Design of Experiments Project:
Starter Nitrogen Effects on No-Till Soybean Yield

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Abstract

This project evaluates the effects of four starter nitrogen fertilizers (Control, FM, PL, SN) on no-till soybean yield across five site-years using a randomized complete block design (RCBD). A linear mixed-effects model was used with treatment as a fixed effect, and site-year and block nested within site-year as random effects. Both real and simulated datasets were analyzed to validate model assumptions and assess treatment effects. Results indicate that none of the fertilizers produced a statistically significant increase in yield compared to the control. Variance decomposition showed that environmental differences among site-years accounted for most of the variability, while blocks within site-years contributed very little. These findings suggest that starter N fertilizer did not meaningfully affect soybean yield under the conditions studied.

1 Introduction

This project examines soybean yield data from Allen et al., collected over five site-years to evaluate whether starter nitrogen fertilizer improves yield in no-till systems. Treatments included Control, FM, PL, and SN, each applied within blocks at each site-year using a randomized complete block design (RCBD).

The objectives of this project were:

1. Select an appropriate experimental design and statistical model for the dataset.
2. Simulate a dataset mimicking the experimental design.
3. Analyze the real dataset using the chosen model, assess assumptions, and interpret results.

Agronomic relevance

Starter nitrogen fertilizer is sometimes applied in no-till systems to compensate for nitrogen immobilization by cereal rye residue. Understanding whether these fertilizers meaningfully affect yield helps farmers make economically and environmentally informed decisions.

Sustainability

If starter fertilizer does not increase yield, unnecessary nitrogen inputs can be avoided, reducing both cost and environmental impact, such as risk of nitrogen leaching.

2 Hypotheses

The main objective of this study was to determine whether starter nitrogen fertilizer influences soybean yield across multiple site-years. The hypotheses for the fixed treatment effect were:

$$H_0 : \tau_{\text{CT}} = \tau_{\text{FM}} = \tau_{\text{PL}} = \tau_{\text{SN}}$$

Interpretation of H_0: Starter nitrogen fertilizer has no effect on soybean yield. Any observed differences are due to random variation.

$$H_A : \text{At least one treatment mean differs from the others.}$$

Interpretation of H_A: At least one fertilizer treatment affects soybean yield.

To evaluate these hypotheses, we fitted a linear mixed-effects model with treatment as a fixed effect and site-year and block nested within site-year as random effects. In addition to testing the overall treatment effect, we performed Tukey-adjusted pairwise comparisons among all treatment means to determine whether specific fertilizer treatments differed significantly from one another.

Both the global test and the Tukey pairwise comparisons showed no statistically significant differences among treatments. This reinforces the conclusion that starter nitrogen fertilizers did not meaningfully affect soybean yield under the conditions of this study.

Data Description

The dataset analyzed in this project was obtained from the Dryad Digital Repository:

> Allen, G.; Roth, R.; Silva, E.; Silva, L. (2023). *Starter nitrogen fertilizer effects on organic no-till soybean yield across multiple site-years*. Dryad Digital Repository.
> `https://datadryad.org/dataset/doi:10.5061/dryad.xksn02vn6`

The main variables used in this project include:

- **yield.kgha**: Soybean yield in kilograms per hectare.
- **block**: Block (replicate) number within each site-year.
- **siteyr**: A factor identifying the site-year. Codes:
  - NY20 = New York, 2020
  - NY21 = New York, 2021
  - NY22 = New York, 2022
  - WI21 = Wisconsin, 2021
  - WI22 = Wisconsin, 2022
- **treatment**: A factor indicating the starter nitrogen fertilizer treatment applied to each plot:
  - PL = Poultry Litter
  - CT = Control (no fertilizer)
  - FM = Feather Meal
  - SN = Sodium Nitrate

3 Methods

3.1 Experimental Design

The experiment consisted of five site-years, each with 4 or 5 blocks:

- NY20: 4 blocks
- NY21: 5 blocks
- NY22: 5 blocks
- WI21: 4 blocks

- WI22: 4 blocks

Each block contained all four treatments, randomly assigned. RCBD was chosen to control variability within fields.

Why fields were divided into blocks

Fields are not perfectly uniform. One part of the field may have slightly better soil, more moisture, higher rye biomass, different slope, or varying sunlight. Each block represents a different section of the field with its own natural conditions. Blocking removes this local variation from the treatment comparison.

Why site-year was not used as a block

Site-years represent different fields, climates, and growing seasons. They cannot function as blocks and are instead modeled as random effects.

3.2 Statistical Model

A linear mixed-effects model was used:

$$Y_{ijk} = \mu + \tau_i + s_k + b_{j(k)} + \varepsilon_{ijk}. \tag{1}$$

Y_{ijk} : yield for treatment i in block j at site-year k,
μ : overall mean,
τ_i : fixed treatment effect,
$s_k \sim N(0, \sigma_s^2)$: random site-year effect,
$b_{j(k)} \sim N(0, \sigma_b^2)$: random block-within-site-year effect,
$\varepsilon_{ijk} \sim N(0, \sigma^2)$: residual error.

3.3 Model Assumptions

1. Linearity.
2. Independence of observations.
3. Normality of random effects and residuals.
4. Constant variance.
5. Correct nesting of blocks within site-years.

4 Results: Real Dataset

4.1 Assumption Checks

Residual Q–Q plots showed approximate normality with minor deviations. Shapiro–Wilk test: $p = 0.5336$. Random effects appeared normal. Assumptions were satisfied.

4.2 Fixed Effects

Effect	Estimate	Std. Error	t-value	p-value
Intercept (Control)	2633.51	280.47	9.39	0.00026
FM	95.86	138.60	0.69	0.49
PL	147.64	138.60	1.07	0.29
SN	104.50	138.60	0.75	0.45

Table 1: Fixed effects for the mixed-effects model.

4.3 Variance Components

Random Effect	Variance	Std. Dev.
Site-year	3.451×10^5	587.49
Block (site-year)	4.4×10^{-3}	0.066
Residual	2.113×10^5	459.68

Table 2: Variance components for the mixed-effects model.

4.4 Pairwise Comparisons

Contrast	Estimate	SE	df	t.ratio	p.value
CT - FM	-95.86	139	63	-0.692	0.8999
CT - PL	-147.64	139	63	-1.065	0.7118
CT - SN	-104.50	139	63	-0.754	0.8746
FM - PL	-51.77	139	63	-0.374	0.9821
FM - SN	-8.64	139	63	-0.062	0.9999
PL - SN	43.14	139	63	0.311	0.9895

Table 3: Pairwise comparisons of treatment effects.

5 Simulation Results

A simulated dataset reproducing the RCBD structure showed similar patterns: small, statistically insignificant treatment effects and dominant site-year variation.

5.1 Random Effects (Simulated)

Random Effect	Variance	Std. Dev.
Site-year	1.32×10^5	363.6
Block (site-year)	2.07×10^{-5}	0.00455
Residual	1.43×10^5	378.4

Table 4: Random effects for simulated dataset.

5.2 Fixed Effects (Simulated)

Effect	Estimate	Std. Error	t-value	p-value
Intercept	2633.46	181.58	14.50	1.45×10^{-5}
FM	33.10	114.11	0.29	0.7725
PL	-192.68	114.11	-1.69	0.0952
SN	93.32	114.11	0.82	0.4159

Table 5: Fixed effects for simulated dataset.

Assumption checks confirmed normality (Shapiro–Wilk $p = 0.981$).

6 Discussion and Conclusion

Both the real and simulated analyses show that starter nitrogen fertilizer had no significant effect on soybean yield across environments. Treatment effects were small relative to environmental variability. Site-year contributed the majority of yield variation, while blocks had negligible impact. These findings suggest that applying starter nitrogen may not provide agronomic or economic benefits under the studied conditions.