Integrating Manure Management with Winter Rye for Sustainable Intensification of No-Till Corn Silage Systems for Sequestering Soil Carbon

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Introduction

Dairy farmers in Illinois often grow corn (*Zea mays* L.) for silage in a three-to-four-year period and then rotate to alfalfa (*Medicago sativa* L.). During the corn silage years, growers apply liquid manure to match the corn nitrogen (N) requirement (N-based management). This results in more applied phosphorus (P) than what corn can remove. A practical solution to this is to shift from N-based management to a P-removal rate (P-based) and supplement the N by applying N fertilizer. During the corn years, intensifying the cropping system by integrating winter cereals such as winter rye (*Secale cereale* L.) could not only help with avoiding the soil test P (STP) build up by removing excess P, but also can improve soil health indicators and sequester carbon (C) through adding C via winter rye root system.

Research Hypotheses

We hypothesized that shifting from single season fertilizer-based corn for silage to N-based or P-based manure and intensifying corn for silage with winter rye can:

1. Improve soil physical properties (e.g., decrease bulk density and increase soil aggregate stability);
2. Increase carbon input (especially with rye root; Fig. 1) and therefore, soil C and N stocks and organic matter fractions;
3. Increase earthworm abundance, and microbial biomass (phospholipid fatty acid; PLFA).

Objectives

Our objective was to evaluate whether intensifying corn for silage with winter rye at N-based vs. P-based manure rates when compared to a single season corn managed with UAN fertilizer could improve soil physical (bulk density, aggregation), chemical (soil organic N), and biological properties (Soil organic C, C stocks, SOM fractions, earthworm, and microbial biomass).

Experimental Site and Design

- An experiment was initiated in 2019 in a farmer's field in Breese, IL with an Oconee-Darmstadt silt loam soil.
- Experimental design was a randomized block design with four replicates and five treatments including: (1) Fertilizer-based (UAN) corn for silage without rye; (2) Injected manure at P-based rate without rye (INJPNOCC); (3) Injected manure at N-based rate without rye (INJNNOCC); (4) Injected manure at P-based rate with rye (INJPCC); and (5) Injected manure at N-based rate with rye (INJNCC) (Fig 1.).

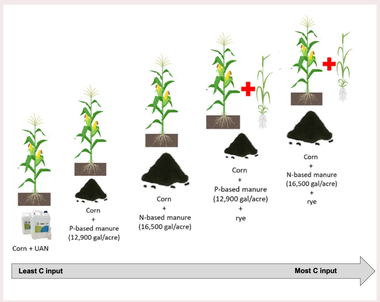

Figure 1: List of treatments from high to low C inputs.
- Rye inputs are the roots that are not harvested.
- N- vs. P-based rates are close to each other due to the fact that both were injected in spring.

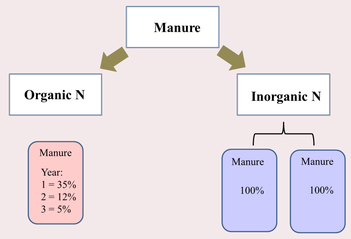

Figure 2: Assumptions for organic and inorganic N availability during the corn growing seasons and the following years.

Table 1: manure characteristics of the farm:

Year	Total N	Ammonia N	Organic N	P_2O_5	K_2O	Total solids
	..... g kg^{-1}					
	Dairy liquid manure					
2019	1.9	0.9	1.0	0.7	2.0	69.0
2020	1.6	0.7	0.9	0.8	1.9	28.4

Sampling and Analysis

- Soil samples were collected in April 2022 including shovel sampling (0-5 and 5-20 cm depth) for aggregate size distribution, aggregate stability, and soil organic matter fractions (loss-on-ignition; 360 °C) and rhizosphere sampling for PLFA.
- A deep core sampler was used to collect soil bulk density up to 90 cm depth. A penetrometer was used to evaluate soil compaction from 0-10 and 10-20 cm depth.
- Carbon and N (plant or soil) were analyzed using an elemental analyzer.
- The Permanganate-oxidizable C (POXC) method involved reacting a dilute $MnO4^-$ solution with a soil sample of a given mass (2.5 g).

Figure 3: Field and lab activities for collecting and processing soil and earthworms in spring 2022.

- Data was assessed for normality of residuals and transformed if needed.
- Sampling by depth was subjected to repeated measure analysis in mixed models in SAS.
- For some dependent variables (e.g., POXC), we used non-parametric Wilcoxon test by sampling depth to assess whether treatments influenced the dependent variable.

Results

None of the treatments influenced soil bulk density. Soil bulk density was lower at 0-5 cm depth compared to all other depths (Fig. 4A).

Soil POXC data were analyzed using non-parametric Wilcoxon test by depth. At 0-5 cm UAN had lower POXC than other treatments (P<0.04). At other depths, there was no significant differences among treatments (Fig. 4B).

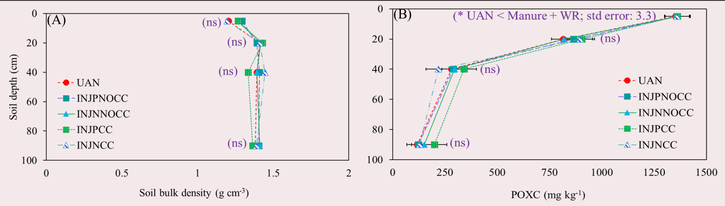

Figure 4: Soil bulk density (A) and POXC (B) as influenced by depth of sampling and treatments.
*: significant at 0.1; ns: no significant differences.

Soil organic carbon stocks was influenced by depth but not by treatment or treatment by depth interaction. At 0-5 cm depth, contrast analysis showed UAN had lower SOC stocks than other treatments (Fig. 5A).

Soil organic N was only affected by depth of sampling where deeper soil layer (40-90 cm) had higher SON stocks than other depths (P< 0.001) (Fig. 5B).

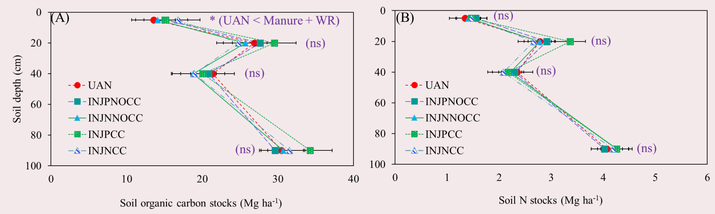

Figure 5: Soil organic C (A) and N (B) as affected by sampling depth and treatments.
*: significant at 0.1; ns: no significant differences.

Results (Continued)

Aggregate size distribution and soil compaction were similar among treatments (data not shown).

Aggregate stability increased with manure and winter rye treatments (data not shown).

Particulate (> 0.25 mm) and light fractions of soil organic matter (0.053-0.25 mm) improved with manure/winter rye combination when compared to UAN (Fig. 6 A-B).

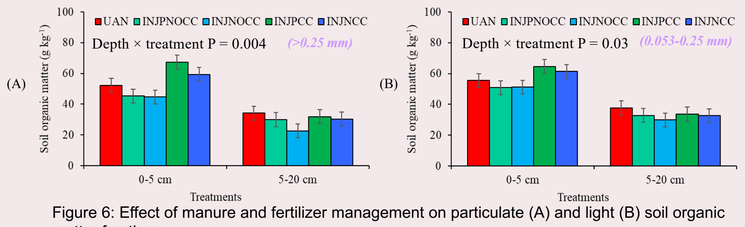

Figure 6: Effect of manure and fertilizer management on particulate (A) and light (B) soil organic matter fractions.

UAN had similar total PLFA biomass to N-based manure or N-based manure plus winter rye.

N-based manure and winter rye increased microbial diversity, total fungi, and fungi:bacteria ratio compared to UAN reflecting a potential for increase in soil organic matter or organic C build up (Fig. 7A-D).

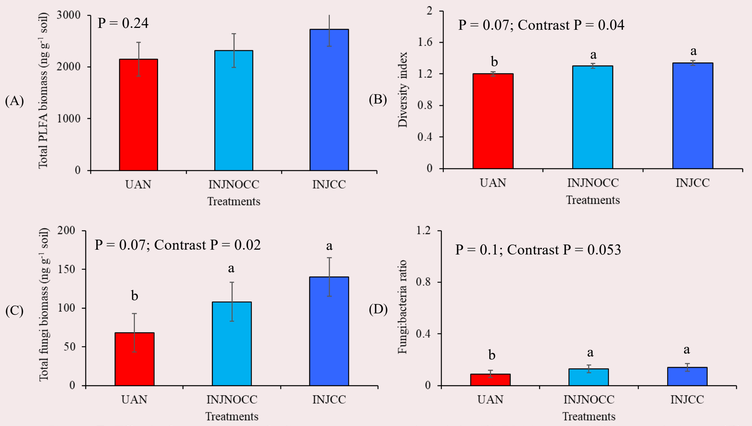

Figure 7: Effect of manure and fertilizer management on total PLFA biomass (A), diversity index (B), total fungi biomass (C), and fungi:bacteria ratio (D). Different letters indicate statistical significance at P=0.1.

Contrast analysis indicated that earthworm number and weight were increased by manure plus winter rye compared to UAN (Fig. 8A-B).

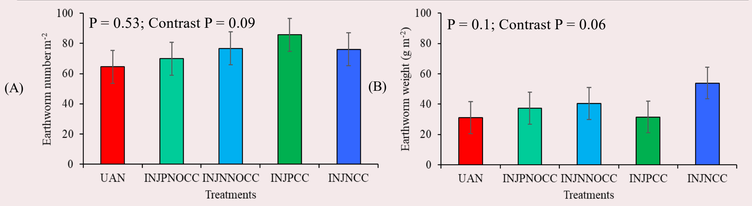

Figure 8: Effect of manure and fertilizer management on earthworm number (A) and weight (B).

Conclusions/Future Research

Shifting from single season fertilizer-based corn for silage to N-based or P-based manure and intensifying corn for silage with winter rye:

1. Only improved soil aggregate stability;
2. Increased topsoil POXC and SOC stocks along with particulate and light organic matter fractions;
3. Increased earthworm abundance, biomass, and microbial diversity, fungi, and fungi:bacteria ratio but not soil microbial biomass (total PLFA).
4. Future research should include N_2O losses for C credit assessment.

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