INVESTIGATING CORN NITROGEN SUFFICIENCY AT THE FIELD LEVEL*

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Within field soil variation and placement of strips to evaluate plant nitrogen status poses a problem. Field level research in six producer fields in Iowa addressed quantification of N sufficiency relative to application rates and resulting grain yield. Fields were stratified, using soil survey and remotely sensed bare soil imagery, to evaluate zonal management potential, and striped with nitrogen treatments that incorporated minimal N sufficiency. Soil nitrate-N, ear leaf nitrogen concentration, leaf chlorophyll, hand harvest yield, and high spatial resolution aircraft multispectral data were collected from statistically located plots within each strip. Strip yields were determined by yield monitor and weigh wagon. Statistical and quantitative analysis evaluated the relationship between N application rates and plant N status for plot and strip measurements. Spatial arrangement of nitrogen strips within fields may not be as critical as previously thought, however, sample size for soil and plant observations emerged as a critical parameter.

INTRODUCTION

There is a growing concern that over use of nitrogen (N) by corn producers in the Midwest is contributing not only to increased stream, lake and groundwater nitrate-N concentrations but also to the Gulf of Mexico hypoxia problem. However, producers are reluctant to adopt management practices that they perceive as economically detrimental because of the variation within fields.

An experiment was conducted to evaluate methods for quantifying plant nitrogen

MATERIALS AND METHODS

EXPERIMENTAL DESIGN

The study consisted of 6 field sites in west-central- and central-Iowa, ranging in size from 15-58 hectares. Fields were chosen to represent a range of landscape and soils differences but not extremes. The fields were identified according to the county in which they were located, Carroll 1, Carroll 2, Sac 1, Shelby 1, Story 1 and Story 2. The Story county fields were the most uniform, particularly Story 2 with one dominant soil and very little relief. The western Iowa fields exhibited more diversity than the Story fields, with different landscapes and soils: one with slopes exceeding 10%.

Fields were stratified based on soil survey polygons and aircraft acquired multispectral imagery. Up to three candidate “smart” sample strata were identified in each field. Eight nitrogen test strips, 46 to 50 meters wide were laid out in five fields with six strips in Story 1. 12 or more plots, five rows by five meters in size, were randomly located in each strip. In some cases a predetermined number of plots were allocated to strip-stratum. A constraint was placed on the randomization process to ensure that plots were distributed throughout the length of each strip-stratum. The process was to divide the stratum-strip length by the number of assigned plots and randomly locate a plot in the interval.

Most plots in the Carroll county fields were paired in order to test treatment differences between two adjacent strips. The paired plots were separated by eight rows, four in each treatment, with a single random selection made to locate each plot pair. In Carroll 1 pairing was done in the replicated 112 and 157 kg ha-1 strips. In Carroll 2 a 112 kg ha-1 nitrogen strip was flanked by a 67 and 157 kg ha-1 nitrogen strip, so the 112 was paired with both strips. Plots were on the west and east side of the 112 kg ha-1 nitrogen strip. Additionally, there were two replications of 157 and 180 kg ha-1 nitrogen strip pairs.

The experiment was a randomized block design with each field receiving two replications of three or four levels of nitrogen treatments. The fields in west-central Iowa received nitrogen treatments of 67, 112, 157, and 202 kg ha-1 in 46-meter wide strips at planting. However, in Shelby 1 only the 157 and 202 kg ha-1 nitrogen strips were replicated. Two of the strips that were designated to receive 67 and 112 kg ha-1 nitrogen received an unknown quantity of nitrogen fertilizer. The Story county fields received a base nitrogen rate of 50 kg ha-1 at planting, with nitrogen treatments side dressed around the V5 stage of development. The Story county nitrogen strips were 66 meters wide. Story 1 received three levels of nitrogen treatments, 0, 45, and 90 kg ha-1. Story 2 received the same treatments as Story 1 plus an additional treatment of 134 kg ha-1.

FIELD MEASUREMENTS

20 plants were randomly selected within each plot. There was a constraint on the randomization process to ensure that selected plants would be uniformly distributed throughout each plot.

The following measurements were made in each plot to evaluate plant nitrogen status: leaf greenness with a Minolta SPAD-502 Chlorophyll Meter, leaf nitrogen concentration, tissue analysis, hand-harvest plot yields, and late season basal stalk nitrate analysis. Leaf chlorophyll measurements were collected on each of the flagged plants at pre tassel and twice during the reproductive stages of corn plant development in the western Iowa fields, and at R1, R3, and R5 in the Story county fields (Ritchie et al., 1996). Leaf tissue data was collected coincident with the last set of chlorophyll meter readings, on every other flagged plant during at R3 or R5 depending on the field. Basal stalk segments, for stalk nitrate analysis, and ears were hand harvested from the remaining flagged plants after R6 had occurred. Stratum/strips were harvested separately with combines equipped with dGPS yield monitors. All field collected data were georeferenced by dGPS.

ANALYSIS

Each field stands alone as an analysis unit. It was hoped that some trends or commonality would be evidenced across fields allowing extension of knowledge gained to a larger number of corn fields in Iowa.

Main effects of nitrogen were evaluated for Carroll 2, Shelby 1, and Story 2 with the general linear models procedure in SAS (PROC GLM). The main effects and interactions of soil and nitrogen were evaluated in Sac 1 and Story 1 with the GLM procedure in SAS. Differences between treatment means were further tested with Duncan's multiple range-test when appropriate (Lorenzen and Anderson, 1993, p. 30-31). T tests were performed in SAS (PROC TTEST) on paired plot data from Carroll 1 and Carroll 2 (SAS Institute, 1988). The SAS correlation procedure (PROC CORR) was used to evaluate the relationships between field measurements averaged for each strip, and combine strip yields (Cody and Smith, 1997, p. 117). Treatment differences and Pearson correlation coefficients are reported as significant at the 0.05 level of probability.

Aircraft remotely sensed imagery is being evaluated to determine the potential to detect strip greenness difference. Image data will be blocked by stratum/strip/segment. The plan also calls for registering VT and R3 imagery at the plot level providing a spectral measurement that can be subjected to the same analysis as all other plot measurement data.

Satellite (Landsat 5 and 7) data are coarse (30 by 30 meter pixels) relative to the strip width (roughly 50 meters). The best registration of data will result in an irregularly spaced string of pixels. Analysis if this type of data does not fit well in the experimental design but a temporal change approach (perhaps as many as 6 vegetation images) by strip may reveal patterns that can be interpreted.

RESULTS AND DISCUSSION

CARROLL 1

There was no evidence that the main effects of nitrogen treatments influenced grain yield or plant nitrogen status. The data suggests that nitrogen treatments above 67 kg ha-1 in Carroll 1 provided no advantage in crop performance. Strip grain yields, measured from the combine, were 8424 to 8596 kg ha-1 for the 67 and 202 kg ha-1 nitrogen treatments, respectively. Based on yield estimates obtained from hand-harvest data there were no significant differences in yield. Plots from the 67 kg ha-1nitrogen strips had estimated yields of 8690 kg ha-1, where as average yield estimates from the remaining treatments were between 7860 and 7967 kg ha-1. SPAD measurements collected at V14, R1 and R3 also indicate that leaf greenness was not influenced by the nitrogen treatments. Average SPAD values across all treatments were 57.9, 60.5 and 59.1 for V14, R1 and R3, respectively.

Based on the results from other fields in this study, the relationship between leaf greenness, as measured by the SPAD chlorophyll meter, and grain yield in maize is reasonably strong. However, in Carroll 1 there were no significant relationships between SPAD readings and grain yield. Conversely, the relationship between grain yield and leaf nitrogen concentration from ear leaves collected at the R3 stage of development, was significant with a Pearson correlation coefficient of 0.77. The relationship between R3 SPAD measurements and leaf N content was not significant.

PAIRING IN CARROLL 1 AND 2

Results of pairing were mixed. T test results for the paired strips in Carroll 1 show that there were no significant differences between treatment means for SPAD measurements, leaf N content nor plot yields in either strip pair. Grain yields in Carroll 2 increased with nitrogen treatments. However, in Carroll 2 hand-harvested grain yield and leaf nitrogen concentration at R3 was significantly increased by the higher nitrogen rate in the 67 and 112 kg ha-1 nitrogen treatment comparison. Average plot grain yields were 9339 and 10302 kg ha-1 for the 67 and 112 kg ha-1 nitrogen treatments, respectively.

R3 SPAD values increased in all strip pairs but one of the 157 and 202 kg ha-1 nitrogen treatment comparisons. SPAD values collected at R3 were 57.3 and 58.9 in the 112 and 157 kg ha-1 nitrogen strip and the increase was significant. However, a greater increase was observed when R3 SPAD data was collected from the 67 and 112 kg ha-1 nitrogen strip pair (56.9 and 58.2, respectively), but was significant only at the 0.06 level of probability. The decrease in significance for 67-112 kg ha-1 nitrogen strip pair may have been due to the reduced number of observations per strip. There were 10 and 12 plots per strip in the 67-112 and 112-157 kg ha-1 nitrogen strip pairs, respectively.

Grain yields in Carroll 2 increased with nitrogen treatments (average plot yield estimates were 9545, 10010, 10169, 10489 kg ha-1 for the 67, 112, 157, and 202 kg ha-1 nitrogen treatments, respectively). However, the increase in yield was only significant in one strip pair, 67-112 kg ha-1 nitrogen comparison, which may indicate that 112 kg ha-1 nitrogen was a sufficient level of nitrogen for Carroll 2. Based on the results from Carroll 1, 67 kg ha-1 was a sufficient level of nitrogen.

SAC 1

Plot grain yield estimates primarily decreased with increasing nitrogen rates in Sac 1. The estimated treatment yields were 9317, 9173, 9107, and 8690 kg ha-1 for the 67, 157, 112 and 202 kg ha-1 nitrogen treatments, respectively. However the nitrogen treatment effect on grain yield was not significant. Additionally, SPAD measurements collected at VT and R5 were not significantly influenced by the nitrogen treatments, Conversely, SPAD measurements collected during R3 from the 67 kg ha-1 nitrogen strips were significantly lower than SPAD values from the 157 and 202 kg ha-1 nitrogen treatments. Average SPAD values collected at R3 were 57.5, 57.9, 58.4, and 58.4 for the 67, 112, 157, and 202 kg ha-1 nitrogen treatments, respectively.

The relationship between combine yields and hand-harvested plot yields was significant (r = 0.80). Additionally, SPAD measurements collected at the R5 stage of corn plant development had a significant relationship with combine strip yields and ear leaf nitrogen concentration at R5, with Pearson correlation coefficients of 0.78 and 0.86, respectively.

The trend of negative a negative relationship between grain yield and increasing with nitrogen treatments was also observed from the combine yield data. However, based on the plot data, showing virtually no response to nitrogen treatments, differences in combine grain yields among nitrogen treatments most likely were not significant. Therefore, a nitrogen fertilization rate of 67 kg ha-1 may have been sufficient for Sac 1 grain production.

SHELBY 1

Plot grain yields and SPAD measurements were not significantly influenced by the nitrogen treatments in Shelby 1. Combine grain yield measurements ranged from 10201 to 10311 kg ha-1 across the known nitrogen treatments and 9225 and 9802 kg ha-1 in the strips with unknown nitrogen levels. The known nitrogen treatments had no influence on leaf nitrogen concentration measured during the R3 stage of development. However, a significant reduction in ear leaf nitrogen concentration was observed in the two strips with unknown fertilizer nitrogen levels. Ear leaf nitrogen concentration ranged from 3.01 to 3.06 %N in the strip with known nitrogen rates and 2.79 to 2.87 %N in unknown nitrogen treatments.

Relationships between grain yields and SPAD measurements collected during R1 and R3 were not significant. However, a significantly negative relationship between combine measured grain yields and SPAD measurements collected at V12 was observed (r = -0.78). Conversely, leaf nitrogen concentration at R3 had a significantly positive relationship with grain yields (r = 0.77).

STORY 1

Grain yields increased if nitrogen was side dressed. For instance, plot yield estimates were 10107, 10780, 10937.6 kg ha-1 for the 0, 90 and 45 kg ha-1 nitrogen treatments, respectively. Leaf greenness and nitrogen concentration increased with nitrogen rates. However, the main effects of nitrogen on grain yield, leaf greenness and nitrogen concentration. R3 and R5 SPAD measurements were significantly influenced by the nitrogen treatments at the 0.08 and 0.06 levels of probability, respectively. Average SPAD values collected at R5 were 53.7, 57.4, and 58.6 for the 0, 90, and 45 kg ha-1 nitrogen treatments, respectively. Additionally, R5 SPAD values as well as plot yield estimates were significantly correlated with combine grain yield estimates (r = 0.83 and 0.89, respectively). SPAD measurements collected at R5 also were highly correlated with ear leaf nitrogen concentration (r = 0.90).

The main effect of soil and the interaction of soil by nitrogen significantly influenced R5 SPAD measurements and plot grain yield estimates, respectively. R5 SPAD measurements and grain yield was significantly reduced in the Ottosen soil relative to the Harps-Okoboji soil. R5 SPAD measurements averaged 57.2 and 55.7 in the Harps-Okoboji complex and Ottosen soil series, respectively. Average plot grain yield estimates in the Harps-Okoboji complex were 10737 kg ha-1 and 10069 kg ha-1 in the Ottosen soil series. The magnitude of difference between plot yield measurements in Harps-Okoboji and Ottosen was much greater in the 0 nitrogen treatment than in the 40 kg ha-1 nitrogen treatment (see figure).

The statistical analysis of the Story 1 data set would indicate that side-dressing nitrogen would not have provided a significant increase in grain yields. However, there was a 381 kg ha-1 yield increase, measured by the combine, when 45 kg ha-1 nitrogen was side dressed. By not applying the side dress nitrogen the farmer would have potentially lost $30.00 per hectare, based on a cash price of $2.00 per 25.4 kg.

STORY 2

The main effect of nitrogen was significant on all response variables except for plot yield estimates. The values of most response variables had a positive relationship with increasing nitrogen rates (see table). Leaf greenness and nitrogen concentration at R5 increased with nitrogen treatments of 0 to 90 and up to 135 kg ha-1, and decreased slightly when nitrogen treatments increased from 45 to 90 kg ha-1.

However, the differences in treatment means from the 45 and 90 kg ha-1 nitrogen strips were not significant for leaf greenness and nitrogen concentration at R5.

The relationships between SPAD measurements of leaf greenness, leaf nitrogen concentration at R5, and plot yield estimates were significantly correlated with combine measured strip yields. The strongest relationship with combine measured grain yields occurred from leaf greenness and nitrogen concentration at R5 (r = 0.93 and 0.96, respectively). Additionally, the relationship between the R5 SPAD measurements and ear leaf nitrogen concentration was highly correlated with a Pearson correlation coefficient of 0.99. Relationships between grain yields measured by the combine and R1 and R3 SPAD measurements and plot yield estimates were also encouraging (r = 0.77, 0.84 and 0.83, respectively).

CONCLUSION

The data from the six fields indicate that leaf chlorophyll measurements were an effective method for tracking potential yield differences among the nitrogen test strips. Additionally the chlorophyll meter was sufficient for measuring plant nitrogen status, as chlorophyll measurements generally had a significant relationship with leaf nitrogen concentration.

The overall conclusion is that pairing offered little gain in increasing the sensitivity of detecting difference. Still, pairing would seem a better choice than not pairing particularly if relatively few plots (fewer than 15) were to be allocated for measuring between strip differences.

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