes with a small grain (i.e., Winter Wheat) have been shown to increase SOM and PAN. Our results demonstrate a similar trend possibly due to management efforts in both 25 and 15 year organic farms (Table 1).

The next step in our research is to dive deeper into the linkages between how farm management practices influence soil health and nutrient density of crops, and how consumption of food grown in these ways can positively impact human health. As we look forward to the next year of the initiative, we are planning research programs to evaluate additional changes in both soil biology and crop nutrient quality as they relate to farm management practices and overall soil health. Our future directions also aim to translate the cumulative data into a useful tool(s) for farmers as they consider the transition from conventional to organic farm management practices. By fostering sustainable changes in our regional food systems, we are ultimately promoting a more healthful, equitable and resilient food system that connects the health of people, farms and soil.

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