Project Semi-Annual Reports

Quantifying Nitrogen Credits from Soybean

By

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Submitted to

Multi-Regional Soybean Checkoff

Period of performance: January 1, 2024 to December 31, 2024

January 31, 2025

Project Summary

We leverage the Science for Success team, a coalition of nationwide Soybean Specialists, to quantify soybean N credits across the US. There has never been a nationally coordinated effort to quantify soybean N credits. If accurately quantifying N credits from soybean residue can reduce the N application rate to subsequent crops, this will provide evidence of the economic and environmental value of soybeans as a sustainable rotational crop.

Major Accomplishments (Jan 1, 2024 to Dec 31, 2024)

- We completed the first rotation of the experiment, establishing crop history treatments
- We presented a review on soybean N credits at the American Society of Agronomy Conference (ASA).
- We presented preliminary results at stakeholder meetings

1.0 Introduction

Soybean (*Glycine max* L.) is often credited with augmenting soil nitrogen (N) pools by engaging in biological N fixation (BNF) (Jani et al., 2020). On average, BNF ranges between 40 to 80% of total N uptake, with the remainder obtained from the soil (Santachiara et al., 2017). Cropping sequences involving the rotation of a nonlegume with soybean are widely cultivated in the United States of America (USA). Extension services in soybean growing regions often recommend that growers should reduce N fertilization to nonlegumes planted after soybean by 20-50 lbs N acre^{-1} (Reitsma et al., 2008; University of Georgia, 2008).

We define N credits as the N fertilizer replacement value from soybean to a subsequent nonlegume crop (Bundy et al., 1993; Gentry et al., 2001). While most research has been focused on the economic and global food security implications of harvested N, very little research has been done on the financial and sustainability value of non-harvested N within soybean residue that remains in the field. Improved management of soybean residue may be considered an environmentally smart agricultural practice since N is mineralized and made available to the next crop, which is expected to also improve soil organic matter, soil structure, and water infiltration. This overlooked environmental benefit of soybean production can save farmers money by reducing N fertilizer application rates to subsequent crops. Our research highlights previously overlooked environmental services provided by soybean in a rotation, which will inform the National Sustainability Soybean Initiative.

1.1 Project justification and rationale

There has never been a nationally coordinated project to definitively address the amount of N made available to subsequent crops. Currently, N credit recommendations from soybean consist of a hodgepodge of disparate values, even among contiguous states (Figure 1). A coordinated, multi-regional effort to quantify N credits from soybean is needed to quantify the amount of fertilizer N savings and provide scientifically verified data for soybean sustainability initiatives.

Economically, it is important to accurately quantify N credits from soybean given high N fertilizer prices because producers may be able to reduce the amount of N applied to subsequent nonlegume crops. For example, if the N rate to a subsequent nonlegume could be reduced by 20 lbs N/ac while maintaining yield, at current prices ($475/ton urea), a farmer would save $10.33/ac. However, we expect that this amount should change based on environment and the amount of residue remaining in the field. Current N credit recommendations must be revised, especially considering new soybean varieties, management practices, record yields, and weather conditions. This project is expected to provide a robust framework to quantify N contributions from soybean residue using modern cultivars and management practices representative of soybean farmers across the USA.

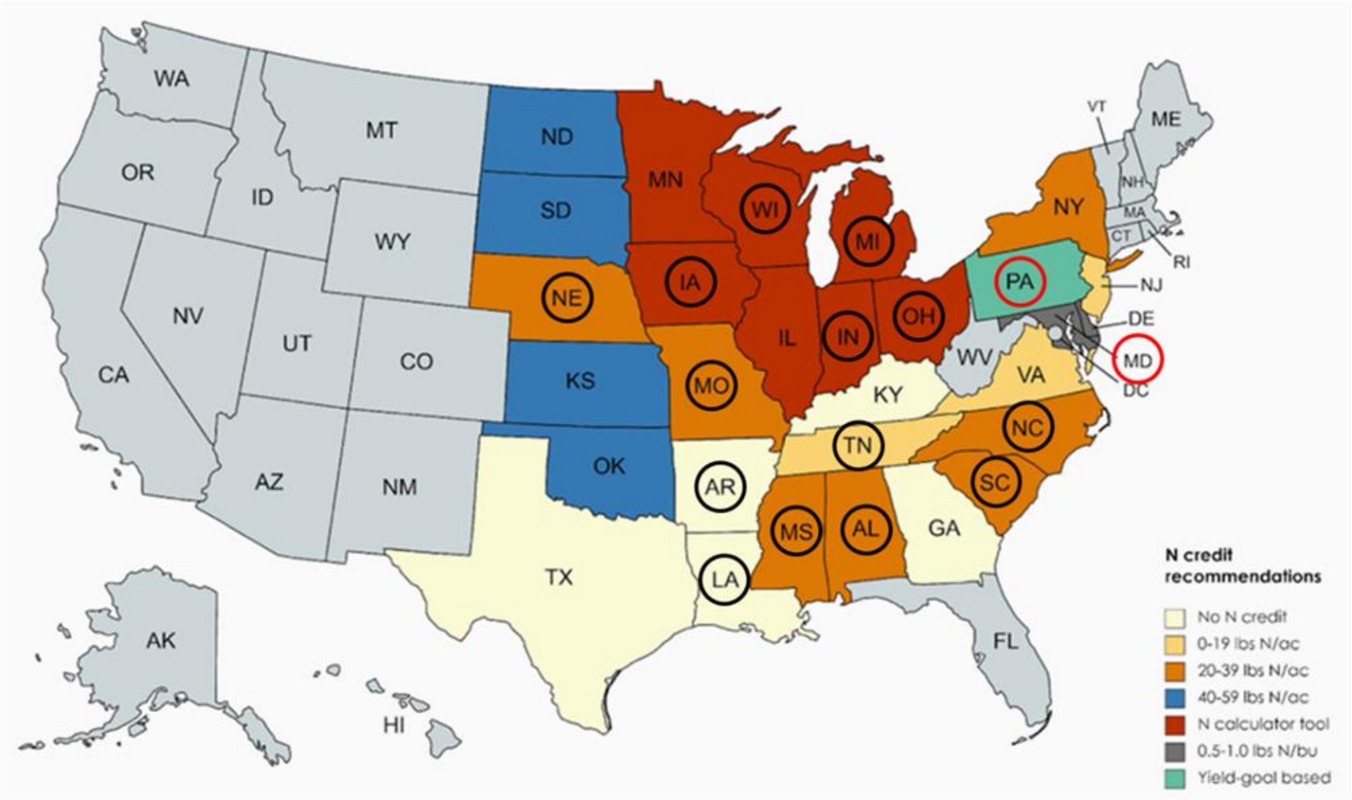


Figure 1: Soybean N credit Extension recommendations across the US. States participating in field trials are shown with black circles. Collaborating states are shown with red circles.

1.2 Goals & Objectives

The goal of this project is to quantify soybean N credits across the US. The objectives of this research are to:

1. Quantify total C and N of soybean residue after harvest, across a wide range of weather, soil, management practices, and yield levels.

2. Determine total soybean N credits to the following nonlegume crop.

4. Identify weather, soil, and crop management variables that could be used to predict soybean N credits across the US soybean regions.

5. Disseminate results to soybean farmers and other stakeholders through the United Soybean Board's Science for Success initiative.

1.3 Project Deliverables

1. Quantification of soybean residue C and N after harvest from 14 states across the USA.

2. Create an N response curve of nonlegume crop response to cropping history to quantify soybean N credits.

3. Produce at least 1 Fact Sheet, 1 webinar, and 5 videos by project completion.

4. Train at least one PhD student and 10 undergraduate students by project completion.

1.4 Benefits to soybean farmers

This project has the potential to save soybean producers money by applying soybean N credits to subsequent crops. For example, if the N rate to a subsequent nonlegume could be reduced by 20 lbs N acre^{-1} while maintaining yield, at current prices, a farmer would save \$13.60 acre^{-1}. Current N credit recommendations need to be revised, especially in consideration of new soybean varieties, management practices, record yields, and weather conditions. The N credits project is expected to provide a robust framework to quantify N contributions from soybean residue using modern cultivars and management practices representative of soybean farmers across the USA.

2.0 Methods

2.1 Study sites

A fourteen site-year study was conducted across some of the major soybean-producing states in the US (MS, OH, SC, WI, NC, IA, MO, MI, IN, AL, NE, AR, TN, and LA) as shown in Figure **1**. An additional two sites (MD, PA) were selected as collaborators on the project. Sites were selected based on participation in the United Soybean Board's Science for Success program, availability of funding, and capacity to execute this relatively complicated experimental design.

2.2 Experimental design

The experimental design was a split-plot randomized complete block design with four replications. The main plots consisted of history treatments (corn, soybean, and fallow). Fallow plots were maintained weed-free throughout the first year of the rotation. Subplots consist of N rate (0, 80, 160, 210, 260, 310 lbs N ac^{-1}) to a subsequent corn crop. A maximum rate of 310 lbs N ac^{-1} was selected to obtain adequate resolution near the agronomic optimum N rate (AONR). The experimental units are 4 rows wide by at least 35 feet long, respectively.

2.3 Time zero soil samples

Time-zero soil samples were taken from multiple points within each field to account for variability. The samples were collected at a depth of 0-6 inches and the collected soil samples were bulked to obtain a homogeneous sample. Collected samples were immediately stored in cool, dry conditions to preserve their integrity. Each sample was labeled with detailed information, including the field location, date of collection, and soil depth. A subsample was sent to the laboratory for physico-chemical analysis.

2.4 Data collection

Stand counts were measured after emergence. Residue biomass was collected from the main plot history treatments by harvesting plants within two 1-meter rows (non-harvest rows). Samples were taken from representative areas per plot and dried to a constant weight at 60°C. Soybean and corn were combine harvested from the middle two rows of the plots, and yield were determined on 13% and 15.5% moisture content respectively.

2.5 Data analyses

Soil samples were analyzed for texture, pH, cation exchange capacity, soil organic matter, nitrate-N, and ammonium-N using standard laboratory procedures. Soybean and corn residue biomass were ground to pass a 1 mm sieve and then ball milled using the Mixer Mill. Samples were analyzed for C, N, and nitrate-N concentration based on standard laboratory procedures. Residual N concentrations were determined by multiplying the percent N of biomass by biomass dry weight. The Harvest index was determined by dividing the grain yield by biomass yield.

2.6 Statistical analyses

Data were analyzed using descriptive statistics. Yield data were presented using a bar plot. Principal component analyses were performed to identify the relationship among traits using the FactoMineR package (Sebastien et al., 2008) and Pearson’s correlation was used to show the relationship between the traits of soybean. All analyses were conducted using R version 4.4.2 (R Core Team, 2024).

3.0 Results

3.1 Time zero soil properties at the study sites

Soil properties across the research locations in 2024 are shown in Table 1. A wide variation in soil textural classes, pH, CEC, nitrate-N, and ammonium-N among research sites will provide a range of environments to test our hypotheses. We expect that clay soils, with higher CECs and water-holding capacity, may retain more N from soybean residue than light-textured soils, which do not hold nutrients and are prone to nutrient leaching. The variability in soil organic matter (0.7 to 3.2%) was representative of farms in soybean growing areas (Table 1).

Table 1: Time 0 soil properties at 0-6 inch depth at the study sites in 2024

State	Textural class	pH(w)	pH(b)	CEC (Meq/100g soil)	SOM (%)	NO_3-N (ppm)	NH_4-N (ppm)
Alabama	Loam	6.3	7.1	10.4	1.9	6.8	3.1
Arkansas	Sandy loam	5.9	7.1	6.6	1.0	17.3	6.3
Iowa	Sandy clay loam	5.4	6.4	21.2	3.0	11.6	3.7
Louisiana	Silty clay loam	7.5	7.4	33.1	1.7	6.5	4.3
Michigan	Loam	6.5	7.1	9.1	1.4	14.5	5.4
Missouri	Sandy loam	6.9	7.1	15.4	2.0	15.6	5.7
Mississippi	Clay	6.1	6.4	28.4	3.2	3.0	7.3
Nebraska	Sandy loam	7.7	7.5	18.6	1.4	17.4	6.1
North Carolina	Loamy sand	6.0	7.2	4.3	0.7	7.3	3.6
Ohio	Clay	6.6	7.0	22.2	2.4	11.6	5.9
Purdue	Loam	6.1	7.3	8.5	1.3	19.2	7.1
South Carolina	Loamy sand	6.1	7.1	5.7	1.0	13.8	4.0
Tennessee	Silt loam	6.1	7.1	11.6	1.7	11.3	4.9
Wisconsin	Clay loam	6.2	7.0	15.5	2.4	20.8	6.2
Min	-	5.4	6.4	4.3	0.7	3.0	3.1
Max	-	7.7	7.5	33.1	3.2	20.8	7.3
Mean	-	6.4	7.1	15.0	1.8	12.6	5.3
Std. deviation	-	0.6	0.3	8.7	0.8	5.3	1.3

pH(w) = Soil pH in water (1:1); pH(b) = soil pH in buffer solution; CEC = cation exchange capacity; SOM = soil organic matter; NO_3-N = nitrate-N; NH_4-N = ammonium-N.

3.2 Residue biomass, and residue nutrient content

Soybean residue biomass ranged from 2,813 to 11,092 lbs acre^{-1} with a mean value of 6,492 lbs acre^{-1} (Table 2). We expect more biomass to lead to increased N credits across soybean-growing regions. The average soybean residue biomass carbon content across sites was 41.7 (%). When combined with residue biomass data, this resulted in carbon (C) application rates from 22.8 to 76.5 lbs C acre^{-1} (Table 2). Residue N content from soybean ranged from 0.6 to 2.0% with a mean value of 1.1%. Interestingly, soybean residue C:N ratios ranged from 22.8 to 76.5 with a mean value of 45.0 across the study sites, indicating that N is likely going to be immobilized before it is subsequently mineralized. Soybean residual N ranged from 30.6 to 155.4 lbs N acre^{-1}. This provides an upper limit on how much N can be transferred from soybean to subsequent nonlegume crops through residue decomposition. Soybean harvest index ranges were quite variable, from 27.8 to 53.3%. There was a positive correlation between residue biomass and residual N ($P \leq 0.01$) as shown in Figure **6**. There was a negative correlation between C:N and residue N, and harvest index and residue N ($P \leq 0.001$) while other traits follow a similar trend as shown in Figure **6**.

Principal component analyses (PCA) were conducted on all response variables. The first two principal components with an eigenvalue greater than one accounted for most of the variability in the dataset (67.69%), shown in Figure 4. Residue biomass, residue N, residual N, and yield correlated positively to PC1, while harvest index, C:N, and residue C correlated negatively to PC1. A similar pattern in the relationship was found among traits with PC2 (Table **4** and Figure 4).

There was wide variability in corn residue biomass, residue carbon, residue C:N, residual N, and harvest index, but the variability in residual nitrogen was low (Table 3). The high C:N ratio indicates that when the corn residue is returned to the soil, it should lead to N immobilization. This will help to distinguish between N immobilization from N mineralization from corn vs. soybean. Residue biomass, residual N, C:N, and yield correlated positively to PC1, while residue carbon, residue N, and harvest index correlated negatively to PC1 (Figure **5**). A similar pattern in the relationship was observed among traits with PC2 (Table **5** and Figure **5**).

residue N, residue carbon, and harvest index correlate negatively to PC2 (Figure 5).

3.3 Yield

Soybean yield across study sites ranged from 40.8 to 86.3 bu acre^{-1} with a mean value of 62.7 bu acre^{-1} (Table 2 and Figure 2). Corn yield across the study sites ranged from 30.8 to 292.3 bu acre^{-1} with a mean value of 156.0 bu acre^{-1} (Table 3 and Figure 3). Our yield data were comparable to the national average, such that we may be confident that results from this project will be comparable to real-world conditions. Variability across sites will capture the broad range of conditions under which soybean N is transferred to subsequent crops.

Table 2: Soybean yield and post-harvest residue quality across 2024 research sites.

State	Yield (bu $acre^{-1}$)	Res. biomass (lbs $acre^{-1}$)	Residue C (%)	Residue N (%)	C:N	Residual N (lbs $acre^{-1}$)	Harvest index (%)
Alabama	71.2	11,092	39.5	1.2	32.3	137.1	27.8
Arkansas	55.9	7,875	43.3	2.0	22.8	155.4	29.9
Iowa	68.7	6,414	42.2	0.6	76.5	35.6	39.1
Louisiana	40.8	3,221	40.2	1.1	36.2	36.9	43.2
Michigan	73.7	4,581	43.4	0.7	68.8	30.6	49.1
Missouri	80.7	7,937	43.8	0.9	50.7	71.2	37.9
Mississippi	49.3	6,164	45.1	1.1	44.2	64.7	32.4
Nebraska	63.6	8,277	39.1	0.9	44.7	72.9	31.6
North Carolina	86.3	4,537	42.2	1.2	37.2	55.5	53.3
Ohio	66.5	7,538	40.3	1.0	43.1	72.1	34.6
Purdue	73.3	8,172	39.8	0.9	42.4	76.9	35.0
South Carolina	50.3	6,969	43.9	1.4	34.4	105.8	30.2
Tennessee	51.4	2,813	42.3	1.2	34.8	35.9	52.3
Wisconsin	45.8	5,303	38.3	0.6	61.7	32.8	34.1
Min	40.8	2,813	38.3	0.6	22.8	30.6	27.8
Max	86.3	11,092	45.1	2.0	76.5	155.4	53.3
Mean	62.7	6,492	41.7	1.1	45.0	70.2	37.9
Std. deviation	13.9	2,249	2.1	0.4	14.9	39.0	8.5

Res. biomass = residue biomass yield; Residue C = residue carbon, Residue N = residue nitrogen

Table 3: Corn yield and post-harvest residue quality across 2024 research sites.

State	Yield (bu acre^{-1})	Res. biomass (lbs acre^{-1})	Residue C (%)	Residue N (%)	C:N	Residual N (lbs acre^{-1})	Harvest index (%)
Alabama	130.1	52,312	41.8	0.9	47.8	47.3	12.2
Arkansas	192.3	24,737	43.5	0.6	70.6	156.5	30.3
Iowa	105.0	10,314	40.8	0.5	77.9	53.9	36.3
Louisiana	30.8	2,944	41.7	0.9	49.2	26.6	36.9
Michigan	266.9	22,098	43.6	0.7	74.9	150.0	40.3
Missouri	145.6	12,853	41.5	0.9	45.5	120.2	38.8
Mississippi	78.1	9,449	37.2	0.9	42.5	81.5	31.6
Nebraska	218.6	18,576	41.0	1.2	51.7	218.2	39.7
North Carolina	92.9	8,293	42.7	0.6	80.2	48.1	38.5
Ohio	105.8	15,513	42.7	0.6	71.8	93.3	27.6
Purdue	241.9	16,806	43.8	0.8	60.3	126.4	44.6
South Carolina	292.3	22,458	42.9	0.8	54.0	182.0	42.2
Tennessee	123.2	4,189	44.4	0.9	50.4	38.4	62.2
Wisconsin	159.9	21,906	38.0	0.4	93.6	96.7	29.0
Min	30.8	2,944	37.2	0.4	42.5	26.6	11.2
Max	292.3	24,737	44.4	1.2	93.6	218.2	62.2
Mean	150.0	13,955	41.8	0.8	62.2	102.8	36.4
Std. deviation	76.6	7,388	2.1	0.2	15.8	58.5	11.0

Res. biomass = residue biomass yield; Residue C = residue carbon, Residue N = residue nitrogen

Table 4: PCA values and eigenvalues for soybean across sites in 2024

	PC1	PC2
Eigenvalue	3.05	1.69
Percentage of variance	43.52	24.17
Cumulative percentage of variance	43.52	67.69
Factor loadings of various traits		
Yield (bu/acre)	0.07	-0.12
Residue biomass (lbs/acre)	0.76	-0.58
Residue carbon (%)	-0.02	0.51
Residue N (%)	0.75	0.64
C:N	-0.76	-0.57
Residual N (lbs/acre)	0.94	-0.08
Harvest index (%)	-0.66	0.58

PC1 = principal component 1, PC2 = principal component 2

Table 5: PCA values and eigenvalues for corn across sites in 2024

	PC1	PC2
Eigenvalue	3.02	2.04
Percentage of variance	43.32	29.12
Cumulative percentage of variance	43.31	72.44
Factor loadings of various traits		
Yield (bu/acre)	0.52	0.79
Residue biomass (lbs/acre)	0.86	0.39
Residue carbon (%)	-0.28	0.61
Residue N (%)	-0.76	0.48
C:N	0.72	-0.38
Residual N (lbs/acre)	0.61	0.57
Harvest index (%)	-0.69	0.43

PC1 = principal component 1, PC2 = principal component 2

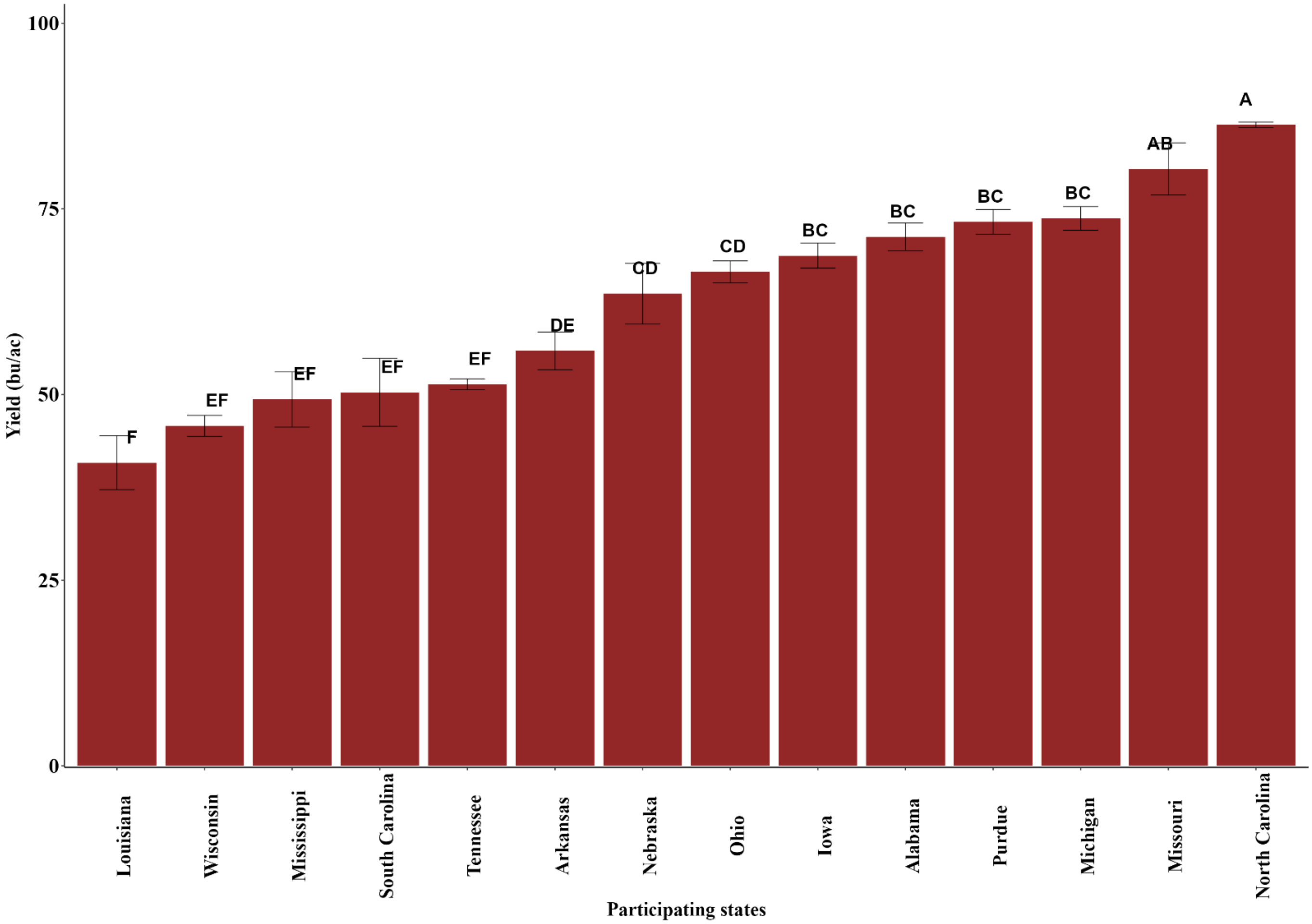


Figure 2: 2024 soybean yield. Error bars represent standard error of means. Means having the same letters denote no difference in yield based on Tukey's honestly significant difference (α=0.05).

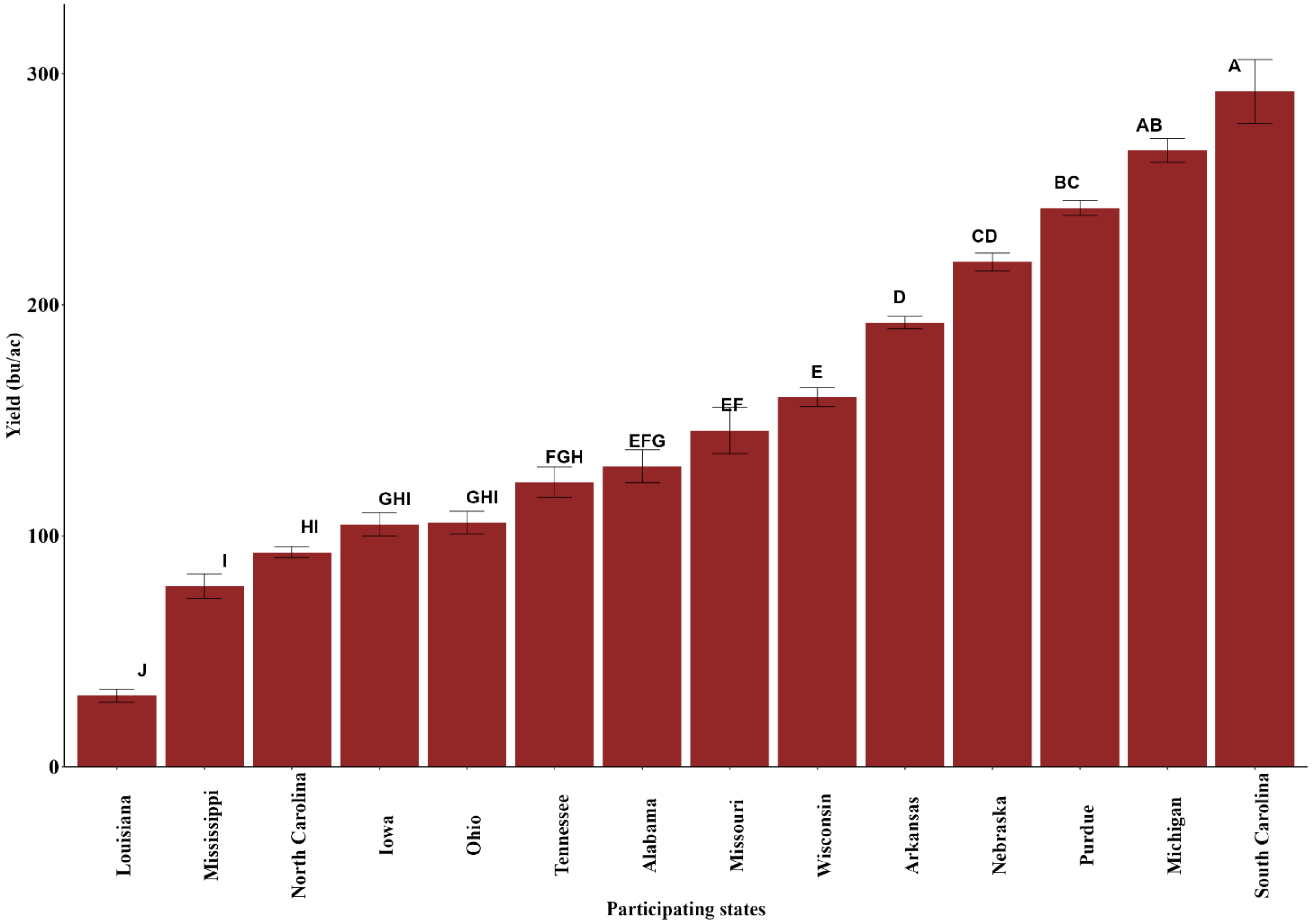


Figure 3: 2024 corn yield. Error bars represent standard error of means. Means having the same letters denote no difference in yield based on Tukey's honestly significant difference (α=0.05).

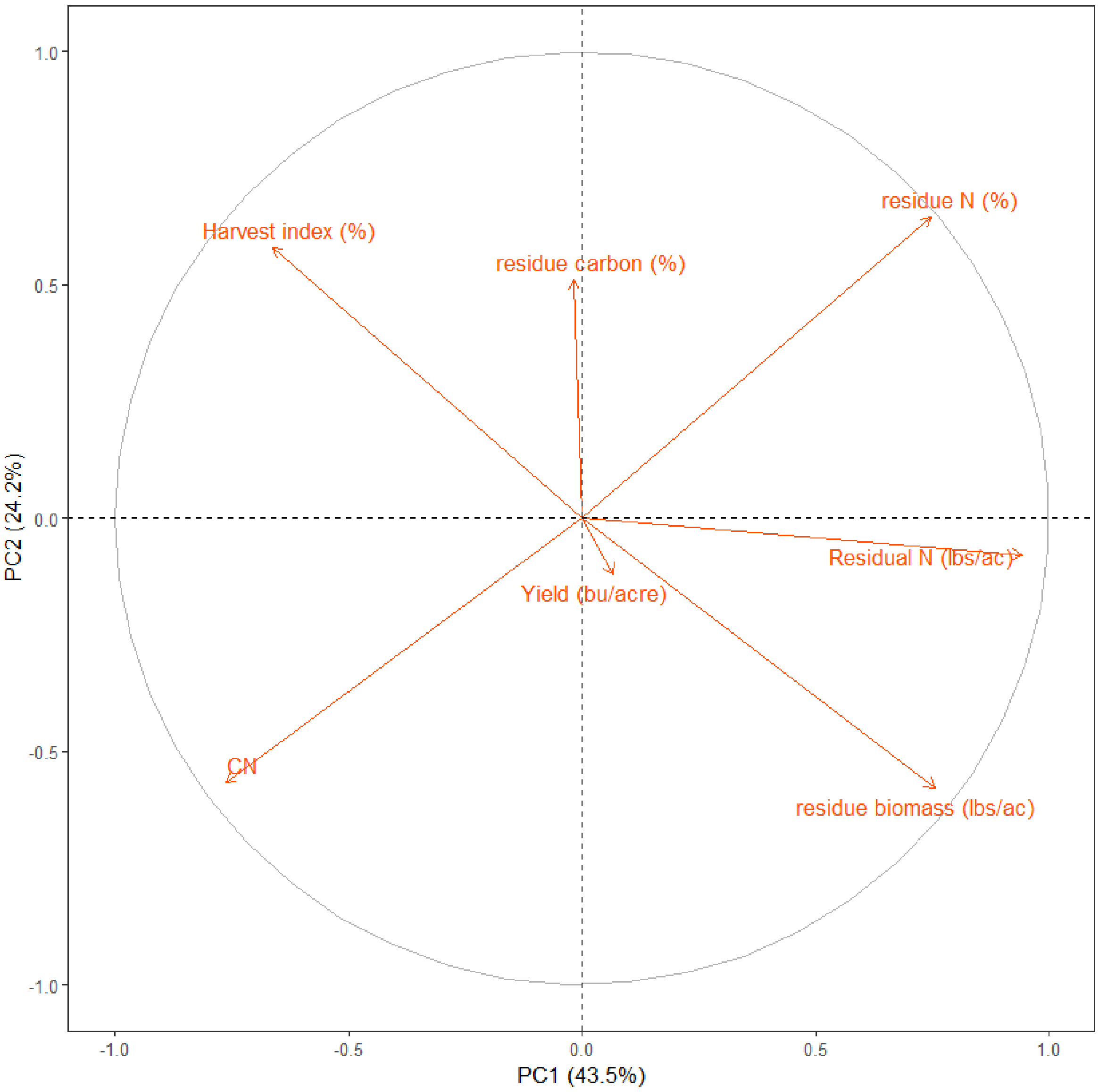


Figure 4: PCA biplot showing the relationship among soybean traits across study sites in 2024.

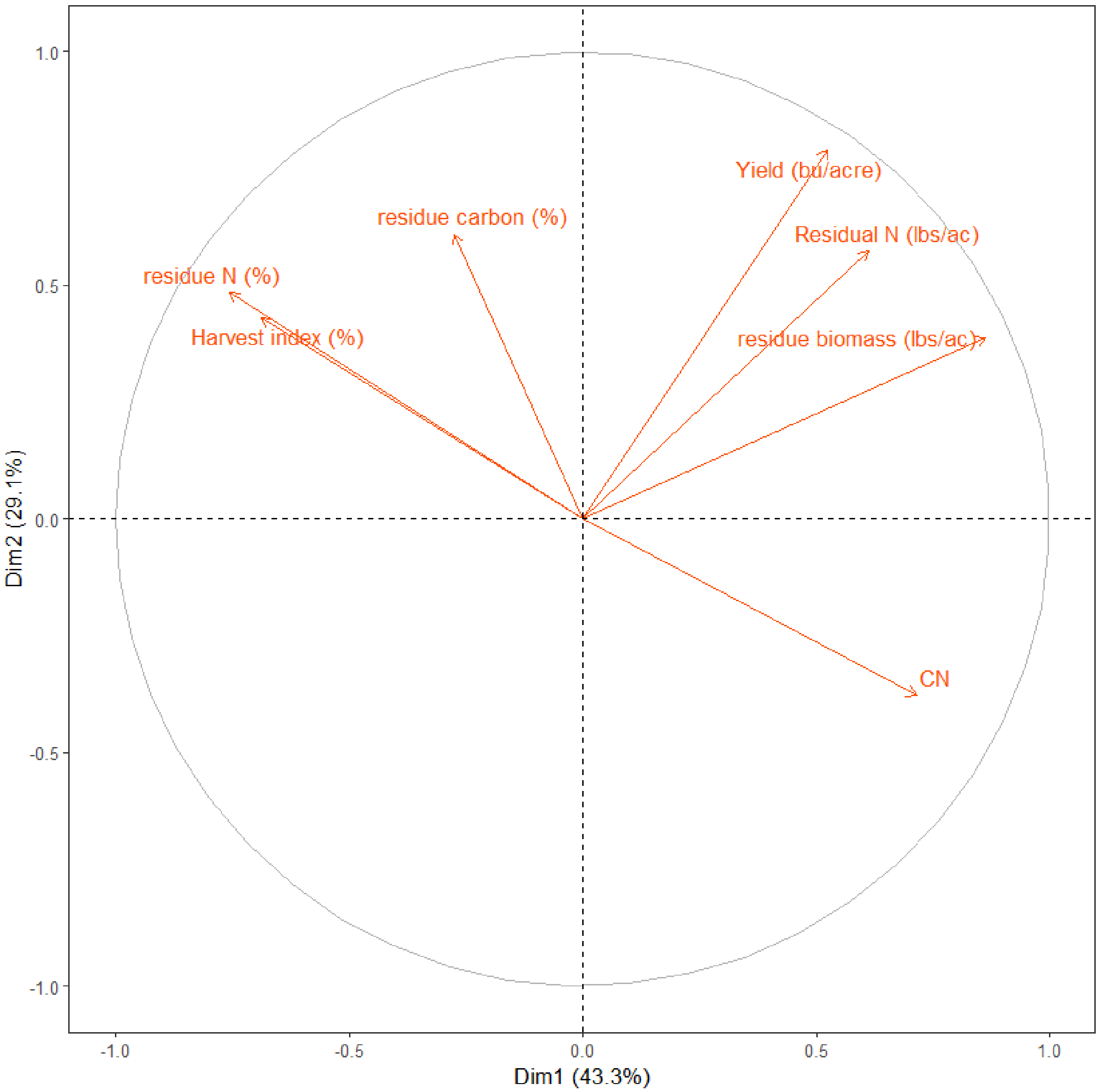
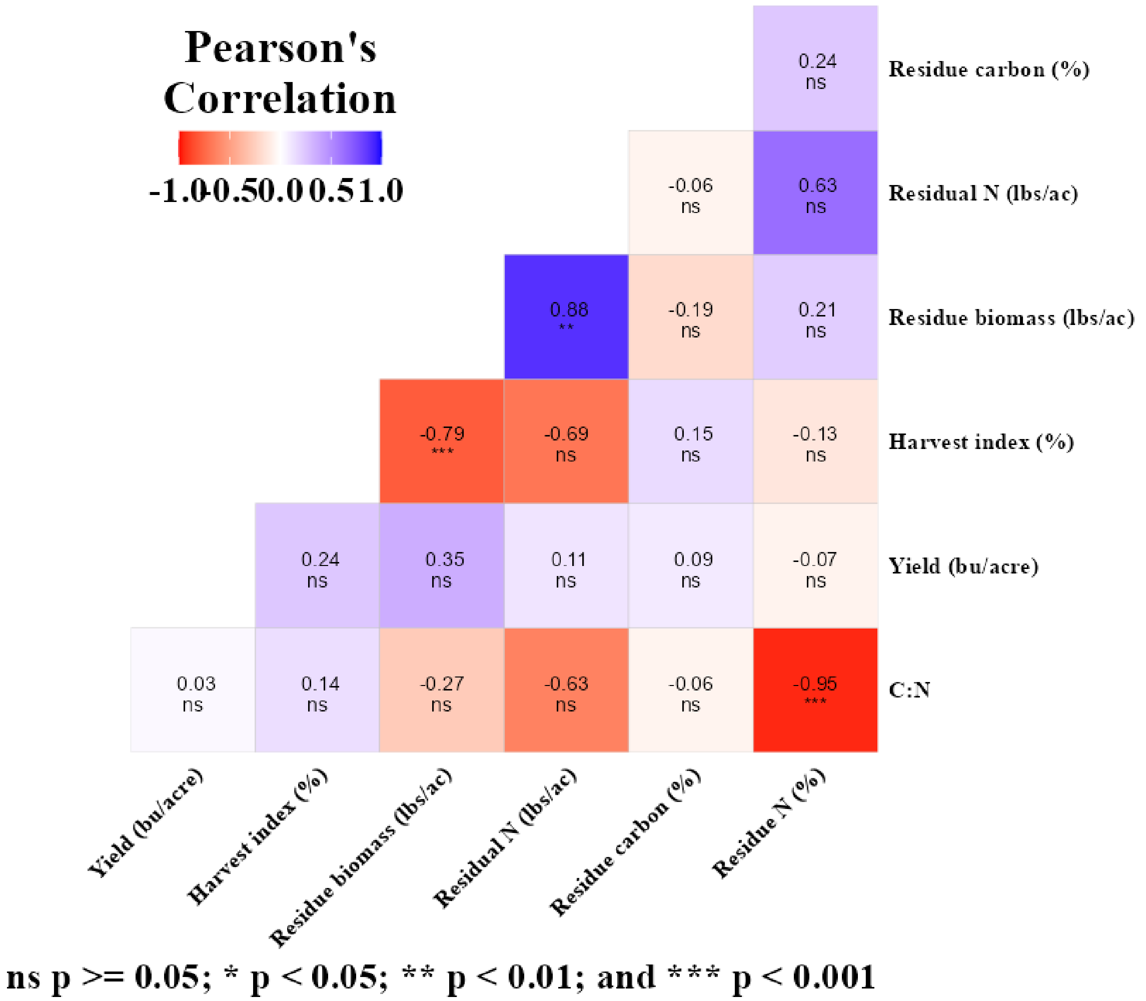


Figure 5: PCA biplot showing the relationship among corn traits across study sites in 2024.



	Yield (bu/acre)	Harvest index (%)	Residue biomass (lbs/ac)	Residual N (lbs/ac)	Residue carbon (%)	Residue N (%)
Residue carbon (%)						0.24 ns
Residual N (lbs/ac)					-0.06 ns	0.63 ns
Residue biomass (lbs/ac)				0.88 **	-0.19 ns	0.21 ns
Harvest index (%)			-0.79 ***	-0.69 ns	0.15 ns	-0.13 ns
Yield (bu/acre)		0.24 ns	0.35 ns	0.11 ns	0.09 ns	-0.07 ns
C:N	0.03 ns	0.14 ns	-0.27 ns	-0.63 ns	-0.06 ns	-0.95 ***

Figure 6: Pearson correlation matrix showing the relationship among the various soybean traits. The color gradient represents correlation strength, with red indicating negative correlations and blue indicating positive correlations. Statistical significance is denoted as ns (not significant, $p \geq 0.05$), * ($p < 0.05$), ** ($p < 0.01$), and *** ($p < 0.001$).

Conclusion:

There were wide variations in soil nitrate, ammonium, soil organic carbon, cation exchange capacity, pH, yield, post-harvest biomass, and residual nitrogen. Yield data were comparable to the national average. We determined upper limits on soybean residue N contribution to be in the range between 30.6 to 155.4 lbs N acre^{-1}, depending on site. The second year of the rotation will be conducted in 2025.

Showcasing the Project and Presenting Results

- In November 2024, my graduate student made an oral presentation at the ASA-CSSA-SSSA International Annual Meeting in San Antonio, Texas, where he indicated the benefit, the project would have on USA farmers.

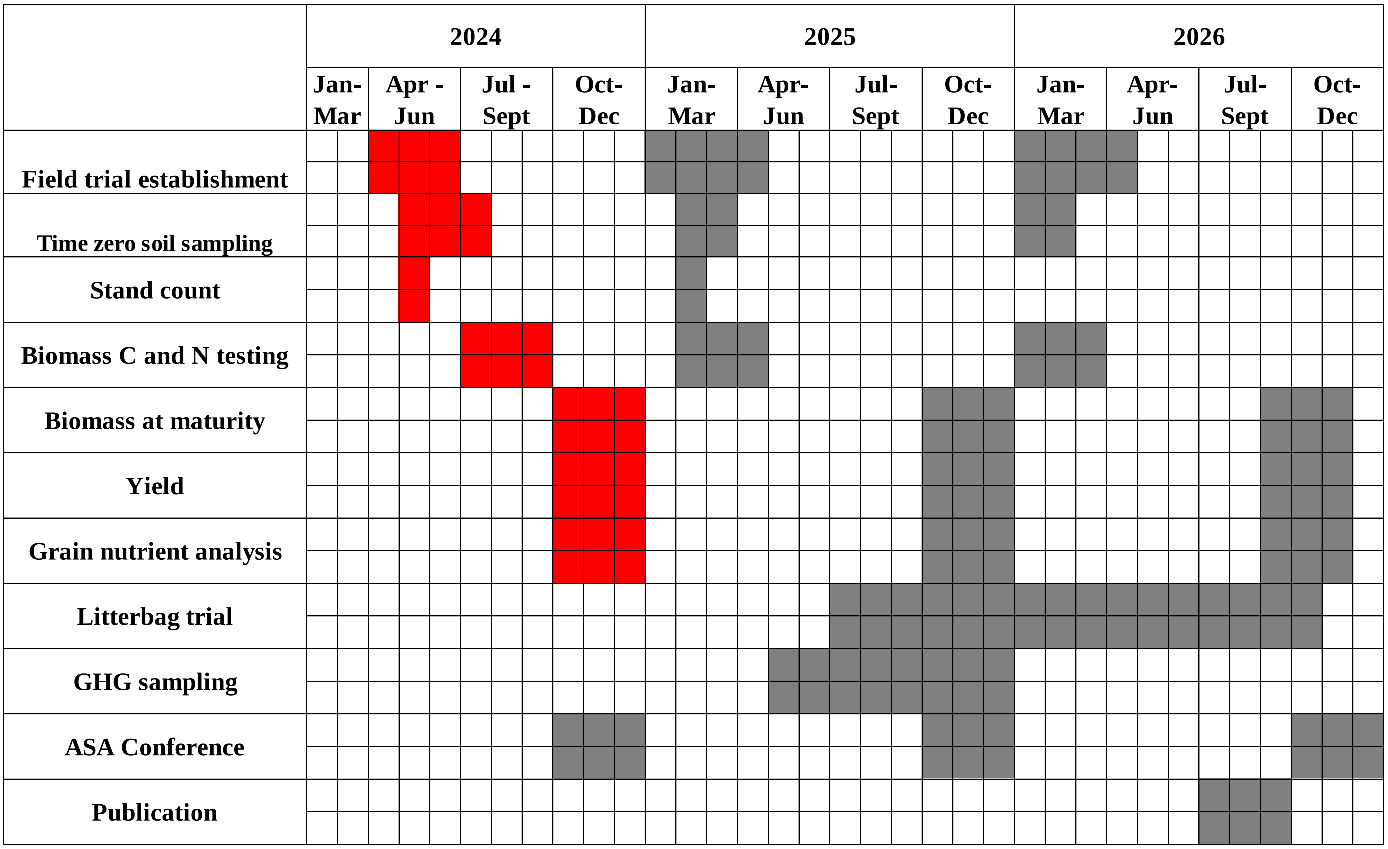
Oyedele, O. Mulvaney, M. J., Olomitutu, O. E., Wallace, J., Shavers, G. M., & Hilyer, T. Nitrogen Credit after Soybean: A Review. ASA-CSSA-SSSA International Annual Meeting, San Antonio, TX, Nov. 10 - Nov. 13, 2024. https://scisoc.confex.com/scisoc/2024am/meetingapp.cgi/Paper/158389

Mulvaney, M. J., Oyedele, O. (2024). Quantifying Nitrogen Credit from Soybean. Stakeholders meetings of Multi-Regional Soybean Checkoff. St. Charles, MO, December 9th, 2024.

Future work

- We plan to address these questions further by conducting a litterbag trial in five states
- We plan to quantify the greenhouse gas emissions from the main plot history in 2025
- We plan to run the trial for the second year.

Research schedule and timeline



	2024											**2025**												**2026**											
	Jan-Mar		**Apr - Jun**			**Jul - Sept**			**Oct-Dec**			**Jan-Mar**			**Apr-Jun**			**Jul-Sept**			**Oct-Dec**			**Jan-Mar**			**Apr-Jun**			**Jul-Sept**			**Oct-Dec**		
Field trial establishment			🟥	🟥	🟥							▨	▨	▨	▨									▨	▨	▨	▨								
Time zero soil sampling				🟥	🟥	🟥							▨	▨										▨	▨										
Stand count				🟥									▨																						
Biomass C and N testing						🟥	🟥	🟥					▨	▨	▨									▨	▨	▨									
Biomass at maturity									🟥	🟥	🟥										▨	▨	▨									▨	▨	▨	
Yield									🟥	🟥	🟥										▨	▨	▨									▨	▨	▨	
Grain nutrient analysis									🟥	🟥	🟥										▨	▨	▨									▨	▨	▨	
Litterbag trial																		▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	
GHG sampling																▨	▨	▨	▨	▨	▨	▨	▨												
ASA Conference									▨	▨	▨										▨	▨	▨										▨	▨	▨
Publication																															▨	▨	▨			

🟥 Completed ▨ Future work

Reference

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