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Crop Rotation and N Input Effects on Mineral Elements in Soil, Corn, and Grain as Revealed by Discriminant Analysis

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INTRODUCTION

Understanding the complex interactions of soils, plants, and management practices is a first step towards development of agricultural systems that conserve soil and water resources while sustaining crop production. We were interested in identifying soil, plant, and grain mineral nutrient variables that best discriminate N input treatments as well as rotation treatments from one another. Study objectives were to use multivariate discriminant analysis to measure soil, shoot, and grain mineral nutrient responses to corn monoculture (C-C), 2-yr rotation (C-S) with soybean, or 4-yr rotation (C-S-W/A-A) with soybean, wheat, and alfalfa under different N input levels.

MATERIALS AND METHODS

This 2-yr field study was conducted at the Eastern South Dakota Soil and Water Research Farm near Brookings, SD in the ninth and tenth year of the long-term 'input plot' experiment. Additional information on the experiment can be obtained from *Agronomy Journal* (2005; Vol. 97 pages 854-863). We evaluated N fertilizer input (135 or 85 bushel/acre yield goal, or no N) and crop rotation (C-C, C-S, or C-S-W/A-A) treatment effects on soil, corn plant (V12 leaf stage), and grain minerals (N, P, K, S, Ca, Mg, Fe, Mn, and Zn) using multivariate discriminant analysis statistical tests. Preseason soil samples (depth of 1 foot) were analyzed for nitrate-nitrogen (NO₃-N) using calcium phosphate extraction, for P using the Bray P1 method, and for concentrations of K, S, Ca, Mg, Fe, Mn, and Zn using DTPA extraction.

Corn shoots (V12 stage) and grain were dried, ground, and analyzed for N using the Kjeldahl method. Ground tissue was digested in nitric acid and an ICP-AES was used to measure P, K, S, Ca, Mg, Fe, Mn, and Zn concentrations.

Given a classification variable with several groups as dependent variables (e.g. years, N input, or crop rotation treatments) and several quantitative independent variables (e.g. soil, plant and grain nutrients), canonical discriminant analysis (using Statistica Software, release 8) derives canonical discriminant functions which are linear combinations of the quantitative variables that have the largest possible multiple correlation with the groups in the classification variable. Used in this manner, canonical discriminant analysis is a powerful tool in determining the multivariate correlations between these groups and their characteristics based on the independent variables.

Correlation coefficients between each independent variable and the first two canonical discriminant functions (i.e. CAN1 on the x-axis and CAN2 on the y-axis) were plotted and used to interpret the nature of discrimination between N input (Fig. 1) and between crop rotation (Fig. 2) treatments.. The percentage of the total variation explained by each CAN was also listed on axis label of the graphs. The larger the value of the percentage of total variation explained, the greater the contribution of the respective canonical discriminant function to discrimination between groups. The correlation between the individual nutrient variables and the canonical function for each axis (i.e. loading) were also listed on the graph axis labels. These loading values, used in conjunction with treatment groups that are separated across the origin, allow the reader to determine the characteristics of the mineral nutrients in separating treatments.

RESULTS AND DISCUSSION

The first and second canonical discriminant functions (CAN1 and CAN2) extracted from the whole data set for N input treatments accounted for 68 and 32% of total variation, respectively (Fig.

1). Discriminant analysis indicated large negative loadings (i.e., correlation between the nutrient and a particular canonical function) of plant N, grain N, and grain S as well as large positive loading of plant Zn on CAN1. Negative loadings of soil Zn and soil P as well as positive loadings of soil Ca and soil N were evident on CAN2. The scatter plot of high N and no N input treatments were mostly separated along CAN1 (Fig. 1). Intermediate N input was separated from the high N and low N inputs along CAN2. This indicates a stronger separation between high N and no N input treatments, and a smaller separation between these two N input treatments and the intermediate N input treatment. The scatter plot and loadings on CAN1, in particular, indicate that large values of plant N, grain N, and grain S as well as small values of plant Zn were characteristics of high N inputs; whereas the opposite is true for low N inputs. Similarly, albeit with smaller discriminatory power on CAN2, large values of soil N and soil Ca were characteristic of intermediate N input; whereas, large values of soil P and soil Zn were characteristics of both high N and no N input treatments.

A stronger level of discrimination was observed between crop rotations when compared with the level of discrimination between N-inputs. The C-C and C-S-W/A-A rotations, each of which were 100% correctly classified, were totally separated from each other along CAN1, which accounted for a large portion (85%) of total variation (Fig. 2). The C-S rotation, also 100% correctly classified, was scattered on both sides of CAN1 (Fig. 2). However, the C-S rotation was totally separated from the other rotations along CAN2, which accounted for 15% of total variation. Soil N, grain N, plant Ca, and grain S were most significant in differentiating between all three crop rotations on CAN1; whereas, grain N, grain P, grain S, grain Zn, and plant Ca were the most significant in differentiating between the C-S and the other two rotations. Small values of soil N, grain N, plant Ca, and grain S as well as large values of soil P were characteristics of the C-C crop rotation. Large values of soil N, grain N, plant Ca, and grain S as well as small values of soil P were characteristics of the C-S-W/A-A rotation.

Several common mineral nutrient responses to treatments were evident when the experiment was viewed at the univariate and multivariate levels. The importance of soil N likely resulted from the relationships between soil N fertilizer applications, the inclusion of legumes in rotations, and the effects legumes have on providing N-rich

substrates for soil N mineralization. The importance of soil P likely resulted from the inclusion of a forage legume and the lack of P fertilizer applied to that phase of the C-S-W/A-A rotation which in turn altered the extractable levels of this important soil mineral element. Thus, it was not unusual to find that both soil N and soil P exhibited large loadings on canonical discriminant functions calculated for N input and crop rotation treatments (Figs. 1 and 2). Plant Ca responded to rotation treatment (and its interaction with N input) in a manner similar to that of plant N. Additionally, plant Ca had large loading on both canonical discriminant functions (CAN1 and CAN2) important for discriminating between rotation treatments (Fig. 2). We speculate that N deficiency reduced root exploration needed to promote the absorption of Ca from the soil.

Given the effects of N input and rotation treatments (and their interactions) on grain N, it was not surprising that grain N played an important role in discriminating between N inputs and between rotations. Grain N, as well as grain S, had large loading on CAN1 important for discriminating between N input treatments (Fig. 1) as well as on both CAN 1 and CAN2 important for discriminating between rotation treatments (Fig. 2).

The similarity in loadings of grain N and grain S may have resulted because grain S responded to N input and rotation treatments in a manner similar to that of grain N. These data confirm a close association between N and S concentration in corn.

Crop rotation has been an important component of agricultural systems for centuries. With the advent of synthetic pesticides and fertilizers during the mid-20th century, however, extensive crop rotations were supplanted by intensive monoculture or short rotation cropping in many areas of the US. Concerns and costs associated with these intensely-managed systems include decreased soil organic matter, degraded soil structure, increased soil erosion, increased surface and groundwater contamination, and increased production costs. Under the 4-yr C-S-W/A-A rotation, where corn followed a forage legume, corn grain yield was stable across all N input levels studied (data not shown). Conversely, corn yield decreased as N input level was reduced under the C-C monoculture and 2-yr C-S rotation treatments. Thus, growing corn in extended rotations that include forage legumes may be a more sustainable practice than growing corn in either monoculture or 2-yr rotation with soybean.

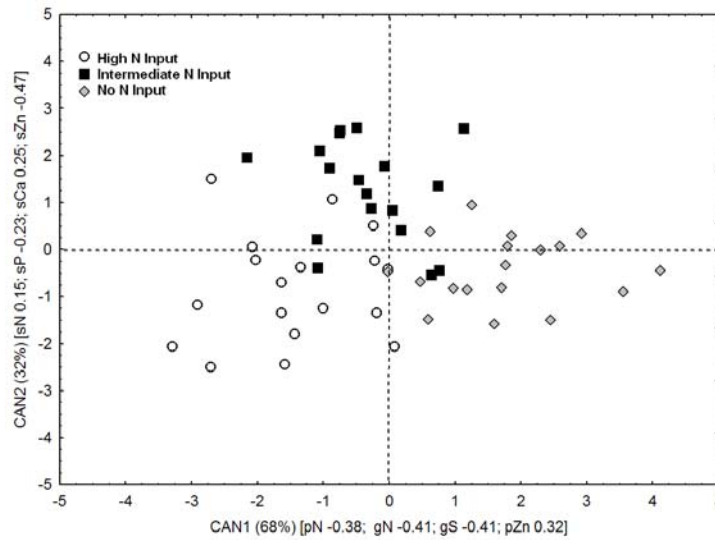


Figure 1. Discriminant analysis plot of canonical discriminant functions derived from soil, V12 plant, and grain mineral nutrient data within N input treatments across years and rotation treatments. The dotted line marks the origin of each of the discriminant functions. Values in parentheses represent the total variation explained by each discriminant function. Loadings of mineral nutrients which contributed significantly to discrimination between N-inputs on each discriminant function are also presented on the x- and y-axis labels. (CAN1, first canonical discriminant function; CAN2, second canonical discriminant function; pN, plant N; gN, grain N; gS, grain S; pZn, plant Zn; sN, soil N; sP, soil P; sCa, soil Ca; sZn, soil Zn).

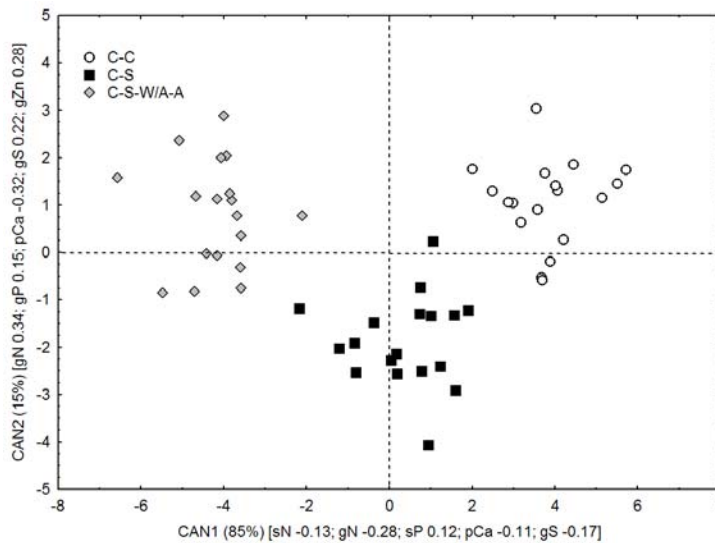


Figure 2. Discriminant analysis plot of canonical discriminant functions derived from soil, V12 plant, and grain mineral nutrient data within rotation treatments across years and N input treatments. The dotted line marks the origin of each of the discriminant functions. Values in parentheses represent the total variation explained by each discriminant function. Loadings of mineral nutrients which contributed significantly to discrimination between crop rotations on each discriminant function are also presented on the x- and y-axis labels. (CAN1, first canonical discriminant function; CAN2, second canonical discriminant function; pN, plant N; gN, grain N; gS, grain S; pZn, plant Zn; sN, soil N; sP, soil P; sCa, soil Ca; sZn, soil Zn).