
# EXPLORING THE USE OF A MODEL-BASED NITROGEN RECOMMENDATION TOOL FOR IN-SEASON CORN NITROGEN MANAGEMENT ON-FARM TRIALS IN ALABAMA.

**Pablo R. Duarte*[1], Brenda V. Ortiz[1], Mailson F. Oliveira[2], Emmanuel Hayanbui[3], Eros Francisco[1]**

[1] Auburn University, Department of Crop, Soil, and Environmental Sciences, Auburn, AL, U.S.

[2] University of Nebraska–Lincoln, Water, and Cropping Systems Extension Educator, NE, U.S.

[2] University of Cape Coast, Department of Soil Science, Cape Coast, Ghana.

**A paper from the Proceedings of the**
**16th International Conference on Precision Agriculture**
**21-24 July 2024**
**Manhattan, Kansas, United States**

***Abstract.*** *Efficient nitrogen (N) management is critical for sustainable agriculture. The ideal N management for corn fluctuates annually due to variations in weather conditions. Hence, precise and in-season N application strategies are essential to achieve optimum corn yield while minimizing negative impacts on the environment. This study was conducted in two farmers' fields located in Autaugaville, AL (Field A) and Courtland, AL (Field B). Each field was delineated into three management zones (MZs) using historical yield data. The treatments involved three nitrogen (N) levels: the farmer's N rate, below the farmer's N rate, and above the farmer's N rate (±9% of the farmer's N rate for Field A and ±28% of the farmer's N rate for Field B). Each treatment was applied to 24 corn strips across the field within each MZ. Data was collected on corn ear length, kernel weight, kernel % moisture, and grain yield. The result revealed variations between the actual N applied and grain yield. Increasing N above the farmer's rate resulted in an increase in grain yield in the high MZ. However, in the medium MZ, N applied above the farmer's rate did not result in any significant increase in grain yield across all fields. In Field A, the highest nitrogen productivity (NP) was achieved at the lowest N rate (144 kg N ha-1) in both Medium and High MZs, while the highest yields and profits were observed at higher N rates (200 and 255 kg N ha-1). In Field B, similar trends were observed, with the highest yields and profits at the highest N rates (383 and 402 kg N ha-1) in both Medium and High MZs. The EONR varied across MZs, emphasizing the importance of site-specific N management. The different levels of nitrogen rate tested suggest that optimized N applications could maintain yields while enhancing NP and profitability. The study's findings highlighted the benefits of precision agriculture tools for sustainable and efficient nitrogen management.*

***Keywords.***
*precision agriculture, corn yield, model-based, management zones, nitrogen productivity, EONR.*

## Introduction

The United States of America (USA) is the largest producer and exporter of corn. Although nitrogen use efficiency (NUE) has decreased in some regions in recent years, other farmers are increasing nitrogen (N) use to maximize crop yields. However, the over- or under-application of N fertilizer can lead to detrimental effects such as soil acidification, reduced crop yield, and increased nitrate pollution in groundwater (Rath et al., 2021). Farmers and crop consultants face challenges determining the optimal in-season N application rates for corn production due to the inherent variability in soil properties, within-field variability, and weather conditions. Increasing NUE does not only rely on identifying the economic optimum nitrogen rate but also addressing the within-field N needs. This complexity underscores the need for efficient technologies that consider various factors for prescribing in-season N management.

Several methods such as algorithms based on readings from active or passive remote sensors (Aula et al., 2020; Franzen et al., 2016) and crop growth models (Sela et al., 2016; Thompson et al., 2024) have been used to improve in-season site-specific N management. Both approaches rely on an assessment of past or in-season crop yield. A study conducted in Mississippi across eight years showed that the use of chlorophyll content-based vegetation indices was more sensitive to corn nitrogen rate differences than other indices and was better in-season yield predictors. A study conducted in the upper Midwest pointed out that vegetation indices derived from either active or passive sensors have a strong power for corn yield prediction at the growth stages V12 and R1, however, they have limited utility for sidedress application of N which occurs between the V4 and V8 growth stages (Paiao et al., 2020). In contrast, the use of crop growth model-based tools such as Adapt N has shown promising results for in-season N management (Osmond et al., 2018; Sela et al., 2016). Adapt-N is a crop-model-based digital application designed to address these challenges by integrating data on soil conditions, crop status, and management practices with the latest weather data to prescribe variable rate N applications. Previous studies have demonstrated the benefits of site-specific N management in enhancing both economic and environmental sustainability (Barker & Sawyer, 2017; Dobermann et al., 2011; Wang et al., 2020). These benefits include lower fertilizer costs, higher returns, and reduced nitrate leaching (van Es et al., 2020). This study evaluates the performance of Adapt-N prescriptions in on-farm settings across Alabama, comparing its prescriptions with traditional farmer practices. The study also evaluated the corn response to different N rates across within-field management zones. The findings from this research contribute to the growing body of evidence supporting the adoption of precision agriculture tools for sustainable and efficient N management.

## Materials and Methods

### *On-Farm Experimental fields*

In 2023, two on-farm research trials were conducted in corn fields under irrigated conditions. Field A (32°19'03.5"N 86°48'10.0"W) was located in Northwest Alabama (AL), and field B (34°41'47.9"N 87°14'38.8"W)) in the Central part of the state. The predominant soil texture was McQueen silt loam in Field A and Decatur silty clay loam in Field B (SSURGO, NRCS). The information on the location and basic crop planting information for each field is summarized in Table 1.

**Table 1. Location and basic crop management information of the study fields**

| Location | Field A (Autauga, AL) | Field B (Courtland, AL) |
|---|---|---|
| Test Size (ha) | 73 | 40 |
| Seeding rate (seeds ha$^{-1}$) | 79,074 | 79,074 and 84,016 |
| Planting date | 04/11/2023 | 04/05/2023 |
| Corn hybrid | REVERE-1898C | DKC 65-99 |
| Row spacing (cm) | 91 | 76 |
| Soil texture | McQueen silt loam | Decatur silty clay loam |

*Management Zones*

The delineation of Management Zones (MZ) varied between Fields A and B. For Field A, MZ was calculated based on the spatial corn yield variance. For Field B, MZ matched the farmer's defined zones based on field knowledge and two seeding rates. Historical yield data collected from yield monitors were used to calculate spatial yield variance, identifying two management zones with potentially different crop productivity. This process followed the methodology outlined by Basso et al. (2012) and Cammarano et al. (2020), which involves quantifying spatial and temporal variability in crop yield data to delineate zones for optimized management. The spatial variability of yield for field A from 2022 and 2023 was calculated using the relative percentage difference of yield at each location from the average yield of the entire field, according to equation (1):

$$\sigma_{si}^{-2} = \frac{1}{n}\sum_{k=1}^{n}\left[\frac{y_{i,k}-\overline{y_k}}{\overline{y_k}} \times 100\right] \quad (1)$$

where *n* is the total number of available years, k = 1, … , *n* is the integer corresponding to every year, $\sigma_{si}^{-2}$ is the average percentage difference at location *I*, $\overline{y_k}$ is the average of the variable obtained for the whole field at year k, $y_{i,k}$ is the variable monitored at location *I* at year *k*. Points that have high values of $\sigma_{si}^{-2}$ are associated with high yields, and lower values represent lower yields. Figure 2 illustrates the management zones of spatial yield variance for Fields A and B.

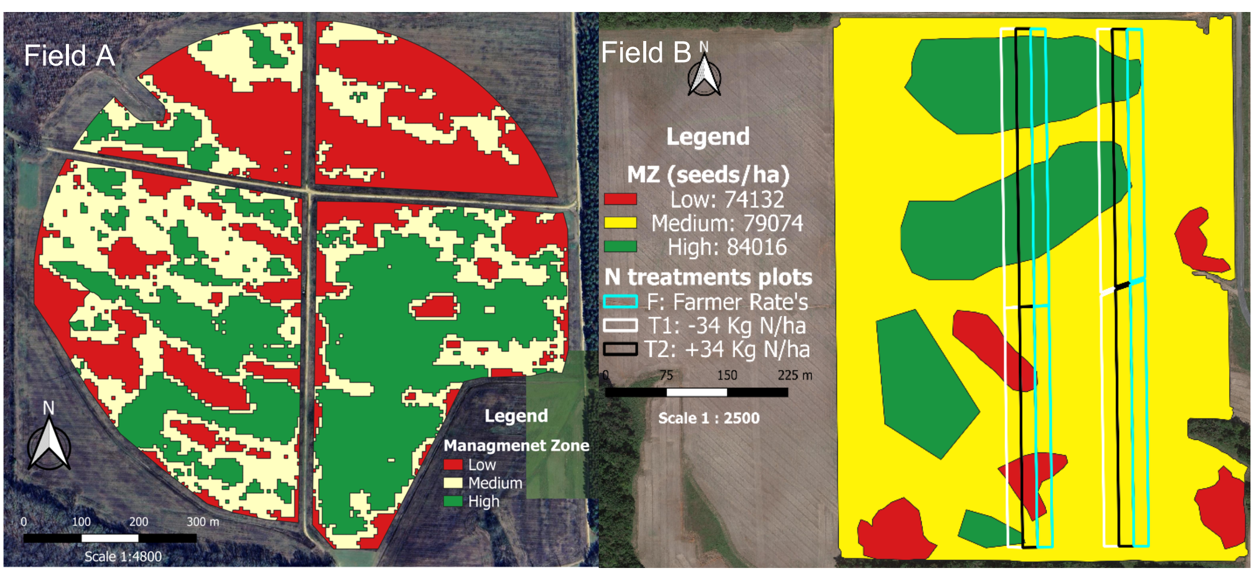


**Fig. 1. Management zones of spatial yield variance delineated based on historical yield data.**

*Nitrogen treatments*

The corn response to N application across management zones was evaluated using three different N rates. In 2023, three replications of three N rates ranging from 55 to 166 Kg N/ha and 133 to 220 Kg N/ha were established at fields A and B, respectively. The N rates corresponded to an increase (T1) or decrease (T2) of the nitrogen rate with respect to the rate established by the farmer (Farmer's practice). In field A, the amount increased or decreased was 56 kg $ha^{-1}$, while in field B it was 33 kg ha-1, as indicated in Table 2. Each N treatment covered various corn rows and spanned the length of the field across various management zones. The liquid Urea Ammonium nitrate (28%-Field A and 32%-Field B) was used as the N source. The liquid Urea Ammonium nitrate was applied using the liquid application equipment 11m wide in Field A and 18m wide in Field B. The application was done in two splits: 1/3 applied at planting and 2/3 applied at the V5-V6 corn growth stage as side-dress.

**Table 2: Information on nitrogen fertilizer application**

| Time of application | Field A | | Field B | |
|---|---|---|---|---|
| | Date | Rate (kg $ha^{-1}$) | Date | Rate (kg $ha^{-1}$) |
| Pre-planting | N/A | 0 | 3/16/2023 | 130 |
| At planting | 4/11/2023 | 89 | 4/5/2023 | 46 |
| At sidedress | 5/16/2023 | T2: 55<br>F: 111<br>T1: 166 | 5/19/2023 | Medium MZ<br>T2: 133<br>F: 169<br>T1: 201<br>High MZ<br>T2: 154<br>F: 188<br>T1: 220 |
| Nitrogen source | UAN (28-0-0)-5S | | UAN (32-0-0) | |

*Experimental design*

The study design is a paired strip trial comparison with three replications, three different nitrogen rates for Field A, and nine different nitrogen rates for Field B, in two management zones. The N treatments were applied at the V5-V6 corn growth stage. Field A received N through a Y-drop surface application system, while Field B utilized a three-point hitch liquid applicator injection system. Additionally, Field B was applied using a variable rate prescription map with the John Deere Farmers account based on the layout of the N treatments. The geometry of the strips was defined based on the width of the farmer's equipment, which facilitates the application of the N rates and ensures each pass of the grain combine will cover the various N rate treatments and also georeferenced the data collected from each treatment zone. Each N rate treatment on field A was composed of 12 rows and 24 rows on field B.

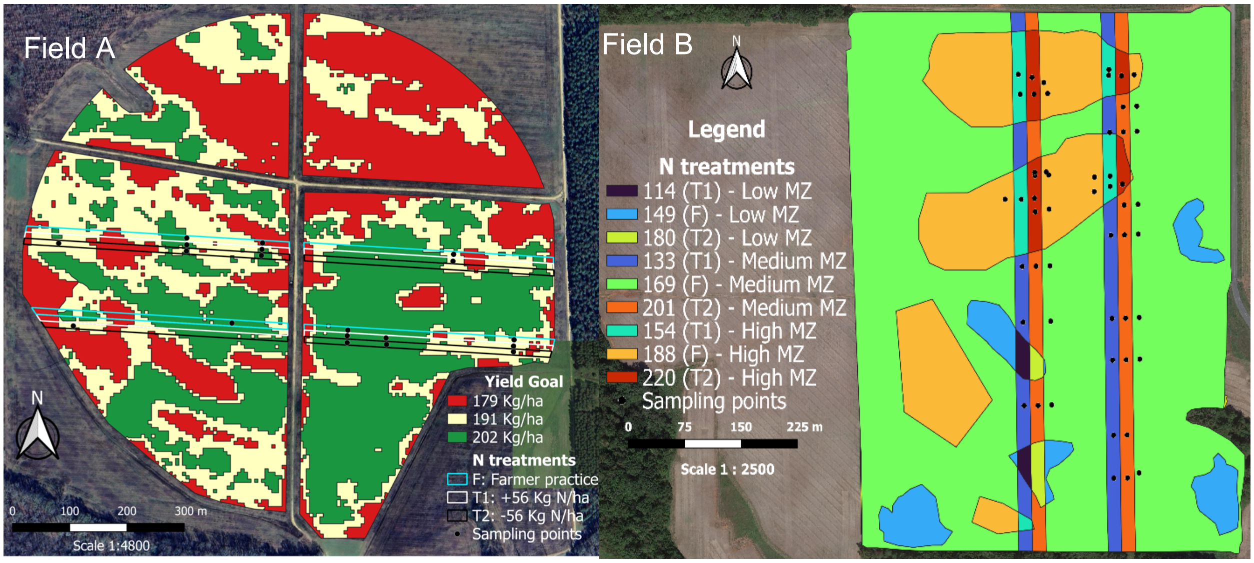


**Fig. 2. Management zones, N treatments layout, and sampling locations.**

*The Adapt-N tool*

This tool is an adaptive in-season nitrogen (N) recommendation tool created to enhance the precision of nitrogen applications in corn production. According to Sela et al. (2016), the tool integrates soil, crop, and management data with real-time weather information to provide site-specific N recommendations. This approach aims to improve N use efficiency, increase economic returns, and reduce environmental impacts associated with N fertilizer application. This tool employs a dynamic simulation model that accounts for various factors affecting N dynamic in corn fields. By using weather data and detailed site-specific inputs, the tool can adjust N recommendations throughout the growing season. For accurate N recommendations, Adapt-N requires weather, soil, crop, management and fertilizer information where some data is weighted heavier than others, the accuracy on these inputs influences the quality of the tool recommendation. The inputs rated as high weight corresponds to soil drainage and organic matter, prior crop, sod information, expected yield, manure and nitrogen applications, irrigation, cover crops, rooting depth and soil nitrate test.

In this study, the Adapt-N tool was employed to assess its nitrogen (N) management recommendations compared to traditional farmer practices during the growing season. Accounts for two fields were created on the Adapt-N website, where necessary data inputs were provided. On the day of sidedress application, the Adapt-N tool was used to generate a variable rate nitrogen prescription map for each field. The goal is to compare the Adapt-N prescriptions with respect to the farmer's conventional N application plans, however, the prescriptions from Adapt-N were not implemented due to the farmers' apprehensions and the fact that it was the first time using the tool. Instead, the farmers agreed to test two different rates besides their own rate. By monitoring these different rates throughout the growing season, I aimed to determine whether the Adapt-N tool could offer more precise and efficient N management compared to the farmer's practice, potentially enhancing crop yield, increasing economic returns, and reducing environmental impacts.

*Data collection*
Comprehensive data was collected within each N treatment and management zone, including measurements of corn ear length and kernel weight at harvest, complemented by moisture% analysis for yield estimation. In total, 23 and 53 sampling locations were identified for final yield data collection in fields A and B, respectively. Sampling was conducted on each treatment by management zone in three replications. In field A, samples were collected from rows 5 and 7, while in field B, samples were collected from rows 5 and 15. Corn growth development and final yield data were collected within 91 cm length/row on two rows/sampling points in each of the N treatments. The data collection spanned the entire growing season, with specific attention to key growth stages.

*Data analysis and calculations*
Corn ear length and grain yield as a response to different nitrogen rates and management zones were subjected to multivariate analysis of variance (MANOVA) to identify significant differences, using a 90% confidence interval; this analysis was performed using the function aov from the package stats in R (R Core Team, 2023). The nitrogen productivity was determined by the ratio of grain yield to the total amount of nitrogen applied (Flynn et al., 2023). Additionally, the economical optimal nitrogen rate (EONR) was calculated from the N response equations by setting the first derivative of the fitted response curve equal to the grain and N fertilizer price ratio (US$ 0.2087 $kg^{-1}$ grain: US$ 0.49 kg-1 N for UAN28% and US$ 0.65 kg-1 N for UAN32%) (NASS, 2023).

## Results and Discussion

*Evaluating Corn Yield Response to Variable Nitrogen Rates and Management Zones*
The corn grain yield across different nitrogen (N) treatments and management zones (MZ) for Fields A and B showed variation. In both fields, an increasing trend in corn yield was observed as the N rate increased, especially in the High MZ. This suggests that areas with better soil conditions and higher productivity potential responded more positively to increased N applications. However, there were no significant differences in yield when considering N rates, management zones, and their interactions.

In Field A, within the Medium MZ, the farmer's practice of 200 kg N $ha^{-1}$ resulted in the highest yield among the N treatments, while the 144 kg N $ha^{-1}$ treatment yielded the lowest. Increasing the N application by 56 Kg N $ha^{-1}$ as a side-dress did not result in a significant yield increase, suggesting that the MZ may have reached its yield potential with the farmer’s rate. In the High MZ, the 255 kg N $ha^{-1}$ treatment outyielded the other two N treatments, with the yield difference being more pronounced compared to the Medium MZ. In Field B, both MZs, showed a moderate yield increase trend as the N rate increased, particularly when comparing the medium and high rates of 351 and 383 kg N/ha, respectively. Increasing the N rate by 33 kg N $ha^{-1}$ resulted in a slight yield increase, indicating that the yield potential might not have been fully reached with the farmer's practice but was close to optimal. In the High MZ, an exponential trend was observed, with yield reaching a plateau at 402 kg N $ha^{-1}$, where no significant difference was seen compared to the farmer's practice.

These results indicate that in both fields, higher N rates generally increased yields, especially in the high MZ. This suggests that areas with better soil conditions and higher productivity potential respond more positively to increased N applications and underscores the importance of tailoring N management to specific field conditions. The yield differences across MZs highlight the need for precise N application rates to achieve both economic and environmental sustainability. Variations in soil fertility, moisture availability, and overall growing conditions between the Medium and High MZs likely influenced the differences in yield responses. The High MZs in both fields showed a more pronounced yield increase with higher N rates, suggesting better soil conditions and higher productivity potential.

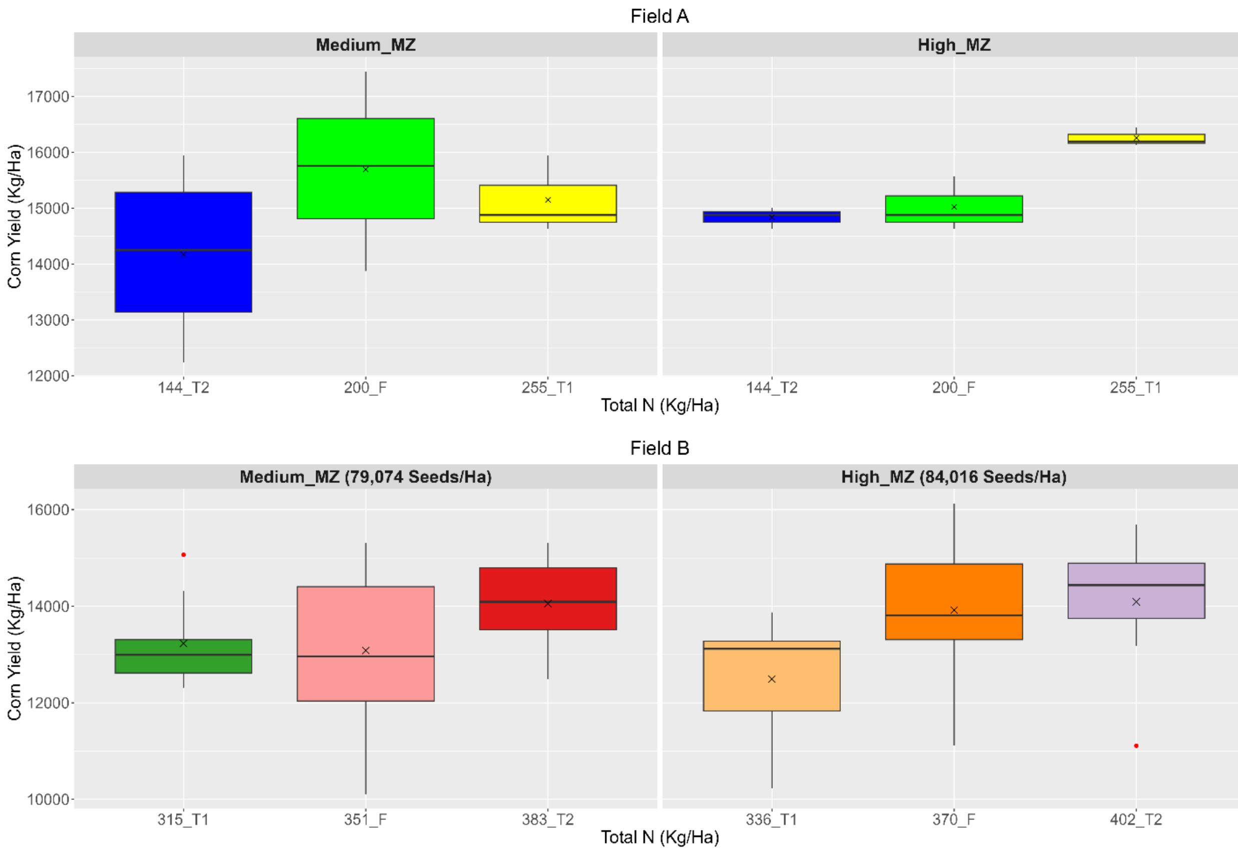


**Fig. 4. Comparison of hand harvest corn yield across different N rates and management zones.**

*Corn ear length and yield response*

The ear length and corn grain yield response showed distinct trends and variations across different N treatments and MZ, highlighting the complexity of nitrogen management in optimizing both yield and crop quality. There was no statistically significant difference in corn ear length. At field A in the Medium MZ, the farmer's practice of 200 kg N ha-1 resulted in the highest grain yield but not the longest ear length, which was achieved with the 144 kg N ha$^{-1}$ treatment. Conversely, in the High MZ, both grain yield and ear length increased as the nitrogen rate increased, with the 255 kg N ha$^{-1}$ treatment leading to the highest values for both variables. In field B, the Medium MZ has less pronounced corn ear length differences with respect to the nitrogen rate increase, with moderate values for both yield and ear length observed at the farmer's practice 351 kg N ha$^{-1}$. The High MZ in Field B, the farmer’s rate of 370 kg N ha$^{-1}$ has a slightly greater response among the N treatments, with the 402 kg N ha$^{-1}$ treatment achieving the highest yield, though ear length did not increase beyond the farmer's practice level.

The findings on corn ear length are consistent with the results reported by Shigueru Okumura et al. (2014) that optimal nitrogen rates enhance ear length by improving the plant's nutritional status and growth. Furthermore, the study by Inman et al. (2005) supports the concept of spatial variability and its impact on nitrogen uptake and crop yield. The variability in ear length observed across different management zones in fields A and B can be attributed to the site-specific nitrogen management strategies. This suggests that these specific N rates were more effective in meeting the nitrogen needs of the corn in these zones, promoting better ear development.

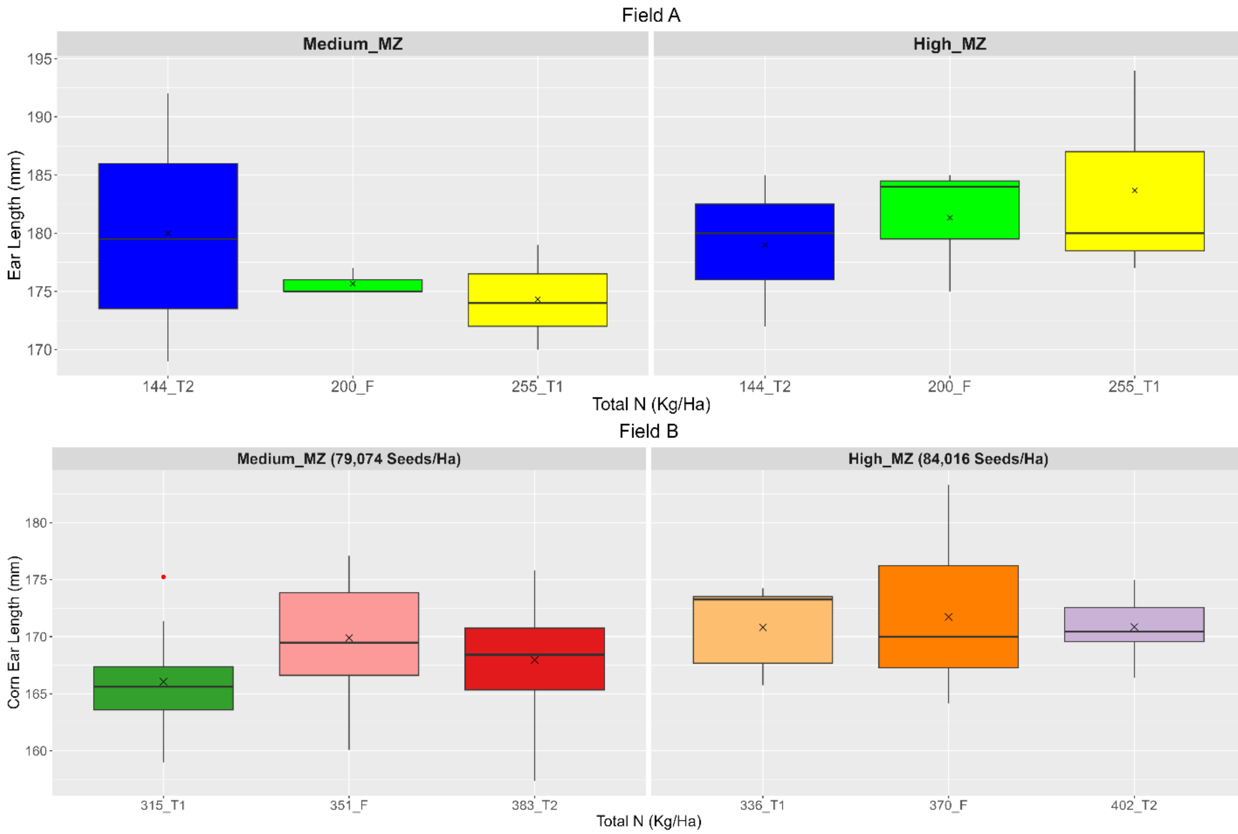


**Fig. 5. Comparison of corn ear length (mm) response across different N rates and management zones.**

*Nitrogen productivity*

The evaluation of nitrogen productivity (NP) across different nitrogen treatments and management zones in fields A and B revealed distinct trends and highlighted the importance of optimizing nitrogen application rates for efficient crop production (Table 3). At field A, in the medium MZ, the lowest nitrogen rate of 144 kg N ha^-1 achieved the highest nitrogen productivity (NP) of 98.40 kg grain/kg N applied, suggesting that this rate was the most efficient in converting applied nitrogen into grain yield. Conversely, the highest N rate of 255 kg N $ha^{-1}$, despite yielding 15,148 kg $ha^{-1}$, had the lowest NP of 59.40 kg grain/kg N, demonstrating diminishing returns at higher N rates. This trend was similarly observed in the High MZ, where the 144 kg N $ha^{-1}$ rate achieved the highest NP of 103.01 kg grain/kg N, while the highest yield at 255 kg N $ha^{-1}$ corresponded with a lower NP of 63.75 kg grain/kg N. These findings suggest that applying nitrogen at 144 kg N $ha^{-1}$ on this field maximizes the crop's ability to utilize available nitrogen effectively without wastage, which is crucial for both economic and environmental sustainability.

At field B in the medium MZ, the lowest N rate of 315 kg N $ha^{-1}$ had the highest NP of 42 kg grain/kg N applied, while the highest N rate of 402 kg N $ha^{-1}$ had the lowest NP of 35.05 kg grain/kg N applied, similar to the trends observed in field A. In the High MZ, the farmer's practice of 370 kg N ha$^{-1}$ resulted in the highest yield of 13,921 kg ha$^{-1}$ and a moderate NP of 37.62 kg grain/kg N, balancing yield and efficiency. The highest N rate, 402 kg N ha$^{-1}$, produced 14,091 kg ha$^{-1}$ but had the lowest NP of 35.05 kg grain/kg N, reflecting reduced efficiency at the highest N rate. These results indicate that lower nitrogen rates generally lead to higher nitrogen productivity, highlighting the importance of efficient nitrogen use. Higher N rates, while increasing yields, tend to decrease NP, underscoring the need for balanced nitrogen management to optimize both yield and nitrogen productivity.

Previous research has indicated that the observed trends in NP across fields A and B, where lower nitrogen rates generally resulted in higher NP, emphasize the need for optimized nitrogen application rates. Brentrup et al. (2016) argue that balanced nitrogen use, which maximizes NP, is crucial for sustainability and efficiency to minimize environmental risks. Similarly, Flynn et al. (2023) show that excessive nitrogen application can decrease nitrogen uptake and yield, suggesting that lower, optimized nitrogen rates enhance NP and overall efficiency validating the importance of site-specific nitrogen management to maximize NP, yield, and sustainability.

*Economical optimal nitrogen rate (EONR) and profit ($)*

The EONR and corn yield response indicate that higher nitrogen rates generally led to increased yields but do not always align with the highest EONR (Table 3). At field A in the Medium MZ, the EONR was 209 kg N ha$^{-1}$, the highest yield in this zone was achieved with the farmer's practice of 200 kg N ha$^{-1}$, yielding 15,692 kg ha$^{-1}$ on average and resulting in the highest profit, demonstrating an effective balance between yield and profitability. In the High MZ, the EONR and treatment N rate of 255 kg N ha$^{-1}$ was the same, resulting in the highest yield of 16,257 kg ha$^{-1}$ on average and the highest profit. At field B in the Medium MZ, the EONR was 383 kg N ha$^{-1}$ with the highest yield and profit observed at the highest nitrogen rate of 383 kg N ha$^{-1}$, yielding 14,054 kg ha$^{-1}$ on average. Similarly, in the High MZ, the EONR was 389 kg N ha$^{-1}$, with the highest yield of 14,091 kg ha$^{-1}$ at the highest nitrogen rate of 402 kg N ha$^{-1}$. These results suggest that while higher nitrogen rates maximize yields and profits, aligning with EONR values is crucial for achieving both economic and environmental sustainability. The economic and environmental benefits of site-specific nitrogen management include lower fertilizer costs and potentially higher returns, as demonstrated by Sela et al. (2017), as well as reduced nitrate leaching, a critical environmental concern, as shown by Van Es et al. (2020).

**Table 3. Nitrogen Rates, Corn Yield, Nitrogen Productivity (NP), Economically Optimum Nitrogen Rate (EONR), and Profit Across Different Management Zones and Treatments in Fields A and B.**

| Field | MZ | Treat | Total N (Kg/ha) | Yield (Kg/ha) | Nitrogen Productivity | EONR | Profit ($) |
|---|---|---|---|---|---|---|---|
| A | Medium_MZ | T2 | 144 | 14170 | 98.40 | 209 | 2887 |
| A | Medium_MZ | F | 200 | 15692 | 78.46 | 209 | 3177 |
| A | Medium_MZ | T1 | 255 | 15148 | 59.40 | 209 | 3036 |
| A | High_MZ | T2 | 144 | 14834 | 103.01 | 255 | 3025 |
| A | High_MZ | F | 200 | 15022 | 75.11 | 255 | 3037 |
| A | High_MZ | T1 | 255 | 16257 | 63.75 | 255 | 3268 |
| B | Medium_MZ | T1 | 315 | 13230 | 42.00 | 383 | 2607 |
| B | Medium_MZ | F | 351 | 13081 | 37.27 | 383 | 2558 |
| B | Medium_MZ | T2 | 383 | 14054 | 36.69 | 383 | 2745 |
| B | High_MZ | T1 | 336 | 12491 | 37.18 | 389 | 2442 |
| B | High_MZ | F | 370 | 13921 | 37.62 | 389 | 2724 |
| B | High_MZ | T2 | 402 | 14091 | 35.05 | 389 | 2744 |

# Conclusion

This study demonstrates that optimizing nitrogen application rates is crucial for enhancing corn yield, ear length, nitrogen productivity (NP), and achieving the economically optimum nitrogen rate (EONR). The findings indicate that higher nitrogen rates generally lead to increased yields, particularly in high-productivity zones, but do not always align with the highest NP values. In Field A, the highest NP was observed at the lowest N rate, while the highest yields and profits were achieved at higher rates. Field B exhibited similar trends, with the highest yields and profits corresponding to the highest nitrogen rates. The EONR from field A demonstrates that in the Medium MZ, the EONR was 209 kg N ha$^{-1}$, which closely aligned with the farmer's practice of 200 kg N ha$^{-1}$. This rate resulted in the highest yield of 15,692 kg ha$^{-1}$ and the highest profit, highlighting an effective balance between yield and profitability. In the High MZ, the EONR and the highest yield were achieved at the same nitrogen rate of 255 kg N ha$^{-1}$, yielding 16,257 kg ha$^{-1}$ and resulting in the highest profit. In contrast, in field B, both MZ showed that the highest yield and profit were observed at the highest nitrogen rate of 383 and 402 kg N ha$^{-1}$, respectively. These findings highlight the benefits of precision agriculture tools in achieving economic and environmental sustainability through tailored nitrogen management strategies.

## Acknowledgments

This project was funded by the Alabama Wheat & Feed Grain Checkoff, the Alabama Cooperative Extension System (Alabama A&M and Auburn Universities), and Yara International. We thank Dan and Andy for providing a field for this research. We are also grateful to the undergraduate students and people involved for their assistance with data collection. Our gratitude extends to these organizations for their generous funding and support, which made this research possible.

## References


Aula, L., Omara, P., Nambi, E., Oyebiyi, F. B., & Raun, W. R. (2020a). Review of active optical sensors for improving winter wheat nitrogen use efficiency. In Agronomy (Vol. 10, Issue 8). MDPI AG. https://doi.org/10.3390/agronomy10081157

Barker, D. W., & Sawyer, J. E. (2017). Variable rate nitrogen management in corn: Response in two crop rotations. Journal of Soil and Water Conservation, 72(3), 183–190. https://doi.org/10.2489/jswc.72.3.183

Basso, B., Fiorentino, C., Cammarano, D., Cafiero, G., & Dardanelli, J. (2012). Analysis of rainfall distribution on spatial and temporal patterns of wheat yield in Mediterranean environment. European Journal of Agronomy, 41, 52–65. https://doi.org/10.1016/j.eja.2012.03.007

Brentrup, F., & Lammel, J. (2016). Nitrogen Use Efficiency, Nitrogen balance, and Nitrogen productivity-a combined indicator system to evaluate Nitrogen use in crop production systems. www.ini2016.com

Cammarano, D., Zha, H., Wilson, L., Li, Y., Batchelor, W. D., & Miao, Y. (2020). A remote sensing-based approach to management zone delineation in small scale farming systems. Agronomy, 10(11). https://doi.org/10.3390/agronomy10111767

Dobermann, A., Wortmann, C. S., Ferguson, R. B., Hergert, G. W., Shapiro, C. A., Tarkalson, D. D., & Walters, D. T. (2011). Nitrogen response and economics for irrigated corn in Nebraska. Agronomy Journal, 103(1), 67–75. https://doi.org/10.2134/agronj2010.0179

Flynn, N. E., Comas, L. H., Stewart, C. E., & Fonte, S. J. (2023). High N availability decreases N uptake and yield under limited water availability in maize. Scientific Reports, 13(1). https://doi.org/10.1038/s41598-023-40459-0

Franzen, D., Kitchen, N., Holland, K., Schepers, J., & Raun, W. (2016). Algorithms for in-season nutrient management in cereals. In Agronomy Journal (Vol. 108, Issue 5, pp. 1775–1781). American Society of Agronomy. https://doi.org/10.2134/agronj2016.01.0041

Inman, D., Khosla, R., Westfall, D. G., & Reich, R. (2005). Nitrogen uptake across site specific management zones in irrigated corn production systems. Agronomy Journal, 97(1), 169–176. https://doi.org/10.2134/agronj2005.0169

Mamo, M., Malzer, G. L., Mulla, D. J., Huggins, D. R., & Strock, J. (2003). Spatial and temporal variation in economically optimum nitrogen rate for corn. Agronomy Journal, 95(4), 958–964. https://doi.org/10.2134/agronj2003.9580

Nafziger, E. D., & Rapp, D. (2021). Corn yield response to late-split nitrogen fertilizer. Agronomy Journal, 113(1), 527–536. https://doi.org/10.1002/agj2.20472

National Agricultural Statistics Service. (2023). Alabama state agriculture overview. United States Department of Agriculture. Retrieved July 15, 2024, from https://www.nass.usda.gov/Quick_Stats/Ag_Overview/stateOverview.php?state=ALABAMA

Osmond, D., Austin, R., Shelton, S., van Es, H., & Sela, S. (2018a). Evaluation of Adapt-N and Realistic Yield Expectation Approaches for Maize Nitrogen Management in North Carolina. Soil Science Society of America Journal, 82(6), 1449–1458. https://doi.org/10.2136/sssaj2018.03.0127

Paiao, G. D., Fernández, F. F., Spackman, J. A., Kaiser, D. E., & Weisberg, S. (2020). Ground-based optical canopy sensing technologies for corn–nitrogen management in the Upper Midwest. Agronomy Journal, 112(4), 2998–3011. https://doi.org/10.1002/agj2.20248

Rath, S., Zamora-Re, M., Graham, W., Dukes, M., & Kaplan, D. (2021). Quantifying nitrate leaching to groundwater from a corn-peanut rotation under a variety of irrigation and nutrient management practices in the Suwannee River Basin, Florida. Agricultural Water Management, 246. https://doi.org/10.1016/j.agwat.2020.106634

Sela, S., van Es, H. M., Moebius-Clune, B. N., Marjerison, R., Melkonian, J., Moebius-Clune, D., Schindelbeck, R., & Gomes, S. (2016). Adapt-N outperforms grower-selected nitrogen rates in northeast and midwestern united states strip trials. Agronomy Journal, 108(4), 1726–1734. https://doi.org/10.2134/agronj2015.0606

Shigueru Okumura, R., Soares Vidigal Filho, P., Alberto Scapim, C., José Marques, O., Augusto Nogueira Franco, A., Soares de Souza, R., & Lincoln Reche, D. (2014). Effects of nitrogen rates and timing of nitrogen topdressing applications on the nutritional and agronomic traits of sweet corn. Food, Agriculture & Environment, 12(2), 391–398. www.world-food.net

Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Soil Survey Geographic (SSURGO) Database. Available online at https://sdmdataaccess.sc.egov.usda.gov. Accessed 06/20/2024.

Thompson, L., Archontoulis, S., & Puntel, L. (2024). Determining site-specific corn nitrogen rate over time with APSIM model. 15th International Conference on Precision Agriculture, 1099–1105.

van Es, H., Ristow, A., Nunes, M. R., Schindelbeck, R., Sela, S., & Davis, M. (2020). Nitrate leaching reduced with Dynamic-Adaptive nitrogen management under contrasting soils and tillage. Soil Science Society of America Journal, 84(1), 220–231. https://doi.org/10.1002/saj2.20031

Wang, X., Miao, Y., Dong, R., Chen, Z., Kusnierek, K., Mi, G., & Mulla, D. J. (2020). Economic optimal nitrogen rate variability of maize in response to soil and weather conditions: Implications for site-specific nitrogen management. Agronomy, 10(9). https://doi.org/10.3390/agronomy10091237