DETERMINING THE ECONOMIC OPTIMUM NITROGEN RATE FOR DIFFERENT COVER CROP SYSTEMS USING ON-FARM PRECISION EXPERIMENTATION

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ABSTRACT

Successful integration of cover crops into corn-soybean production systems requires adjusting interconnected management factors. Nitrogen (N) is a critical input in corn production, and because cover crops influence nitrogen dynamics, it is essential to evaluate both as an integrated system. To address this, field trials in two locations near Moultrie County, Illinois, were established in the fall of 2023 and 2024 as part of a four-year (2024–2027) project aimed at improving understanding of nitrogen and cover crop interactions in corn-soybean rotations. Corn and soybean are grown each year. For corn sites, cover crops were planted after soybean harvest using an air drill with dual bins to variable rate seed and chemically terminated two weeks before planting corn. Strip-till with a shank (6-in depth) was used in the fall and a strip freshener in spring prior to corn and soybean planting. Four cover crop systems were used prior to corn: no cover crop, 50 lb austrian pea ac^{-1}, 40 lb winter barley ac^{-1}, 25 lb pea ac^{-1} + 20 lb barley ac^{-1}; with five nitrogen rates applied to each (56, 108, 158, 210 and 266 lb N ac^{-1}). Prior to soybean, cover crops were planted using only two systems: no cover crop or 40 lb barley ac^{-1}. Soil samples for corn were collected at the V6 growth stage from two depths (0-12 and 12-24 inches), and plant tissue samples were taken at both V6 and R6 (grain and stover) to determine total nutrient uptake. Corn and soybean yield data were post-processed in QGIS. As-applied N data were also evaluated, and plots that did not achieve the target nitrogen rate were eliminated. Quadratic, linear-plateau, and quadratic-plateau models were used to evaluate the relationship between N rate and corn yield using the *nlraa* package in R. Best fit models were selected based on AIC and R^2. Soybean yield did not differ significantly ($p \leq 0.1$) between the no cover crop and barley treatment (88.8 and 89.0 bu ac^{-1}, respectively), indicating that barley cover cropping did not affect soybean yield in 2025. Effects of N rate and cover crop on corn yield varied by year. In 2024, barley and pea+barley treatments consistently reduced yields across all N rates compared to no cover crop. In contrast, corn yield in 2025 only differed between the no cover crop and barley at the lowest N rate. The EONR for corn varied by site-year and cover crop treatment, ranging from 108 to 179 lb N ac^{-1} in 2024 and from 144 to 177 lb N ac^{-1} in 2025, with overall higher EONR values observed in 2025 compared to 2024. In 2024, barley increased EONR relative to all other treatments, indicating greater N fertilizer demand. In 2025, barley continued to increase EONR among the cover crop treatments, whereas the no cover crop treatment required the highest N rate. These contrasting responses highlight site-year dependence, which the full-scale project will address through multi-environment evaluations of integrated nitrogen and cover crop management across Illinois.

INTRODUCTION

Corn grown in the highly productive U.S. North Central region relies on commensurate nitrogen (N) supplied by fertilizer and soil organic N mineralization. As mineralized organic N is inherent, though at varying amounts, profitable fertilizer N management entails supplying what the corn crop and soil system requires to supplement already available soil N. A portion of the N fertilizer input is recovered by plants in the year of application and remaining N can be stored in soil organic matter or lost (Canisares et al., 2021; Sebilo et al., 2013). Therefore, farmers wanting to change cropping system components that affect soil N supply or fertilizer N recoverability may shift potential corn yield and N loss outcomes. For example, interest or incentivization in cover crops and reduced tillage continues to grow for Illinois farmers.

Cover crops are primarily adopted with goals to reduce soil erosion and N loss by nitrate (NO_3-N) leaching. In aligning function with reliability, cereal rye (*Secale cereale* L.) is the most common cover crop used in corn-soybean rotations in the North Central region. Leguminous cover crops can fix atmospheric N into plant-available forms, and after termination, a portion of this N ideally becomes available to subsequent cash crops. For instance, winter annual legumes grown before corn have been shown to replace approximately 60 lb N ac^{-1} (Perrone et al., 2020). Despite various proposed and documented benefits, cover crops represent an additional component within the cropping system and therefore influence soil-to-plant water and nutrient relationships. Integrating cover crops may require adjustments to crop and fertilizer management and timing, which can increase input requirements, management complexity, and, ultimately, production costs.

To effectively quantify the influence of cover crops on N dynamics within soybean-corn systems, a comprehensive and systematic evaluation framework is required. Quantifying crop response to N begins with the implementation of N rate experiments, in which multiple fertilizer levels are applied to characterize yield responses to N. On-farm precision experimentation (OFPE) provides a framework for conducting these trials at high spatial resolution, enabling the assessment of N responses across production fields while accounting for spatial variability. Complementary measurements of soil and plant N help to understand pathways of N cycling within the system, including fertilizer recovery, soil N contributions, and potential N losses.

Evidence from an Eastern Nebraska multi-year trial showed no consistent change in corn yield and N demand after cereal rye, hairy vetch, a rye vetch mix, or no cover crop across three seasons (de Almeida et al., 2025). In the Upper US Midwest region, corn inter-seeded red clover was shown not to provide a significant N fertilizer equivalence, despite improved corn yields in one of four site years (Francis et al., 2025). In Indiana, corn yield responses to N applications were found to vary with rye cover crop, with late-vegetative N applications decreasing yield in all site-years following rye cover crop, while early N applications were optimal (Seavers & Quinn, 2025). Another study with rye in Kentucky showed that lower N requirements are needed when application is split and corn is followed by the cover crop (Quinn et al., 2023). In South Dakota, another study that examined the impact of different cover crop compositions on corn N requirements and yield found that while cover crops can reduce the economic optimum N rate (EONR), their effect on yield varies, particularly influenced by precipitation levels (Bielenberg et al., 2023).

Although cover crops are widely tested as an influence on N supply, retention, and environmental losses in corn systems, there is a lack of on-farm and data-intensive analysis that quantifies how different cover crop species modify corn N requirements, particularly regarding the EONR, as well as on N management recommendations, which are shown to be variable and weather dependent.

Given these considerations, we want to understand what the effects of the cover crop management strategies on soil and plant N status, optimum N fertilizer rate, and economic return to N under different cover crop strategies are. To address this, we the following general and specific objectives: i) to evaluate the effects of cover crop species on soybean and corn yield using OFPE; ii) Quantify how different cover crop systems influence corn EONR; iii) Assess the economic performance of cover crop systems compared to no cover crop; iv) Investigate soil N availability and plant N uptake across cover crop treatments.

MATERIALS AND METHODS

On-farm soybean and corn experiments

Two on-farm experiments were conducted in Central Illinois, where soybean and corn are grown each year. Field 1 was corn in 2024 and soybean in 2025, while field 2 was corn in 2025. For corn sites, cover crops were planted after soybean harvest using an air drill with dual bins to variable rate seed; and chemically terminated two weeks before planting corn. Strip-tillage with a shank set to a 6-in depth was used in the fall and a strip freshener in spring prior to corn and soybean planting. Prior to soybean, cover crops were planted using two systems: no cover crop or 40 lb barley ac^{-1}. Prior to corn, four cover crop systems were used: no cover crop, 50 lb austrian pea (*Pisum sativum*) ac^{-1}, 40 lb winter barley (*Hordeum vulgare* L.) ac^{-1}, 25 lb pea ac^{-1} + 20 lb barley ac^{-1}; with five total N rates applied to each: 56, 108, 158, 210 and 266 lb N ac^{-1}. Nitrogen fertilizer was applied at a base rate of 56 lb N ac^{-1} injected at planting as liquid urea ammonium nitrate (32-0-0, UAN); and UAN injected between the rows at corn growth stage V6 (sidedress) at rates of 0, 52, 102, 154, and 210 lb N ac^{-1}. Phosphorus and potassium were applied based on soil-test results and were managed to be nonlimiting.

Soil and plant analysis

Composite soil samples for corn were collected at growth stage V6 prior to sidedress N application at 0-12 and 12-24-in depths. and analyzed for nitrate and ammonium (Bundy and Meisinger, 1994). Whole corn plants were collected at V6 and analyzed for total mineral nutrients (Zarcinas et al., 1987) and total aboveground corn biomass (stover and grain separated) were collected at R6 and analyzed for total mineral nutrients to calculate nutrient uptake.

Yield data processing and statistical analysis

Yield monitor data for soybean and corn were acquired at the end of the season and post-processed in QGIS to remove errors. As-applied N data were also evaluated, and plots that did not achieve the target N rate were eliminated from the analysis. The experimental layout was a Latin square design (Bullock et al. 2019). For each site-year, the relationship between N rate and corn yield was evaluated using quadratic, linear-plateau, and quadratic-plateau models with the *nlraa* (Miguez, 2023) package in RStudio (R Core Team, 2024). Best fit models were selected based on the Akaike Information Criterion (AIC) and R^2. The EONR was calculated as the N rate that maximized economic return to N (RTN), with RTN defined as (corn yield × corn price) − (N rate × fertilizer price). The maximum return to N (MRTN) was calculated using [(YEONR – Y0N) × corn price] – (EONR × fertilizer price), where YOENR is the yield at EONR and Y0N is the *a* coefficient derived from the models. Profitable ranges were calculated to bracket the N rate that maximized return to N, where return to N is \$1 ac^{-1} less than the MRTN. Economic calculations used a 10:1 corn price to N fertilizer price ratio (\$5 bu^{-1} and \$0.50 lb N^{-1}).

Analysis of Variance (ANOVA) was conducted to evaluate the effect of soil N availability on cover crop systems, the corn biomass difference among cover crop systems, as well as the V6 and total uptake difference among cover crop systems. Treatment effects were considered significant at $p \leq 0.1$, and the Fisher's Least Significant Difference (LSD) was used to assess the difference between the means of the treatments.

RESULTS AND DISCUSSION

Grain yield and Economic Optimum N Rate for corn

Soybean yield did not differ significantly ($p \leq 0.1$) between the no cover crop and barley treatment (88.8 and 89.0 bu ac^{-1}, respectively). In corn, the effects of N rate and cover crop on yield varied by year. In 2024, barley and pea+barley cover crop systems consistently reduced yields across all N rates compared to no cover crop (Fig. 1). In contrast, corn yield in 2025 only differed between the no cover crop and barley at the lowest N rate. Site- and year-dependent yield response to N rate and cover crop systems has been well-documented in previous other North Central region research. In 2024, growing season precipitation was 41 in. with notably wet April (8.2 in.) and July (7.1 in.), while temperature abnormalities were few. In contrast, the 2025 growing season was considerably drier (24 in.), particularly in June (2 in.) and August (0.6 in.), with frequent temperature abnormalities higher than usual. Warmer and drier conditions observed in 2025 reflected the limited corn yield potential and restricted cover crop biomass development relative to the cooler, wetter 2024 growing season

Following the trend, EONR varied by year and cover crop treatment, ranging from 108 to 179 lb N ac^{-1} in 2024 with corresponding YEONR ranging from 250 bu ac^{-1} to 259 bu ac^{-1}. In 2025 EONR values ranged from 144 to 177 lb N ac^{-1} with YEONR between 229 and 233 bu ac^{-1}. Overall, higher EONR values were observed in 2025 compared to 2024 (Fig. 1). When compared to the regional benchmark EONR of 187 lb N ac^{-1} derived from the Corn Nitrogen Rate Calculator (based on a corn price of \$5 bu^{-1} and N fertilizer price of \$0.50 lb N^{-1}), both years exhibited lower N requirements than the regional N rate guidelines for central Illinois. In 2024, barley increased EONR relative to all other treatments, indicating greater N fertilizer demand. In 2025, barley continued to increase EONR among the cover crop treatments, whereas the no cover crop treatment required the highest N rate. Although the no cover crop accumulated more biomass at V6 than the cover crop treatments, this early advantage turned into higher N requirements and greater yield penalties relative to the cover crop treatments as dry conditions emerged during the growing season. The pea treatment continued to demand less N compared to barley in 2025, with the mix showing the lowest N demand in this year.

Overall, partial profits were greater for the no cover crop system in both years (Table 1). In 2024, partial profit differences between the pea and no cover crop treatments were \$60 ac^{-1} in 2024 and \$49 ac^{-1} in 2025, values comparable to typical conservation program payments that aim to offset cover crop adoption costs. It should be noted that the cover crop seed cost was held constant across 2024 and 2025 and was \$58 ac^{-1} for the pea system. Despite requiring less fertilizer N, the pea treatment resulted in the lowest profit in 2025 due to its higher seed cost. When considering the return to N, calculated as MRTN, values in this study ranged from \$64 to \$837 ac^{-1}, compared to the regional benchmark of \$473 ac^{-1} for Central Illinois (based on a corn price of \$5 bu^{-1} and fertilizer price of \$0.50 lb N^{-1}). In 2024, overall MRTN values were lower (\$64 to \$543 ac^{-1}), particularly under the no cover crop and pea systems (null MRTN and \$64 ac^{-1}), which exhibited weaker N responses. In 2025, MRTN values were higher (\$482 to \$837 ac^{-1}) with the barley and mix systems showing stronger economic responses to N (\$837 ac^{-1} and \$803 ac^{-1}, respectively.

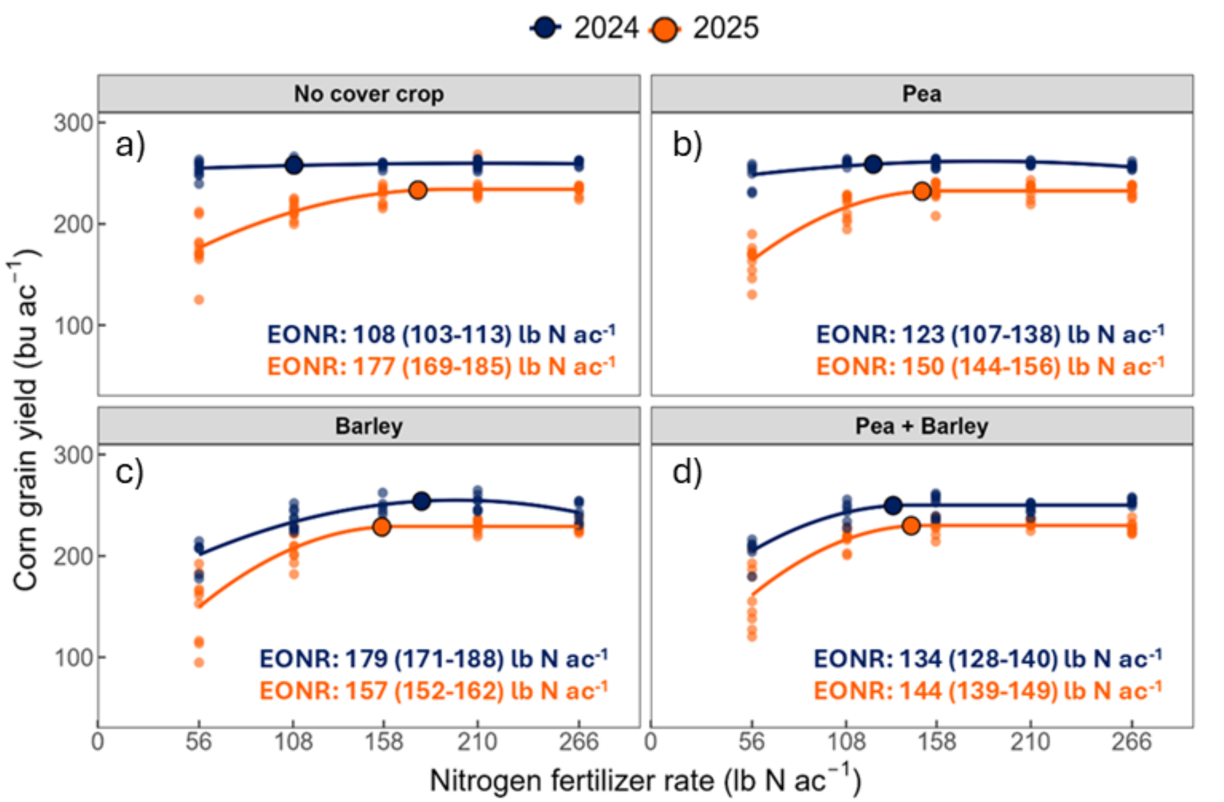

Figure 1. Relationship between N fertilizer rate and corn grain yield from four cover crop systems: a) No cover crop; b) Austrian pea 50 lb ac^{-1}; c) Winter barley 40 lb ac^{-1}, and d) Austrian pea 25 lb ac^{-1} + winter barley 20 lb ac^{-1} in 2024 and 2025. Orange and

blue big dots represent the EONR calculated using a 10:1 corn price to nitrogen fertilizer price ratio ($5 bu^{-1} and $0.50 lb N^{-1}) and respective profitable N rate range at $1 ac^{-1} below and above the MRTN. Continuous orange and blue lines are the models fitted.

Table 1. Optimum nitrogen rate, yield, return to N, and partial profit, for each cover crop system in 2024 and 2025.

	Cover crop rate					Cost[4]				
Year	Barley	Pea	Optimum N rate[1]	Prof. N range[2]	Yield[3]	Barley	Pea	Yield return	MRTN[5]	Partial profit[6]
	---------- lb a^{-1} ----------				bu a^{-1}	---------- $ ac^{-1} ----------				
24	0	0	108	103 - 113	258	0	0	1290	-	1236
24	0	50	123	107 - 138	259	0	58	1295	64	1176
24	40	0	179	171 - 188	254	15	0	1270	431	1165
24	20	25	134	128 - 140	250	8	29	1250	543	1146
25	0	0	177	169 - 185	233	0	0	1165	482	1077
25	0	50	150	144 - 156	232	0	58	1160	750	1028
25	40	0	157	152 - 162	229	15	0	1145	837	1051
25	20	25	144	139 - 149	230	8	29	1150	803	1041

[1] Optimum N using a 10:1 corn to N fertilizer price ratio ($5 bu^{-1} and $0.50 lb N^{-1})
[2] Profitable N rate range, which is $1 ac^{-1} below and above the MRTN
[3] Yield at the optimum N rate
[4] Prices paid for cover crop seed: $0.38 lb^{-1} winter barley and $1.15 lb^{-1} austrian pea
[5] Maximum Return to Nitrogen, no calculations performed when EONR was the same as other N rates
[6] Partial profit = (corn yield x $5) - [(N rate x $0.50) + (cover crop seed cost)]

Soil nitrogen availability and plant nitrogen uptake for corn in 2025

Pre-sidedress soil inorganic N values indicated differences among cover crop systems (Fig. 2). The no cover crop treatment had the greatest soil N content, followed by pea, whereas the barley and pea+barley systems showed significantly lower values compared to the no cover crop treatment ($p \leq 0.1$). These results show that grass cover crop-based systems reduced potentially available soil N early in the season relative to no cover crop. Soil inorganic N at V6 was significantly higher for no cover and pea treatment, however pea treatment did not differ from barley and the mix. These patterns were carried through to early-season corn growth. Corn biomass at V6 for the no cover crop treatment had the greatest biomass accumulation, followed by pea, while barley and the mix produced the lowest biomass. Similarly to what happened to pre-sidedress soil inorganic N, the grass cover crop-based systems limited vegetative growth relative to the no cover crop and the pea treatments. The corn N uptake at V6 reinforced this trend. Corn in the no cover crop treatment uptake the most N early in the season, indicating both higher soil N availability and greater biomass accumulation. The pea treatment exhibited moderate N uptake, reflecting intermediate soil N conditions. Both barley and the mix resulted in the lowest V6 N uptake, somewhat mirroring the reduced early-season N supply and lower biomass.

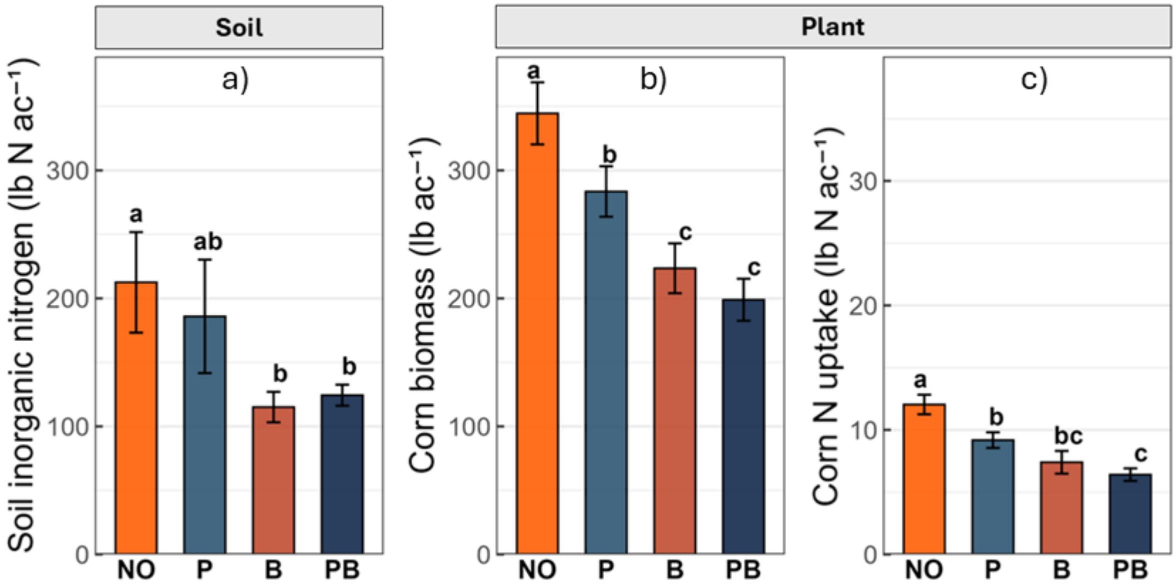

Figure 2. a) Pre-sidedress soil inorganic N (NO_3-N + NH_4-N) for corn at 24-inch depth; b) corn biomass and c) corn N uptake for the cover crop systems NO) No cover crop; P) Austrian pea 50 lb ac^{-1}; B) Winter barley 40 lb ac^{-1} and PB) Austrian pea 25 lb ac^{-1} + winter barley 20 lb ac^{-1} at V6 stage in 2025. Different small letters mean significant statistical differences at $p \leq 0.1$. Error bars represent the standard error of the mean.

Soil NO_3-N measured at 12-in depth in 2025 also help to illustrate early-season N dynamics among cover crop systems. The highest NO_3-N levels occurred in the no cover crop system (19 ppm), followed closely by the pea treatment (17 ppm). Barley and the mix had substantially lower concentrations, around 10 and 11 ppm, respectively. When interpreting12-in depth NO_3-N concentrations in terms of the Illinois Pre Sidedress Nitrate Test (PSNT) guidelines, none of the treatments exceeded the >25 ppm threshold where no sidedress N would be recommended. All treatments fell within the intermediate 10–25 ppm decision range, where recommended sidedress N is calculated as the difference from 25 ppm multiplied by 12 lb N per ppm. Under this framework, the no cover crop and pea systems (17–19 ppm) would require around 72 and 96 lb N ac^{-1}, whereas the barley and mix systems (testing 10 and 11 ppm) would indicate a substantially larger sidedress requirement (around 167 and 170 lb N ac^{-1}). These 12-in NO_3-N patterns are consistent with the total soil inorganic N trends observed at V6, where barley systems exhibited the strongest early-season N limitation, and no-cover and pea maintained comparatively greater N availability.

The patterns in soil N supply at V6 were also reflected in plant uptake patterns across N fertilizer rates (Fig. 3).

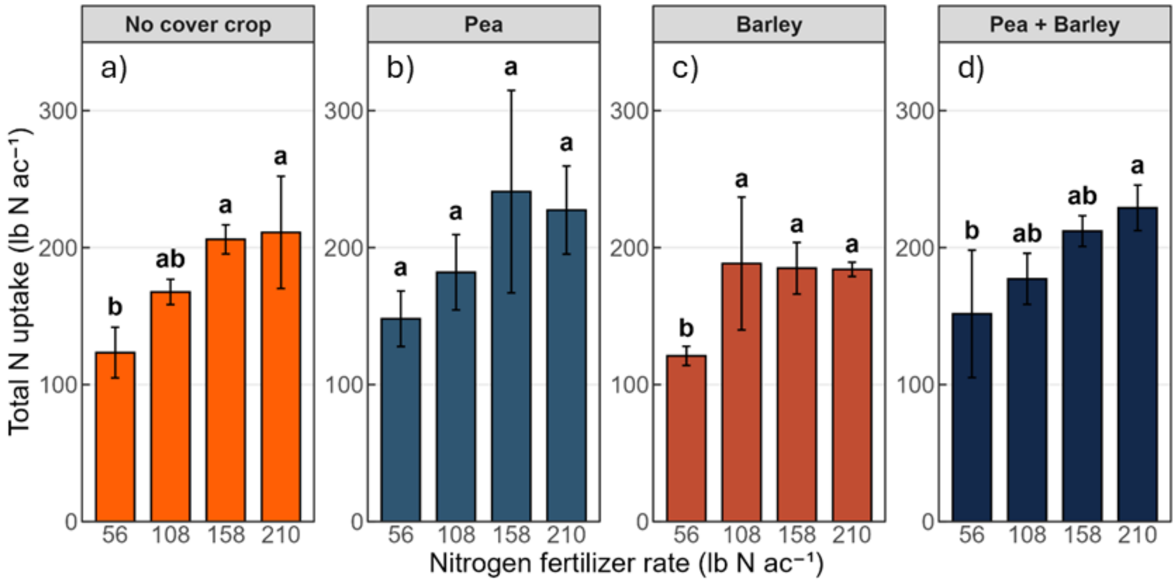

Figure 3. Total nitrogen uptake at N fertilizer rates of 56, 108, 158, and 210 lb N ac^{-1} across cover crop systems: a) No cover crop; b) Austrian pea 50 lb ac^{-1}; c) Winter barley 40 lb ac^{-1}, and d) Austrian pea 25 lb ac^{-1} + winter barley 20 lb ac^{-1} in 2025. Error bars represent the standard error of the mean.

Across all cover crop systems, total plant N uptake increased with N fertilizer rate, reaching its maximum between 108 and 210 lb N ac^{-1}. In contrast, N uptake at the V6 stage remained low across treatments but was relatively greater for the no cover crop and pea systems, which also exhibited the highest soil inorganic N concentrations. The limited N uptake before V6 suggests that most N accumulation occurred later in the season, which is well-documented, and after V6 in response to fertilizer additions. The no cover crop treatment showed a sharp increase from 123 to 206 lb N ac^{-1}, with a plateau around 210 lb N ac^{-1}. Pea exhibited the highest total N uptake overall, reaching 241 lb N ac^{-1} at 158 lb N ac^{-1} and slightly declining thereafter, suggesting a potential additive contribution from both fertilizer N and biologically fixed N. In contrast, barley peaked earlier (188 lb N ac^{-1} at 108 lb N ac^{-1}) and then plateaued, implying that a portion of available N was utilized elsewhere. The mixed system showed a steady increase in total N uptake with rate (152 to 229 lb N ac^{-1}), indicating a balance in N dynamics between barley and pea. None of the cover crop treatments differed in total N uptake for 158 and 210 lb N ac^{-1} rates. These results are also found in previous studies showing that high-biomass, high C:N cereal residues (barley) can temporarily immobilize inorganic N during early corn growth, while low C:N legume residues (pea) release N more synchronously with crop demand (Andrade et al., 2023; Tadiello et al., 2022). Mixtures can moderate extremes; site and timing control net mineralization versus immobilization (Camarotto et al., 2018; Carciochi et al., 2021). Together, soil N availability and uptake patterns demonstrate how cover crops influence early-season N dynamics, with the main N demand occurring after the V6 stage when applied sidedress N effects take precedence over the early influence of the cover crop system.

CONCLUSION

Cover crop system affected optimum N rates (EONR) and economic return to N (MRTN), though effects varied considerably by year. For all cover crop systems, yield at the EONR differed from no cover crop 1 to 8 bu ac^{-1} in 2024 and 1 to 3 bu ac^{-1} in 2025, suggesting cover crop seed cost and increases in fertilizer N demand affect profitability greater than yield losses. Yield losses with cover crops were greatest at the lowest N rates, which, although below most farmer-applied N rates, do affect the yield response function and determination of the MRTN and EONR. Yield, soil N availability and plant uptake did not differ between no cover crops and winter peas. The pea treatment increased N demand compared to no cover crop in one year and decreased in the other, while always demanding less N than barley. Barley also increased N demand compared to no cover crop in one year and decreased in the other, but always demanded more N than pea and the mix. The mix showed mixed responses for N demand, and despite reduced yield in 2024 across N rates, it did not reduce yields in 2025, except at the lowest rate. The mix showed low and similar to barley early-season soil N availability; however, it showed increased total N uptake across the N rates. It is also important to note that the fall and spring strip tillage and early cover crop termination in our study suggest that an approach useful to lessen the yield reductions of cover crops at the optimum N rate.

The results demonstrate that cover crops did not affect soybean yield in the short term. In corn, however, cover crop integration altered N fertilizer demand but not always in ways that reduced fertilizer requirements or improved short-term profitability. Although cover crops provide well-recognized soil and environmental benefits, the highest economic returns in this study were observed under no cover systems. For the legume cover crop, much of the economic difference was attributed to the cost of cover crop seed rather than differences in yield or N response. For instance, pea produced yields comparable to the no cover system, with similar early-season soil N availability and slightly greater total N uptake; however, its higher seed cost limited partial profit. Additional data across multiple seasons is needed to determine whether the N cycling benefits of legumes, such as pea, can offset their establishment costs over time. Furthermore, the effectiveness of pea cover crops in reducing soil erosion or nutrient losses remains uncertain. Continued long-term monitoring will be essential to capture the cumulative impacts of cover crops on yield stability, N fertilizer demand, and nutrient cycling over time.

REFERENCES

Bielenberg, H., Clark, J. D., Sanyal, D., Wolthuizen, J., Karki, D., Rahal, A., & Bly, A. (2023). Precipitation and not cover crop composition influenced corn economic optimal N rate and yield. Agronomy Journal, 115(1), 426–441. https://doi.org/10.1002/agj2.21265

Bullock, D. S., Boerngen, M., Tao, H., Maxwell, B., Luck, J. D., Shiratsuchi, L., Puntel, L., & Martin, N. F. (2019). The data-intensive farm management project: Changing agronomic research through on-farm precision experimentation. Agronomy Journal, 111(6), 2736–2746. https://doi.org/10.2134/agronj2019.03.0165

Bundy, L.G. and Meisinger, J.J. (1994). Nitrogen Availability Indices. In Methods of Soil Analysis (eds R.W. Weaver, S. Angle, P. Bottomley, D. Bezdicek, S. Smith, A. Tabatabai and A. Wollum). https://doi.org/10.2136/sssabookser5.2.c41

Camarotto, C., Dal Ferro, N., Piccoli, I., Polese, R., Furlan, L., Chiarini, F., & Morari, F. (2018). Conservation agriculture and cover crop practices to regulate water, carbon and nitrogen cycles in the low-lying Venetian plain. Catena, 167, 236–249. https://doi.org/10.1016/j.catena.2018.05.006

Carciochi, W. D., Massigoge, I., Lapaz Olveira, A., Reussi Calvo, N. I., Cafaro La Menza, F., Sainz Rozas, H. R., Barbieri, P. A., di Napoli, M., Gonzalez Montaner, J., & Ciampitti, I. A. (2021). Cover crop species can increase or decrease the fertilizer-nitrogen requirement in maize. Agronomy Journal, 113(6), 5412–5423. https://doi.org/10.1002/agj2.20791

da Silva Andrade, B. M., Pedrotti, A., de Lana Sousa, B. M., Holanda, F. S. R., Villwock, A. P. S., & de Santana, A. P. S. (2023). Technical efficiency of forage production from residues of green corn (Zea mays L.) in Sergipe, Brazil. Revista Brasileirade Ciencias Agrarias, 18(2). https://doi.org/10.5039/AGRARIA.V18I2A2971

de Almeida, T. F., Canisares, L. P., Robinson, E., Pesini, G., Poffenbarger, H., & Basche, A. (2025). Cover crops did not change optimal corn nitrogen rate over three variable precipitation seasons in the Western Corn Belt. Agronomy Journal, 117(4). https://doi.org/10.1002/agj2.70129

Francis, H. R., Ma, T. F., Werle, R., Zegler, C. H., Smith, D. H., Soldat, D. J., Marin-Spiotta, E., & Ruark, M. D. (2025). Nitrogen fertilizer equivalence of red clover when inter-seeded into corn. Agronomy Journal, 117(4). https://doi.org/10.1002/agj2.70133\

Miguez, F. (2023, December 2). nlraa: An R package for Nonlinear Regression Applications in Agricultural Research [R package]. https://femiguez.github.io/nlraa-docs/nlraa.html

Pecci Canisares, L., Grove, J., Miguez, F., & Poffenbarger, H. (2021). Long-term no-till increases soil nitrogen mineralization but does not affect optimal corn nitrogen fertilization practices relative to inversion tillage. Soil and Tillage Research, 213. https://doi.org/10.1016/j.still.2021.105080

Perrone, S., Grossman, J., Liebman, A., Sooksa-nguan, T., & Gutknecht, J. (2020). Nitrogen fixation and productivity of winter annual legume cover crops in Upper Midwest organic cropping systems. Nutrient Cycling in Agroecosystems, 117(1), 61–76. https://doi.org/10.1007/s10705-020-10055-z

Quinn, D. J., Poffenbarger, H. J., Miguez, F. E., & Lee, C. D. (2023). Corn optimum nitrogen fertilizer rate and application timing when following a rye cover crop. Field Crops Research, 291. https://doi.org/10.1016/j.fcr.2022.108794

R Core Team. (2024). R: A language and environment for statistical computing (Version 4.2.2). R Foundation for Statistical Computing. https://www.r-project.org/

Seavers, R., & Quinn, D. J. (2025). Corn response to early- and late-vegetative nitrogen applications following a rye cover crop in Indiana. Agronomy Journal, 117(5). https://doi.org/10.1002/agj2.70173

Sebilo, M., Mayer, B., Nicolardot, B., Pinay, G., & Mariotti, A. (2013). Long-term fate of nitrate fertilizer in agricultural soils. Proceedings of the National Academy of Sciences of the United States of America, 110(45), 18185–18189. https://doi.org/10.1073/pnas.1305372110

Tadiello, T., Potenza, E., Marino, P., Perego, A., Torre, D. della, Michelon, L., & Bechini, L. (2022). Growth, weed control, and nitrogen uptake of winter-killed cover crops, and their effects on maize in conservation agriculture. Agronomy for Sustainable Development, 42(2). https://doi.org/10.1007/s13593-021-00747-3

Zarcinas, B. A., Cartwright, B., & Spouncer, L. R. (1987). Nitric acid digestion and multi-element analysis of plant material by inductively coupled plasma spectrometry. Communications in Soil Science and Plant Analysis, 18(1), 131-146.