EVALUATING SOIL HEALTH INDICATORS AS TOOLS FOR NITROGEN RECOMMENDATIONS

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ABSTRACT

Efficient nitrogen (N) management is essential for corn productivity and profitability while reducing unnecessary fertilizer inputs and potential N losses. However, estimating crop N requirements remains challenging because soil N availability and crop N demand can vary considerably across locations. Soil health indicators may provide additional information about soil N availability and nutrient cycling that may improve fertilizer N recommendations. The objective of this study was to evaluate relationships between selected soil health indicators and economic optimum nitrogen rate (EONR) for corn. Studies were conducted from 2023 to 2025 across 21 site-years in central and eastern South Dakota to assess the utility of soil health indicators in improving N fertilizer recommendations. Soil samples were collected from the 0–6-inch depth before planting and fertilizer application. Six soil health indicators were evaluated. Relationships between the soil health indicators and EONR were assessed using correlation analysis and simple and multiple linear regression. Individual soil health indicators explained up to 21% of the variation in EONR. Combining two soil health indicators explained up to 25% of the variation in EONR, representing only a modest improvement compared with the individual soil health indicators. When year was included in the regression models, the explained variation increased to 42%, indicating that year-to-year variability played an important role in determining crop N requirements. The results of this study indicate that soil health indicators provide information related to variation in EONR, but their ability to predict EONR when used alone or in combination is limited. The greater variation explained when year was included suggests that growing-season conditions are also important in determining corn N fertilizer requirements. Integrating soil health indicators with weather, soil characteristics, and other site-specific factors may provide a better approach for improving N fertilizer recommendations across variable growing conditions.

INTRODUCTION

Nitrogen (N) is an essential nutrient for corn (*Zea mays L.*) production and plays an important role in crop growth, yield formation, and profitability. Determining the appropriate N fertilizer rate remains challenging because soil N availability and crop N requirements vary across fields and growing seasons. Insufficient N can reduce crop yield and economic returns, while excessive application increases production costs and

the potential for N losses to the environment (Struffert et al., 2016). 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, and physical factors that influence N availability.

Soil health testing has received increased attention as a tool for improving nutrient management (Norris et al., 2020). Measurements such as soil respiration, permanganate oxidizable carbon (POX-C), total carbon, Illinois Soil Nitrogen Test (ISNT-2), and chemically extractable N fractions may provide information about soil biological activity, organic matter characteristics, and potentially available N pools. These indicators may therefore help explain differences in crop response to fertilizer N. However, relationships between soil health indicators and crop N requirements are not always consistent. A soil test that performs well under one set of conditions may show weaker relationships under different soil or environmental conditions. This variability raises questions about whether individual soil health indicators can reliably estimate the economic optimum nitrogen rate (EONR) or whether combinations of indicators provide more useful information. The objective of this study was to evaluate whether soil health indicators help explain variation in corn EONR, to evaluate relationships among soil health indicators, and assess whether combining selected indicators improves the explanation of EONR variation.

MATERIALS AND METHODS

The study was conducted at 21 sites in central and eastern South Dakota from 2023-2025. Each treatment was replicated four times in a randomized complete block design (RCBD). Soil samples were collected from the 0–6-inch depth before planting and fertilizer application. The evaluated indicators were ammonium-N (NH_4-N), ISNT-2, total carbon, hot 2 M KCl-extractable N, POX-C, and soil respiration (Hu et al., 2025; Pokhrel et al., 2024) . These indicators represent soil N pools and carbon pools. The EONR was used as the response variable for evaluating the soil health indicators. Statistical analyses were performed in R. Pearson correlation coefficients were calculated to describe relationships among soil indicators using pairwise complete observations. Individual linear regression models were used to evaluate the relationship between each soil indicator and EONR. Selected multiple-regression models were evaluated to determine whether combinations of indicators improved model fit. Model performance was summarized using R^2 and adjusted R^2, and statistical significance was evaluated using P-values.

RESULTS AND DISCUSSION

Several soil indicators were strongly correlated with one another (Figure 1). The ISNT-2 test had a strong positive correlation with total carbon (r = 0.90) and Hot KCl (r =

0.89), while total carbon and Hot KCl were also positively correlated (r = 0.79). NH_4-N was positively correlated with Hot KCl (r = 0.75) and ISNT-2 (r = 0.60). In contrast, soil respiration had weak correlations with the other indicators, ranging from approximately −0.19 to −0.01. POX-C showed moderate positive correlations with total carbon (r = 0.49) and ISNT-2 (r = 0.43). The strong correlations among several chemical and carbon-related indicators suggest that some tests may reflect overlapping soil properties. Soil respiration appeared to represent a different soil property from the more strongly correlated N and C indicators.

Among the individual indicators (Figure 2), soil respiration had the strongest relationship with EONR (R^2 = 0.209, P = 0.037). Its fitted relationship with EONR had a negative slope (−0.945), indicating that higher respiration values were associated with lower EONR. However, the model explained about 21% of EONR variation, leaving most of the variation unexplained. The relationship also weakened when year was included in the analysis and was not statistically significant after the year adjustment (P = 0.103). This result indicates that the relationship may partly reflect differences among years and should not be interpreted as a consistent predictor of EONR across growing seasons. These findings are consistent with Bean et al. (2020), who reported a similar relationship between soil respiration and EONR R^2 = 0.21 across 49 Midwest site-years. However, the relationship varied among years, with stronger predictive ability in 2016 than in the previous two years. This supports the interpretation that soil respiration may provide useful information about corn N requirements but is not a consistent stand-alone predictor across growing seasons.

The remaining indicators showed weak relationships with EONR. The ISNT-2 test had an R^2 = 0.05 (P = 0.311), total carbon had an R^2 = 0.03 (P = 0.474), Hot KCl had an R^2 = 0.02 (P = 0.577), POX-C had an R^2 = 0.01 (P = 0.603), and NH_4-N had R^2 = 0.003 (P = 0.814). None of these relationships were statistically significant. These results indicate that the individual indicators had limited ability to predict EONR in the site-years evaluated. This finding is consistent with McDaniel et al. (2020), who found that most individual soil tests had limited accuracy in predicting corn N response across U.S. Midwest site-years, although selected combinations of biological and chemical tests improved prediction.

Combining soil indicators provided only a small improvement in model performance (Figure 4). The selected model containing ISNT-2 and soil respiration had an R^2 of 0.254 and an adjusted R^2 of 0.171, with an overall model P-value of 0.071. Although the model explained more variation than either indicator alone before adjustment, the overall relationship did not meet the 0.05 significance level. Adding ISNT-2 to the respiration model increased adjusted R^2 only slightly, from 0.167 to 0.171, and the nested-model comparison was not significant (P = 0.310). These findings suggest that combining the evaluated indicators provided only a modest improvement in

model performance. However, this does not mean that all possible combinations of soil health indicators would perform similarly. Similarly, Ransom et al. (2023) evaluated approaches for estimating corn EONR using multiple nitrogen recommendation tools, highlighting the importance of evaluating how different tools perform when combined. These results suggest that combining soil health indicators does not necessarily improve EONR prediction and that further evaluation across more site-years and environmental conditions is needed to identify reliable predictors

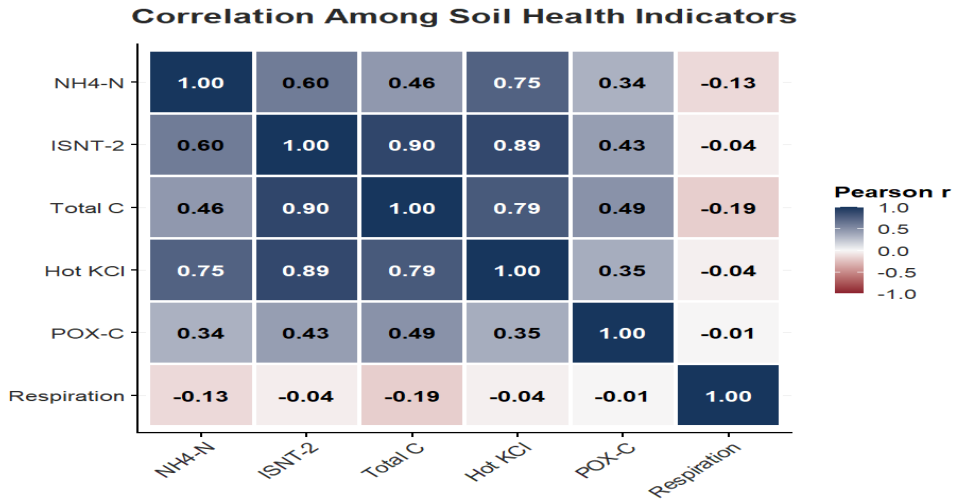


Figure 1: Correlation Among Soil Health Indicators

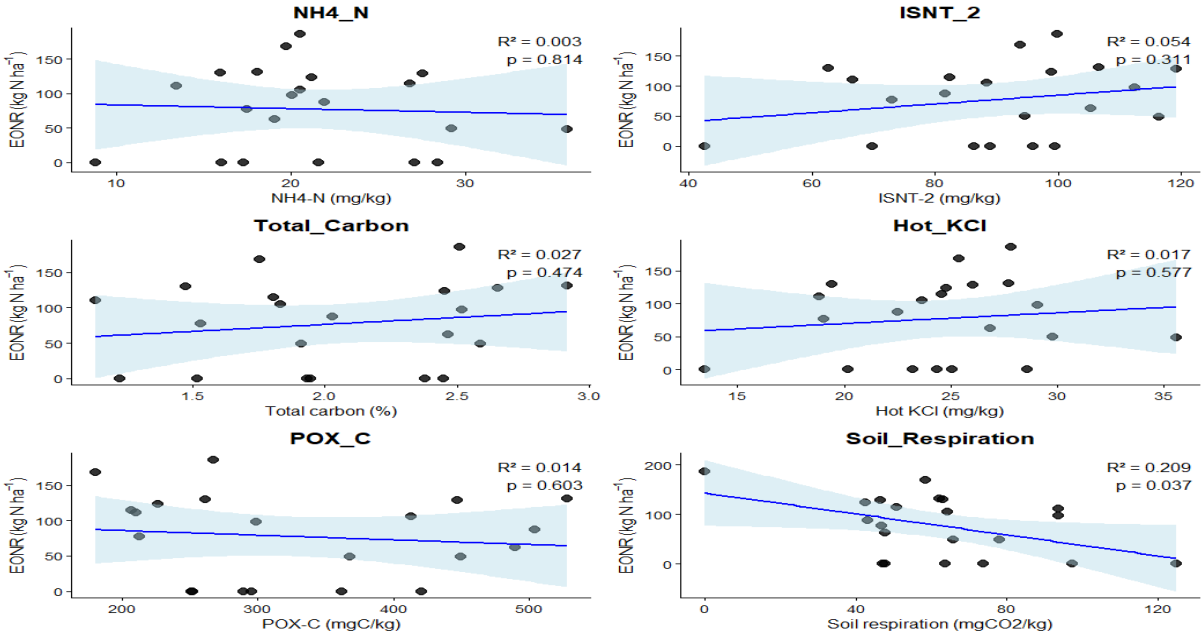
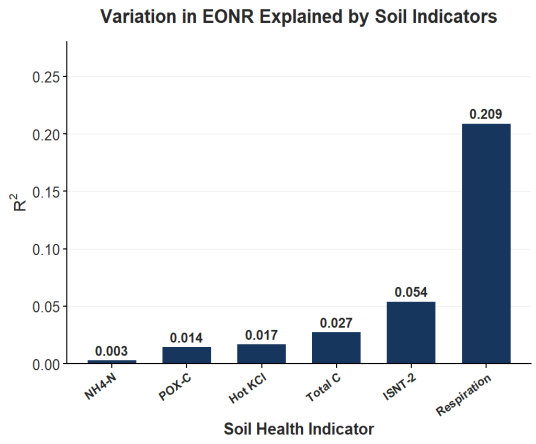


Figure 2: Relationships Between Individual Soil Health Indicators and EONR



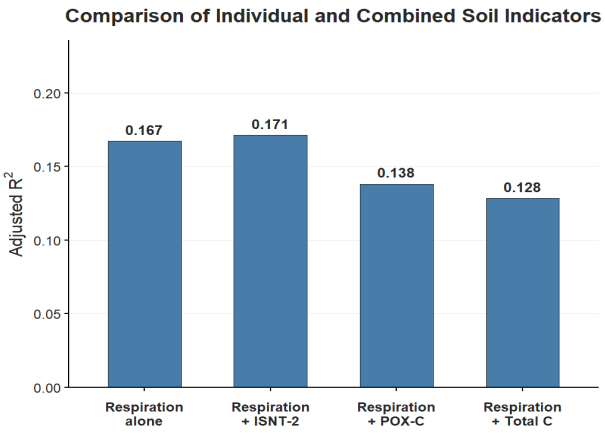


Figure 3: Comparison of Soil Health Indicator Performance in Predicting EONR. Figure 4: Performance of Combined Soil Health Indicator Models

Table 1: Nitrogen and Carbon Pools Measured by Analytical Methods

Method	**Primary Pool Measured**
Mason-Jar Diffusion	Inorganic N (NH_4^+-N)
Heated KCl	Hydrolyzable organic N
ISNT-2	Amino sugar-derived organic N
POXC	Labile organic C
Total Carbon	Total soil organic and inorganic carbon
Soil Respiration	CO_2 released through microbial and root respiration

CONCLUSION

Soil health indicators explained a limited amount of variation in corn EONR. Soil respiration was the strongest individual indicator associated with corn EONR, but it explained only a limited share of the variation, and its relationship was not significant after accounting for year. The other indicators showed weak individual relationships, and combining years and ISNT -2 with soil respiration resulted in only a modest improvement in model fit. These findings indicate that the tested indicators are not sufficient as stand-alone tools for estimating EONR. Integrating soil health indicators with soil N availability, weather, and field management information may provide a more complete approach for improving N fertilizer recommendations.

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