COMMENTS FROM COOLBEAN

Healthy Soil, Happy Soybeans: Insights from Multi-State Research

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In a bean pod

- **Fields with cover crops had greater mineralizable carbon (Min-C) and water-extractable organic carbon (WEOC) than no cover crop.**
- **Artificial drainage was not associated with changes in soil health parameters.**
- **The soil health parameters, soil organic carbon (SOC) and soil protein (ACE-N), were associated with soybean yield.**
- **Longitude and soil test potassium (STK) also influenced soybean yield.**
- **Monitoring soil carbon and nitrogen pools helps to sustain soil health and supports smarter decisions for higher, more consistent soybean yields.**

Introduction

Healthy soil isn't built overnight, but the choices you make each season can move the needle. Healthy soils improve nutrient cycling, retain water more effectively, and help crops better withstand extreme weather. In a recent multi-state study, we analyzed soil samples from field trials across the U.S. to understand how management practices influence both soil health and soybean yield. Specifically, we investigated: (1) whether crop rotation, cover crops, tillage, and artificial drainage were associated with changes in soil health parameters, soil fertility, and inherent soil properties; and (2) how these management practices, soil health parameters, inherent soil properties, location-specific factors, and soil fertility measures affect soybean seed yield.

Materials & Methods

For objective 1, we used soil samples (0–6 inches depth) collected in 2023 from 21 (4–50 years) experimental agricultural research trials (Fig. 1). Sites included in this study compared the effects of at least one of four practices: **cover cropping, crop rotation, tillage, and artificial drainage** (Table 1). **For Objective 2**, we used a subset of 17 agricultural research trials (ranging from 4-40 years) from the larger dataset in Objective 1.

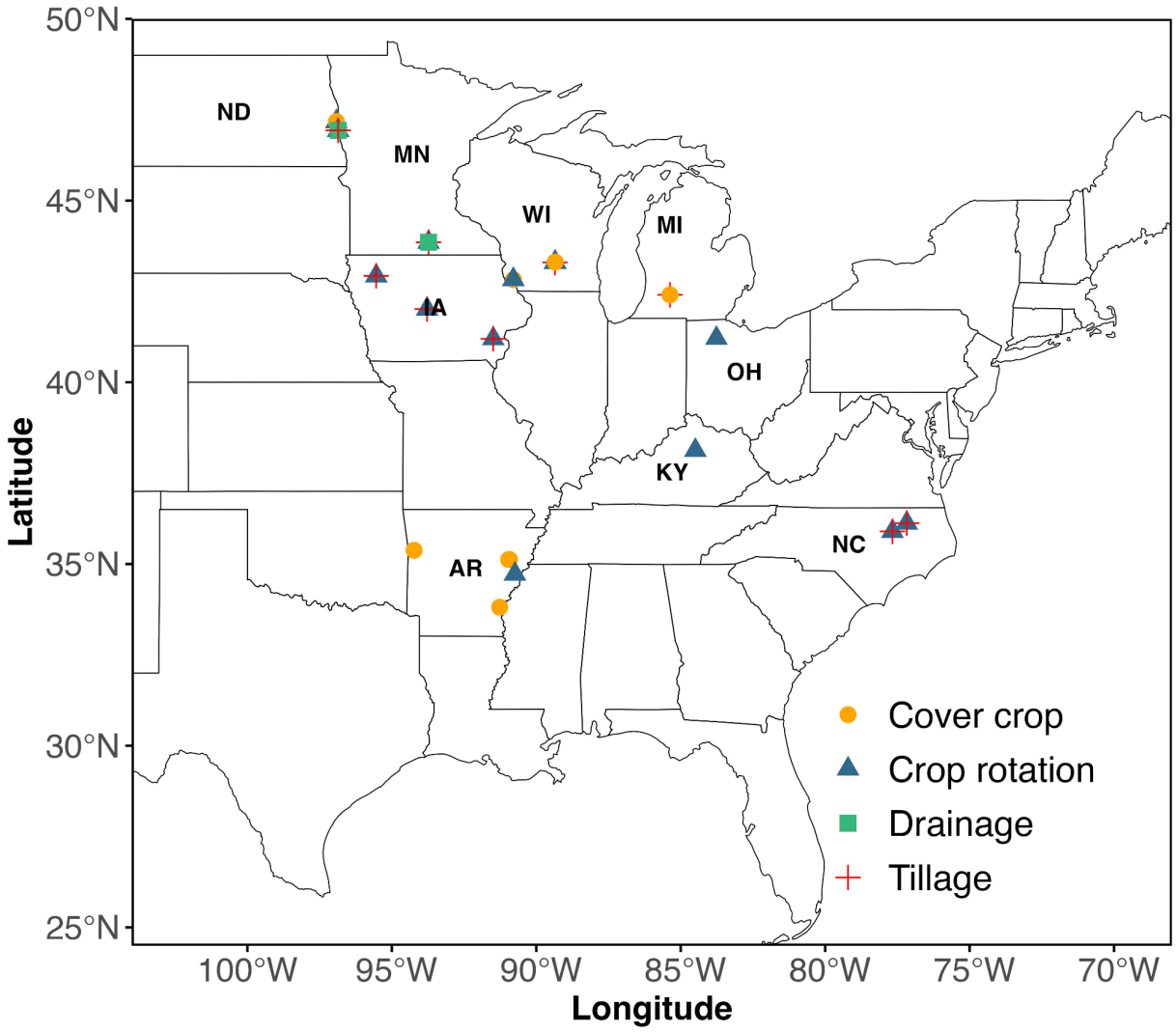

Fig. 1. Map of 21 long-term experiments included in the study. Field trials that included more than one management practice are represented by the different colors and shapes in the figure. Number of trials in each state: Arkansas-AR (5), Iowa-IA (3), Kentucky-KY (1), Michigan-MI (1), Minnesota-MN (1), North Carolina-NC (2), North Dakota-ND (2), Ohio-OH (1), Wisconsin-WI (5).

Table 1. Description of management practices for the studies.

Management practices	Treatment description	Control	Paired observations	Trial-level occurrences[a]
Two crops in rotation	Crop rotation with two crop types in conventional and no-tillage systems	Single-crop monoculture in conventional and no-tillage systems	199	7

Three crops in rotation	Crop rotation with three or more crops in conventional and no-tillage systems	Single-crop monoculture in conventional and no-tillage systems	46	3
Minimal tillage	Lower tillage intensity such as reduced tillage, and strip tillage with two or more crops in rotation	Conventional tillage including any higher tillage intensity such as conventional tillage, chisel plow, deep ripper, and moldboard plow with two or more crops in rotation	121	4
No-tillage	No-tillage with a single or two or more crops in rotation	Conventional tillage including any higher tillage intensity such as conventional tillage, chisel plow, deep ripper, and moldboard plow with a single or two or more crops in rotation	208	8
Cover crops	Cover crop in no-tillage or reduced tillage systems with a single or two or more crops in rotation	No cover crop in no-tillage or reduced tillage system with a single or two or more crops in rotation	162	8

[a]At some experimental trials more than one management treatment was present (e.g. two crops in rotation and no-tillage).

Soil sampling

Soil samples were collected between mid-April and mid-June, near or at crop planting time according to each location's schedule. These samples were used to evaluate soil fertility, soil health, and basic soil properties. Here's what we measured:

Soil fertility:

- Soil test phosphorus (**STP**)
- Soil test potassium (**STK**)

Soil health parameters:

- Organic matter (loss-on-ignition, **OM-LOI**)
- Soil organic carbon (**SOC**)
- Total nitrogen (**TN**)

- Soil protein (autoclaved citrate-extractable nitrogen, **ACE-N**)
- Permanganate oxidizable carbon (**POXC**)
- Mineralizable carbon (**Min-C**)
- Water-extractable organic carbon (**WEOC**)
- Wet aggregate stability (**WAS**)

Inherent soil properties:

- pH
- Soil texture (sand, silt, and clay content)

Results

***How Management Practices Influence Soil Health* (Objective 1)**

- Two-crop rotations were associated with greater soil test phosphorus compared to a single crop (Fig. 2).
- Soils under cover crops had greater organic matter, including 18% more microbial carbon (Min-C, which reflects active microbial life and nutrient cycling) and 7% more water-extractable organic carbon (WEOC, the readily available carbon that feeds soil microbes) than soils without cover crops (Fig. 2).
- No-tillage slightly lowered soil pH (Fig. 2).
- No-tillage, minimal tillage, cover crops, and two- and three-crop rotations were not associated with significant changes in POXC, WAS, OM-LOI, TOC, ACE-N, TN, and soil test potassium indicators (Fig. 2).
- Tile drainage did not significantly affect any of the soil health parameters measured in this study (data not shown).

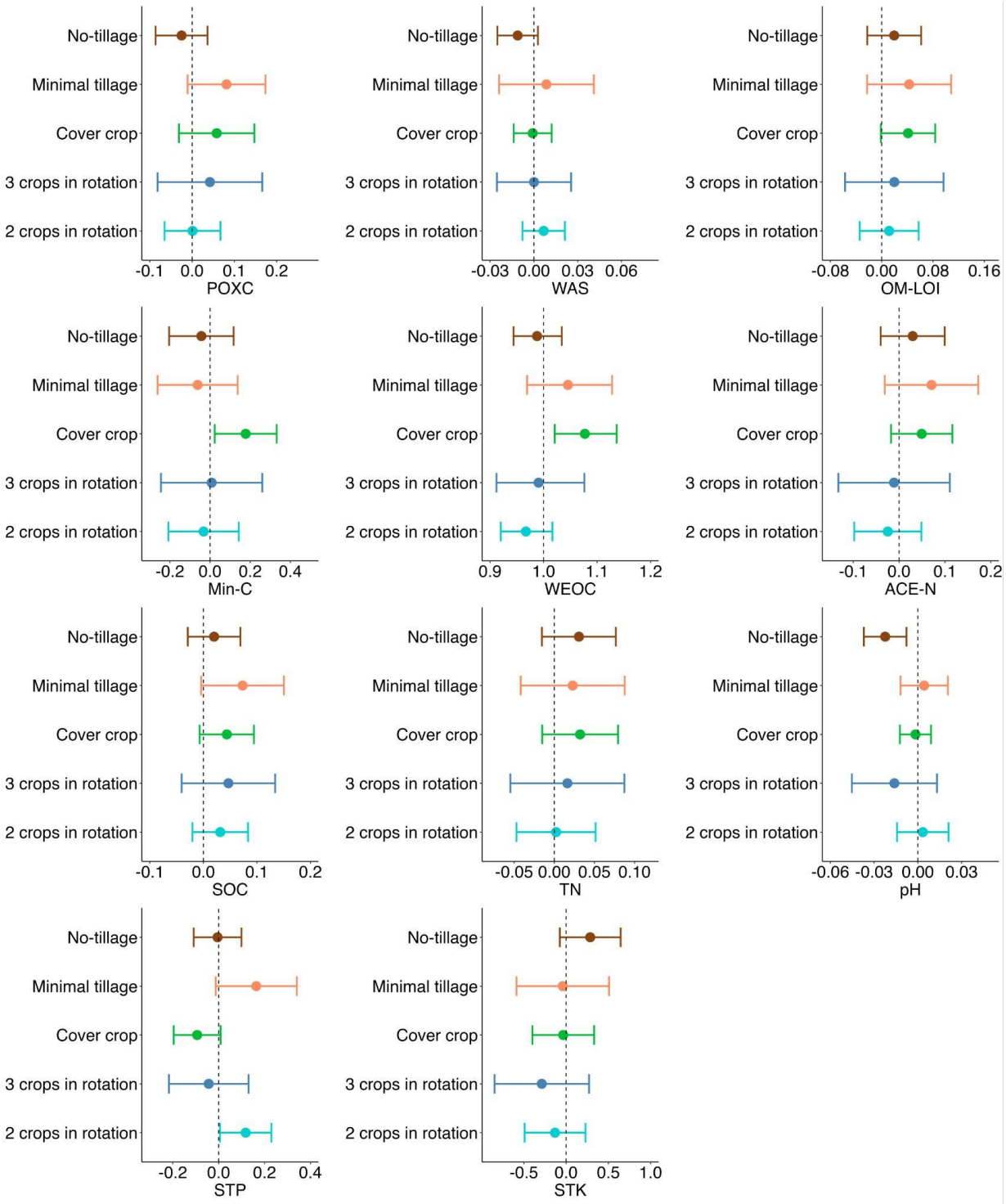

Fig. 2. Each bar shows how each soil health parameter changed with a practice (calculated as the log of the treatment vs. control field averages). Positive values indicate increased indicator values in the treatment relative to the control, while negative values indicate reductions. The vertical black dashed line at zero represents no effect. Dots represent mean effect sizes, and whiskers show 95 % confidence intervals. Effect sizes are considered statistically significant when the confidence interval does not include zero.

Key Factors Driving Soybean Yield **(Objective 2)**

To understand what drives soybean yield (management or soil health parameters), we built a model including:

Management factors: crop rotation, number of crops in rotation, years in rotation, previous crop, planting date, maturity group, seed rating, tillage type, cover crop, artificial drainage, irrigation, and P & K fertilizer.

Soil health parameters: ACE-N, TN, OM-LOI, SOC, POXC, Min-C, WEOC, and WAS.

Inherent soil properties: pH, clay, silt, sand, and soil order.

Location-specific factors: latitude, longitude, precipitation, and temperature.

Soil fertility results: STP and STK.

This model allowed us to determine which factors were most important for soybean yield. The model explained 73 % of soybean yield variability (Fig. 3).

Findings:

- Trials planted before mid-May (day of year − DOY ≤ 135) had the greatest average yield (72 bu/ac; left box).
- For soybeans planted between mid-May and late May (DOY 136–146), fields with higher ACE-N (>5.73 g/kg) produced about 8 bu/ac more than fields with lower ACE-N.
- In the same planting window, if longitude was ≥ -91.26, greater soil test potassium (>139 ppm) resulted in greater yield (58 bu/ac) compared with lower STK (52 bu/ac).
- Planting after late May (DOY > 146) resulted in the lowest yields (39 bu/ac), regardless of other soil or location factors.

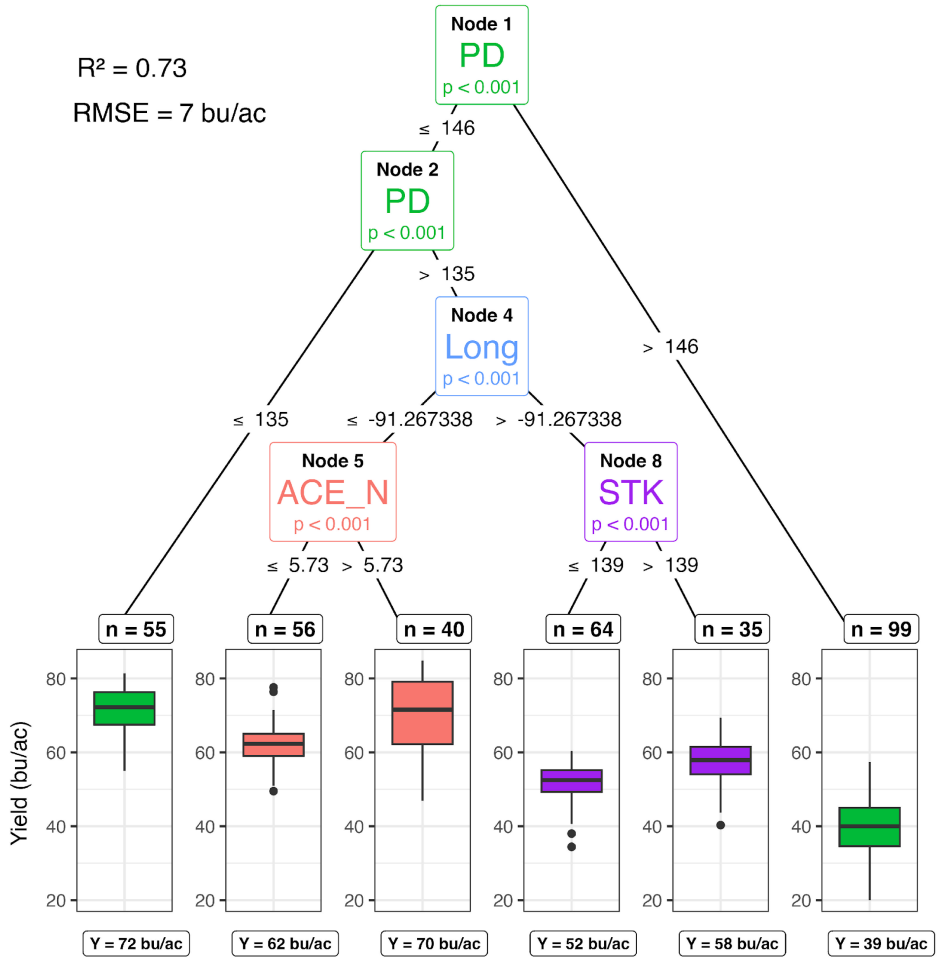

Fig. 3. Conditional inference tree showing significant splits for soybean seed yield. Each box at the bottom shows the soybean yield distribution and the horizontal dark solid line represents the mean, which is also numerically shown at the bottom (Y). The black circles show outlier yields.

To confirm these results, we also ran a simplified model using only the main management factors and key soil and location-specific variables.

What we found:

- Planting date and soil organic carbon were the strongest predictors of soybean yield.
- Fields planted in mid- to late-May with soil organic carbon above 2.3% tended to produce the greatest yields.

Conclusions

Cover crops improved important soil health metrics such as mineralizable carbon and water-extractable organic carbon, whereas artificial drainage did not affect soil health. Soybean yield was strongly influenced by soil organic carbon, soil protein, longitude, and potassium levels. While in-season management practices have a more immediate impact on yield, long-term monitoring of soil carbon and nitrogen remains essential for sustaining soil health and ensuring consistent, high soybean yields.

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