Evaluating Corn Yield Response to Nitrogen According to Soil Parameters in Midwest American Farmland

J.L. Enrria, C. Hernández, F. Palmero, A.J.P. Carcedo, and I.A. Ciampitti

Summary

Nitrogen (N) availability is one of the most common factors limiting corn yields. Corn N requirements are determined mainly by seasonal conditions and soil characteristics. An inaccurate N fertilization program could compromise the economic and environmental sustainability of the activity. The aim of this study was to determine the influence of soil characteristics (clay, sand, water content, pH water, and organic matter) on corn's yield response to N fertilization in the midwestern USA. A published data set was analyzed, containing 49 experiments (year-site combinations) related to corn N fertilization and soil characteristics in eight midwestern American states. The soil variables were analyzed to classify the experiments into two clusters. An econometric spatial model was fitted to explore the corn yield response to nitrogen in each cluster. Grain yield response to N total amount differed between clusters. Moreover, yield estimated values presented were significant for yield potential to 0 N lb/a, Cluster 1= ~149 bu/a and Cluster 2= ~165 bu/a, and maximum yield, ~289 bu/a and ~275 bu/a for Cluster 1 and Cluster 2, respectively. The overall response in yield to a unit of N (lb/a) was ~1 bu/a to Cluster 1 and ~0.85 bu/a to Cluster 2. These findings could lead to further analysis to be carried out considering larger soil parameters in wider environmental conditions.

Introduction

Corn (*Zea mays* L.) is one of the most important crops worldwide, with the United States of America (USA) accounting for ~30% of the total production (Food and Agricultural Organization, 2022). Nitrogen (N) is a common limiting factor for yield, and it is widely recognized by farmers and agronomists not only for its crucial role in crop growth but also as a significant production cost (Ciampitti and Vyn, 2014; Langemeier, 2023; Morris et al., 2018). Consequently, managing N efficiently poses a considerable challenge for corn production across the farmland of the USA.

Generalized N fertilization strategies can lead to undesirable outcomes. Inappropriate management of application rate and timing can negatively impact the sustainability of the system guiding to environmental N pollution and farmers' profit reduction (Galloway et al., 2004). The main determinants of corn N requirements are the conditions of the growing season, such as water availability and solar radiation (van Es et al., 2007), as well as soil texture and fertility (Correndo et al., 2021).

However, to the best of our knowledge, there is a lack of information addressing the impact of grouped soil variables on corn N response in the main corn production area in the USA. This study aims to determine whether corn yield response to N is influenced by clusters of soil characteristics across multiple states within the USA Midwest.

Procedures

A published dataset exploring the response of corn grain yield to N fertilizer was used in this study (Ransom et al., 2021). This dataset comprises 49 experiments (site-year combinations) carried out across eight midwestern USA states (Nebraska, North Dakota, Minnesota, Iowa, Missouri, Illinois, Wisconsin, and Indiana) from 2014 to 2016. The N treatments involved eight fertilization levels and two application timings (pre- and post-planting). Ammonium nitrate was utilized as N source. Additionally, the dataset included soil variables at each experimental site such as: 1) soil water content, 2) soil pH water, 3) soil clay content, 4) soil sand content, and 5) soil organic matter (OM) (Ransom et al., 2021).

A clustering of the experiments using soil characteristics as inputs was carried out employing unsupervised classification through K-means. To determine the number of clusters the R package NbClust was employed (Charrad et. Al, 2014). The observed yields for each cluster were compared through an analysis of variance (ANOVA). Furthermore, a quadratic model with spatial correction was fit to study the relationship between grain yield and N application and the defined clusters. All analyses were conducted using R software (R Core Team, 2023).

Results

The observations were classified into 2 clusters. Cluster 1 was characterized by soils with more sand content than Cluster 2 (59% vs. 15%, respectively) (Figure 1D). While Cluster 2 reported greater values of OM, soil clay content, and soil water content compared to Cluster 1 (3% vs. 2%; 27% vs. 12% and 0.25 vs. 0.16 g g^{-1}, for Cluster 2 and Cluster 1, respectively (Figure 1B, A, and E). In contrast, both clusters presented similar pH water values (~7; Figure 1C).

A small, yet significant difference ($P \leq 0.01$, Table 1) in corn yield appeared between clusters, where Cluster 2 showed a mean value of 190 bu/a, while Cluster 1 presented 199 bu/a. (Figure 2).

Lastly, the interactions between N and Cluster were significant ($P \leq 0.05$) (Table 2). There was a differential response in corn yield to the addition of N unit in each cluster (Figure 3). The predicted yield at 0 N lb/a was 149 bu/a and ~165 bu/a for clusters 1 and 2, respectively. In addition, Cluster 1 reported on average a greater increment in grain yield (~1 bu/a) versus cluster 2 (~0.85 bu/a) per N unit (N lb/a). Thus, with fertilizations over ~85 N lb/a (~238 bu/a) Cluster 1 achieved greater yield values. Furthermore, the N value that maximized yield was different between clusters, presenting Cluster 1 a value of 265 N lb/a and for Cluster 2 and 258 N lb/a, achieving ~289 bu/a and ~275 bu/a, respectively.

Conclusion

Corn grain yield response to N is affected by soil characteristics. These characteristics can be grouped into clusters, mainly differentiated by their texture. Environments with greater sand content showed a larger response to the N amount (~1 bu/a versus ~0.85 bu/a). However, further analysis should consider the incorporation of wider environments and several soil variables that could affect this response. Moreover, the addition of spatial information is a valuable tool to increase the accuracy of these types of studies.

References

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Table 1. Analysis of variance for grain yield comparing the clusters

Factor	Sum Sq	Mean Sq	F value	P-value
Cluster	1.348e+08	134772836	16	$P < 0.001$
Residuals	2.318e+10	8357205		

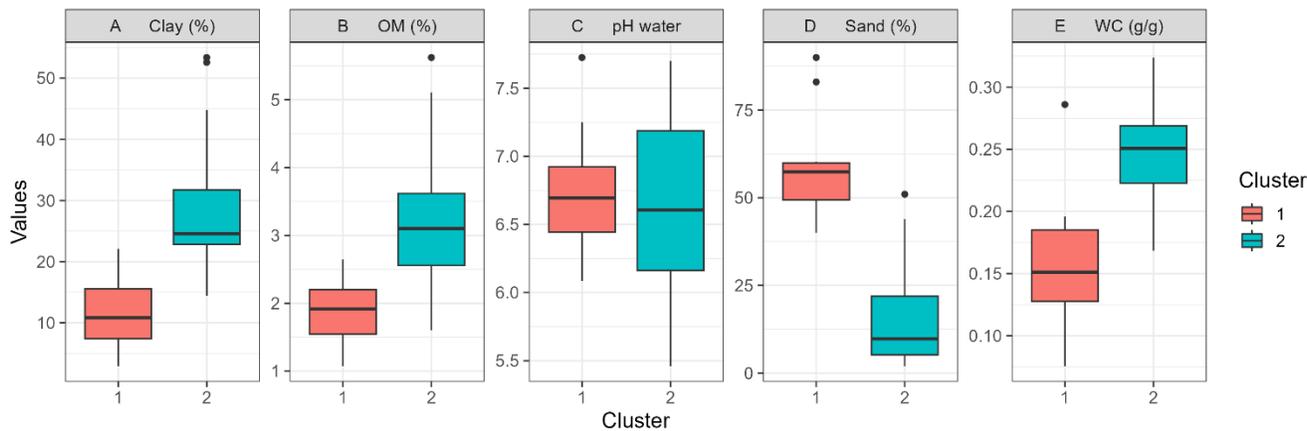Sum Sq = sum of squares. Mean Sq = mean of squares error.

Figure 1. Summary of soil variables split by clusters (Cluster 1 = coral, Cluster 2 = teal) regarding soil variables: A) Clay, B) organic matter (OM), C) pH water, D) sand, and E) water content (WC).
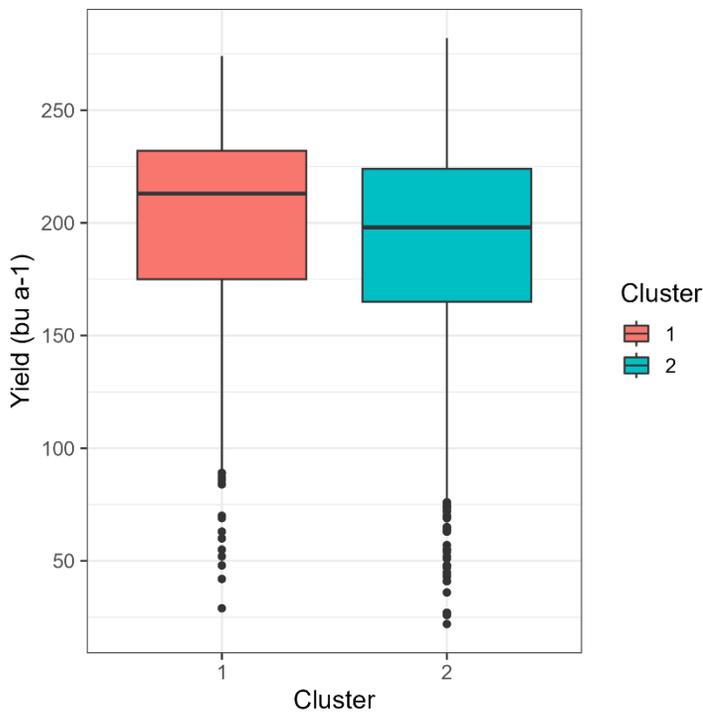

Figure 2. Corn grain yield observed by cluster (Cluster 1 = coral, Cluster 2 = teal)
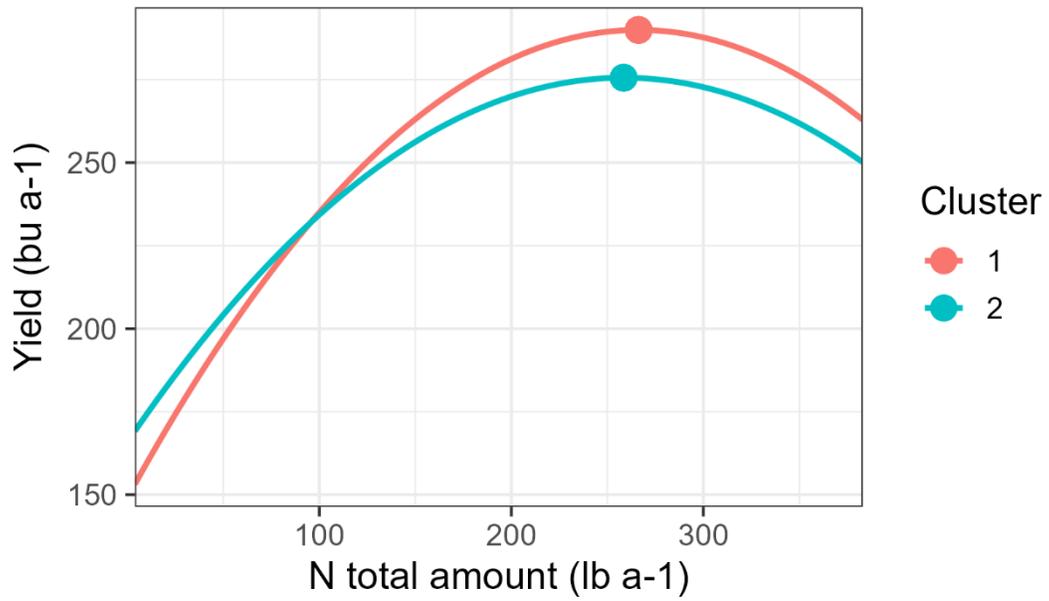
Figure 3. Estimated response of corn grain yield to nitrogen total amount. (Cluster 1 = coral, Cluster 2 = teal). Each symbol corresponds to the maximum grain yield for each cluster.