# LINKING SOIL PROPERTIES AND WEATHER VARIABILITY TO NITROGEN FERTILIZER NEEDS

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## ABSTRACT

Soil Nitrogen (N) availability is known to be affected by weather and soil characteristics. Current fertilizer recommendations are generally based on yield goals, soil type, and past productivity; however, these methods frequently fail to account for the constantly changing interactions between soil chemical, biological, physical, and weather variables that influence N availability. This limitation increases uncertainty in estimating the economic optimum nitrogen rate (EONR), potentially reducing both profitability and environmental sustainability.  Studies were conducted from 2021 to 2024 at 44 sites in central and eastern South Dakota to assess the utility of soil health indicators in improving N fertilizer recommendations. Soil samples (0-6inches, 6-24inches) were collected prior to planting and fertilization. Soil health tests were performed on the 0-6 inches depth samples and the soil nitrate N test for both depths. Nitrogen was applied at rates ranging from 0 to 240lbs/ac, and the EONR was calculated for each site. In this paper, we will discuss the correlation among soil biological, chemical, and physical tests along with weather variables. Furthermore, we will explore the relationships between EONR and individual soil tests and weather data and identify the combination of soil tests for the predictability of EONR. The goal of this study is to improve nitrogen fertilizer recommendations by determining the extent to which soil health indicators and weather variables impact EONR.

## INTRODUCTION

Nitrogen (N) is a crucial nutrient that often limits crop productivity in corn (*Zea mays L.*). Current fertilizer recommendations are generally based on yield goals, soil type, and past productivity; however, these methods frequently fail to account for the constantly changing interactions between soil chemical, biological, physical, and weather variables that influence N availability. In addition to causing agricultural production inefficiencies, inaccurate N rate decisions can also harm the environment and reduce farmer profits. (Struffert et al., 2016). As a result, growers and researchers are increasingly seeking tools that can capture the dynamic behavior of soil nitrogen and improve the precision of N recommendations.

Soil health testing has emerged as a potential solution for improving N management by providing information on nutrient cycling mechanisms related to N rate response (Norris et al., 2020). Although soil health testing alone may not consistently forecast the best N rates, it has the potential to complement existing yield-based and soil testing approaches. When integrated, these assessments have the potential to improve the accuracy of N fertilizer recommendations and reduce uncertainty in decision-making.

Incorporating weather variability alongside soil health and soil properties further strengthens this approach, given the major role of temperature and precipitation in shaping soil N availability and crop uptake (Tremblay et al., 2012). Temperature controls microbial mineralization, nitrification, and denitrification, whereas rainfall distribution affects nitrogen leaching and volatilization losses. Years with early-season drought may inhibit mineralization, resulting in less N being available, whereas overly wet springs might increase nitrate loss from the soil profile. As a result, nitrogen requirements might vary significantly from year to year, even within the same area. Incorporating weather data, such as growing degree days, cumulative precipitation, and rainfall variability, into soil measurements creates a more comprehensive framework for predicting N requirements and economic returns. (Wang et al., 2020). Emerging research suggests that integrating soil health and weather variables could improve the prediction of the economic optimum nitrogen rate (EONR) by capturing both soil N supply potential and conditions that influence N transformations and crop uptake. The objective of this study was to examine the relationships between EONR and soil biological, chemical, and physical indicators, and weather variability to determine if soil health metrics and weather could be used to improve N fertilizer recommendations.

## MATERIALS AND METHODS

The study was conducted in 44 sites across central and eastern South Dakota from 2021–2024. Each treatment was replicated four times in a randomized complete block design (RCBD). Sites represented diverse soil types and management histories. Nitrogen treatments ranged from 0 to 240 lbs/ac in increments of 40 lbs/ac. The N fertilizer source was urea (46-0-0) as SuperU (Koch Fertilizer LLC) broadcast on the soil surface. Soil samples were collected from 0–6 and 6–24 inches prior to planting and fertilization. Soil samples were sent to Ward Laboratories (Kearney, NE) for soil analysis. Soil health indicators, including soil nitrogen, enzymes, soil carbon, and soil texture, were analyzed, which are included in Table 1. These tests were performed on 0-6 inches, while the Soil nitrate ($NO_3^-$-N) concentrations test was performed on both (0-6 and 6-24 inches) depths. Weather variables (total precipitation, average temperature, and growing degree days) were evaluated for each site using local weather station data, which are included in Table 2. Weather data were aggregated for the early season, late season, and full season. Pearson correlations were calculated among soil health indicators, weather variables, and EONR. Random forest modeling was used for ranking the importance of variables that most influenced EONR. Analyses were conducted using R 4.5.1.

## RESULTS AND DISCUSSION

Soil nitrogen was consistently one of the most important variables likely because soil N directly drives crop growth and fertilizer needs. Soil nitrates were a key driver of N fertilizer requirements, suggesting that sites with higher initial N availability or more active microbial populations may require higher N applications to reach EONR.

Water-extractable total N (H2OTotalN) was the strongest predictor (importance = 14.66), indicating that plant-available water-extractable N in the surface soil is the primary driver of the N fertilizer requirement. This aligns with Hu et al. (2024) who found that synchronizing early-season N availability (nitrate and ammonium) under straw-return systems significantly improved yields. Nitrate in topsoil increased EONR, reflecting available N for uptake. Accumulated nitrate N in the 0–24 in. layer also had a strong effect on EONR, confirming that deeper N availability is important. Sand content increased EONR slightly. Organic matter in the topsoil reduced EONR slightly (possibly due to higher inherent fertility). Deeper organic matter increased predicted N need; it reflects mid-layer fertility contribution. Cation exchange capacity deeper in the profile contributed moderately to EONR predictability. Further, the strong influence of nitrate N in the surface and 0–24 cm layers reinforces that measurable available N pools (e.g., $NO_3$-N) are key to accurately estimating N fertilizer needs.

Early-season minimum temperature increased EONR, while late-season cold stress reduced EONR. Early-season heat reduced predicted EONR while late-season warmth increased N requirement. Higher early-season rainfall diversity likely improves soil N cycling, N mineralization, and N use efficiency; reduces fertilizer requirement variability, while maximum precipitation during the full season can either increase or decrease EONR depending on timing. So, early-season heavy rainfall can flush applied N, requiring higher EONR. The well-distributed early rainfall reducing EONR, heavy early rainfall increasing it (likely due to leaching), align with the interactive findings of Donovan et al. (2025), who found that water and N interactions strongly influence net N mineralization and enzyme activity. Thus, accounting for weather allows for a more dynamic N recommendation model rather than a static rate.

POXC, ACE protein, soil respiration, and total C had a low-moderate influence on EONR, likely linked to N cycling but indirect. Organic matter & active C pools support microbial N supply, but they are indirect predictors compared to chemical N measurements. Soil C, not a primary predictor, but it helped in understanding soil fertility dynamics. Enzymes such as N-acetylglucosaminidase (NAG) and β-glucosidase (BG) showed moderate contribution. Enzymatic activity reflects soil microbial function and nutrient cycling efficiency. While not as influential as direct N measures, enzymes helped explain variability in N availability under different soil conditions.

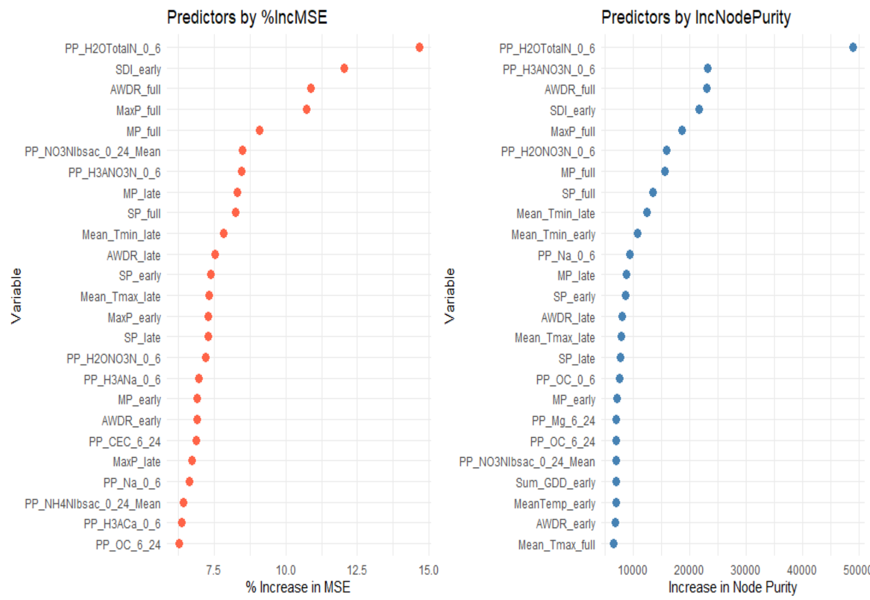


Figure 1: Random Forest variable importance plots ranking measured soil and weather variable on their influence of economic optimum nitrogen rate (EONR).

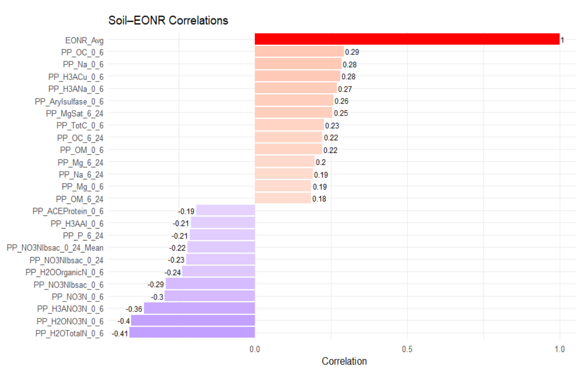


Figure 2: Pearson correlation matrix showing relationships among soil variables and EONR.

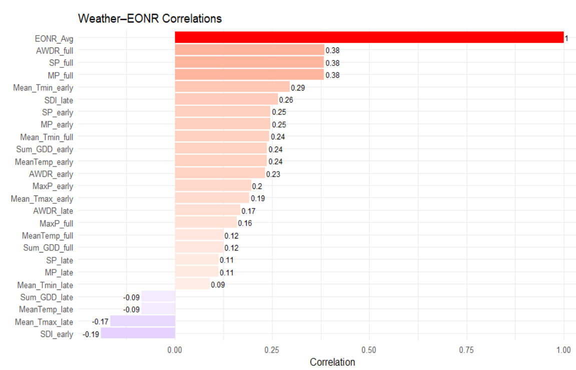


Figure 3: Pearson Correlation Matrix showing relationships among weather variables and EONR.

Table 1: Soil Test Measurements with descriptions and acronyms.

| Preplant Soil Measurement | Description |
|---|---|
| **Soil Nitrogen** | |
| H2O Total N | Water-extractable Total N |
| NO3-N | KCl extraction of NO3-N |

| | |
|---|---|
| H3ANO3-N | Haney H3A extraction of NO3-N |
| H2ONO3-N | Haney H2O extraction of NO3-N |
| NH4N | KCl extraction of NH4-N |
| **Soil Health Test** | |
| Arylsulfatase | |
| β-Glucosidase | |
| N-Acetyl-β-Glucosaminidase | |
| ACE Protein | |
| Soil Respiration | |
| | |
| **Soil Carbon and Other Tests** | |
| OC | Organic Carbon |
| OM | Organic Matter |
| CEC | Cation Exchange Capacity |
| Soil Texture | Sand, Silt, and Clay |

Table 2: Weather Variables evaluated

| **Weather Parameter and Acronyms** | |
|---|---|
| Tmin | Minimum Temperature |
| Tmax | Maximum Temperature |
| GDD | Growing Degree Days |
| MP | Mean Precipitation |
| MaxP | Maximum Precipitation |
| SDI | Shannon Diversity Index |
| AWDR | Abundant and well-distributed rainfall |
| Early season | March 1-June 30 |
| Late season | July 1-September 30 |
| Full season | March 1- September 30 |

## CONCLUSIONS

EONR is influenced by both soil health indicators and weather variability. Nitrate N distribution in both 0–6 and 6-24 inches layers was highly related to N fertilizer needs, emphasizing the importance of monitoring both shallow and deep N availability. Precipitation timing and intensity strongly influenced N uptake, while early- and late-season temperatures altered N fertilizer requirements. Well-distributed rainfall reduced EONR, whereas early-season heavy rainfall increased it likely by applied N being leached. Integrating soil N variables (especially water extractable N) and weather data can likely improve estimates of EONR.

## REFERENCES


Donovan, T. C., Comas, L. H., Schneekloth, J., & Schipanski, M. (2025). Nitrogen and water availability affect soil nitrogen mineralization and maize nitrogen uptake dynamics. *Nutrient Cycling in Agroecosystems*, *130*(3), 387–405. https://doi.org/10.1007/s10705-025-10406-8

Hu, J., Guan, X., Liang, X., Wang, B., Chen, X., He, X., Xie, J., Deng, G., Chen, J., Li, X., Qiu, C., Qian, Y., Peng, C., Zhang, K., & Chen, J. (2024). Optimizing the Nitrogen Fertilizer Management to Maximize the Benefit of Straw Returning on Early Rice Yield by Modulating Soil N Availability. *Agriculture (Switzerland)*, *14*(7). https://doi.org/10.3390/agriculture14071168

Norris, C. E., Bean, G. Mac, Cappellazzi, S. B., Cope, M., Greub, K. L. H., Liptzin, D., Rieke, E. L., Tracy, P. W., Morgan, C. L. S., & Honeycutt, C. W. (2020). Introducing the North American project to evaluate soil health measurements. In *Agronomy Journal* (Vol. 112, Issue 4, pp. 3195–3215). John Wiley and Sons Inc. https://doi.org/10.1002/agj2.20234

Struffert, A. M., Rubin, J. C., Fernández, F. G., & Lamb, J. A. (2016). Nitrogen Management for Corn and Groundwater Quality in Upper Midwest Irrigated Sands. *Journal of Environmental Quality*, *45*(5), 1557–1564. https://doi.org/10.2134/jeq2016.03.0105

Tremblay, N., Bouroubi, Y. M., Bélec, C., Mullen, R. W., Kitchen, N. R., Thomason, W. E., Ebelhar, S., Mengel, D. B., Raun, W. R., Francis, D. D., Vories, E. D., & Ortiz-Monasterio, I. (2012). Corn response to nitrogen is influenced by soil texture and weather. *Agronomy Journal*, *104*(6), 1658–1671. https://doi.org/10.2134/agronj2012.0184

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