DIGITAL AERIAL IMAGERY GUIDES A STATEWIDE NUTRIENT MANAGEMENT BENCHMARKING SURVEY

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ABSTRACT

Large fluctuations in crop and fertilizer prices during the last five years caused many farmers to change their normal fertilizer management practices to better control the rising costs in corn and soybean production. It is difficult to predict the long-term effects of these changes on plant nutrient status. A survey was conducted to establish benchmark distributions of crop nutrient status that can be used to track changes over time and identify site-specific factors responsible for these changes. In 2011, late-season digital aerial imagery (DAI) of the crop canopy was used to select "Target Stress" (higher canopy reflectance and smaller plant biomass) and "Nonstress" areas to collect two soil and plant tissue samples within each of 505 corn and 376 soybean fields across Iowa. The samples were analyzed for four essential nutrients and several micronutrients. For corn, > 50% of samples were found below optimal levels for S, Mn, and B and for K, S, Cu, and B for soybean. A survey categorical analysis showed that the soil test interpretations often did not match plant tissue test interpretations. In corn, the "Target stress" areas tended to test in a lower soil test category for Zn and Mn, and in a lower plant tissue test category for N, P, S, and Mn. Fields with a history of Manure applications usually had a higher nutrient status. Samples collected in areas with higher soil organic matter (SOM) and lower soil pH usually had a higher nutrient status than those with lower SOM and higher soil pH. The low cost DAI of the crop canopy helped to collect soil and plant tissue samples to characterize statewide crop nutrient status. The results of this survey will be used to conduct on-farm experiments to measure yield responses to nutrients that often tested below optimal levels within smaller geographic areas across Iowa.

Keywords: Digital aerial imagery, soil and plant tissue testing, crop nutrient status, statewide survey, benchmark distribution.

INTRODUCTION

During the last five years, instances of visual symptoms of macro and micronutrient deficiencies have increased substantially in many corn and soybean fields in Iowa. The increased level of crop nutrient stress could be partially attributed to a steady increase in yield levels (especially of corn), common adverse weather conditions, increased areas of reduced tillage, or reduced fertilizer applications caused by growing environmental concerns and higher fertilizer prices. Documenting and quantifying these changes in crop nutrient status are important to increase fertilizer use efficiency, reduce potential yield loss, and improve overall profitability in crop production.

Except personal communications and coffee shop discussions, data about the latest changes in nutrient status across the state are virtually nonexistent. An exception is the 2010 survey of soil test values conducted by the International Plant Nutrition Institute (IPNI, 2010). The survey utilized a dataset of soil samples submitted to one university and three commercial laboratories over several years in Iowa. According to the survey, 46% of soil samples tested below the critical P level of 22 mg kg^{-1} of P_2O5 for Bray P1 soil test, assuming low subsoil P across the state. The survey also showed that from 2005 to 2010 the median soil P value decreased by 3 mg kg^{-1} for Bray P1 and the median K value decreased by 11 mg kg^{-1}. These data suggest decreasing trends and the need to assess current statewide nutrient status and monitor its changes over time.

A statewide assessment of nutrient status of both crops is also important to identify soil, weather, and management factors that influence nutrient sufficiency levels across the state. However, the effects of many factors and their interactions on crop nutrient status are not easy to quantify because data from a large number of fields are required to adequately characterize variability in soil, weather, and management practices.

One solution to this problem is to utilize precision farming technologies that can help survey many fields across the state. A recent statewide survey of N status of corn utilized digital aerial imagery (DAI) and GPS technology. Agronomists, crop consultants, and farmers use DAI and the late-season corn stalk nitrate test to survey many corn fields to quantify differences in corn N status among major N management categories (a combination of timing and form of N applications) and to estimate percentage area with deficient and sufficient N status within fields (Kyveryga et al., 2011; Kyveryga et al., 2010). The same methodology can be used to survey status of other macro and micronutrients that are needed in optimal levels to maximize yields of corn and soybean.

In this study, farmers, crop consultants, and agronomists used DAI of the crop canopy to guide soil and tissue sampling to (i) characterize macro and micronutrient status of corn and soybean fields across Iowa, (ii) to establish benchmark or reference distributions of crop nutrient status to monitor changes over time, (iii) verify whether soil test interpretations of nutrient status match those of plant tissue test (iv) to identify soil, weather or management factors that influence crop nutrient status across the state.

MATERIALS AND METHODS

Aerial Imagery Collection and Sampling Methodology

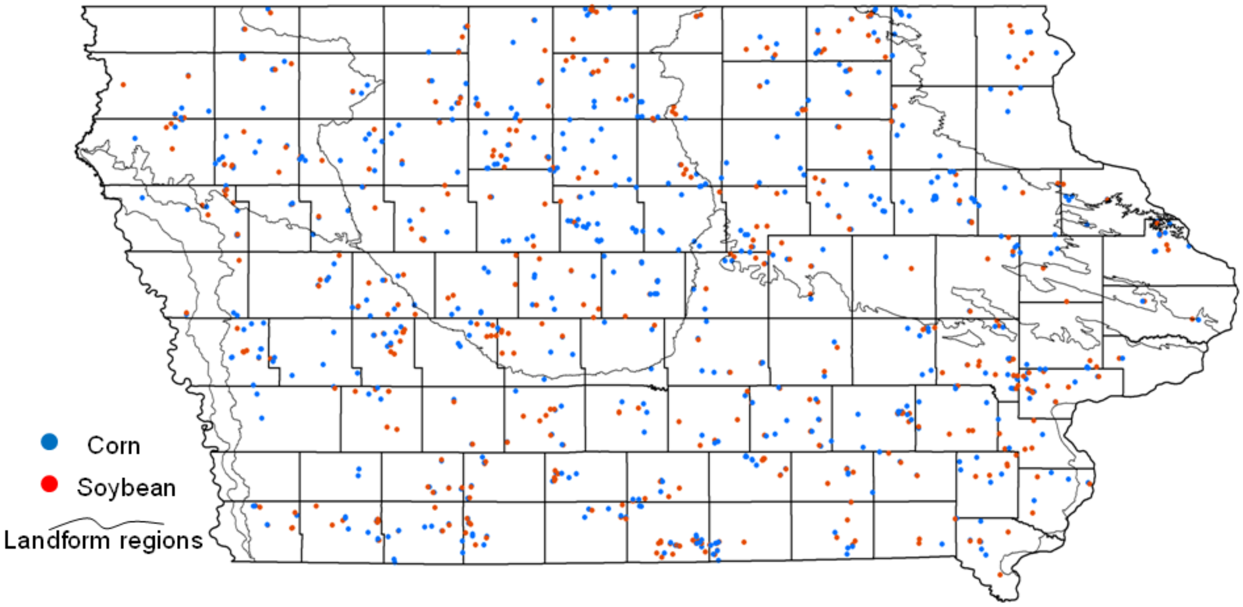

Figure 1. Location of 505 corn and 376 soybean fields surveyed across Iowa in August of 2011 to identify soil and plant tissue macro and micronutrient status using digital aerial imagery (DAI) and GPS technology.

About 500 farmers, agronomists, and crop consultants were involved in a survey study conducted in August of 2011. The participants sampled 505 corn and 376 soybean fields across

Iowa (Fig. 1). At least two corn and soybean fields were sampled in most of the 99 Iowa counties. Locations of the fields, field boundaries, essential management information (previous crop, crop stage, sample locations, crop and fertilizer management) were collected in late July or early August.

The selected fields were flown by commercial aircrafts to acquire late-season DAI of the crop canopy. Each aircraft had four (blue, green, red, and near-infrared) 12-bit digital cameras with CCD (charge coupled display) array of 1600 x 1200. The imagery was taken from a height of about 2400m above the ground, producing the imagery with spatial resolution of about 1 m. Twenty to 30 individual images were taken from each field and the individual images were ortho-mosaiced into one composed image for the entire field. Composed images were GIS ready and georeferenced. For more information about DAI processing, normalization and enhancement see Kyveryga et al., (2012).

Two soil and two plant tissue samples were collected from each of the two sampling areas in each field (Fig. 2). The samples were selected using late-season DAI of the corn canopy. Each participant identified one “Nonstress” and one “Target stress” sampling areas using NDVI or color (blue red and green) imagery. Area 1, “Nonstress”, was selected in an area with the darker color of the crop canopy, normal plant height, and normal biomass without evidence of damage by pests, weeds or diseases. Area 2, “Target stress” area, was selected in an area with the lighter color of the crop canopy, below normal plant height, or areas with plants showing symptoms of potential nutrient deficiencies or within an area with a history of plant nutrient deficiencies. The participants recorded sampling locations in each field by marking sampling areas on a printed imagery or by using handheld GPS to record location coordinates.

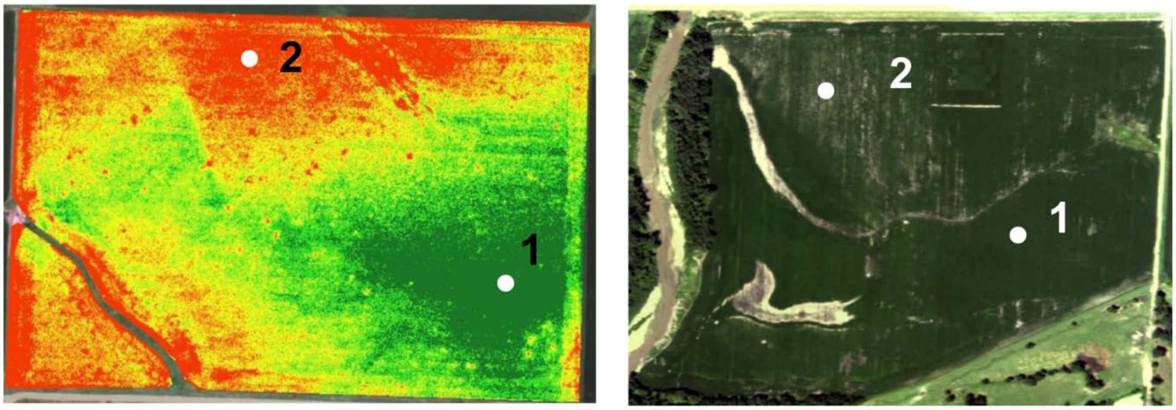

Figure 2. Normalized difference vegetation index (NDVI), left image, and color digital aerial imagery (DAI), right image, were used for selecting two sampling areas within corn and soybean fields. "Nonstress" area was selected within seemingly "good area" with darker color of the crop canopy, normal plant height and biomass. "Target stress" area was selected within a seemingly "bad area" with lighter color of the crop canopy, below normal plant height, or with plants showing symptoms of potential nutrient deficiencies.

Corn fields were sampled during R2 to R5 corn growth stage, with the majority of the fields sampled between R3 and R4. Soybean fields were sampled during R3 to R6, with the majority of the fields sampled between R4 and R5. In general, soil and plant tissue samples were collected slightly later than it was originally planned because of a delay in imagery collection.

Twenty of the ear leaves were collected from each reletively homogenous sampling area (about 10-20 m^2) within corn fields and 20 the youngest fully developed trifoliates leaves were collected in each sampling area within soybean fields. One soil sample was collected from each sampling area where a plant tissue sample was collected. Ten individual soil cores were taken to a depth of 15 cm to produce one composite soil sample. Soil and plant tissue samples were shipped to the Midwest Laboratories, Omaha, NE on the same day or the next day.

Soil and Plant Tissue Tests

Soil samples were analyzed for soil organic matter (SOM), soil pH (water extraction), cation exchange capacity, total and mineral N (NH_4-N and NO_3-N), available P_2O_5 (Bray 1 test for soils with pH <7.3 and Olsen test for soils with pH > 7.3), exchangeable K_2O (ammonium acetate extraction), S (ammonium acetate), Zn (DPTA) , Cu (DPTA), Mn (DPTA), and B (DPTA) (NDSU, 1988). Plant tissue samples were analyzed for total N, P, K, S, Zn, Cu, Mn, and B using nitric acid digestion with ICAP determination. All soil and plant tissue sufficiency categories were determined based on Midwest Laboratories interpretations, except for Bray 1soil P test, soil K, and soil Zn tests. Sufficiency categories for these soil tests were indentified using Iowa State University crop nutrient recommendations (Sawyer et al., 2002).

Statistical Analysis

Analysis of whether soil test interpretations matched plant tissue test interpretations for each nutrient was done by calculating weighted Kappa statistics using “irr” package (Gamer et al., 2010) of the R software (R Development Core Team, 2009). The Kappa index is a measure of the difference between the observed and expected agreement between two tests by also making adjustments for a random chance in the agreement. We used a weighted Kappa that assigned less weight to the agreement if ordered soil or plant tissue categories were further apart that those that were close to each other. The higher the Kappa, the better the agreement. A Kappa value of 1 indicates a perfect agreement and a value of 0 indicates an agreement by random chance. Five ordered soil and plant tissue categories (Deficient or Very Low, Low, Medium or Optimum or Sufficient, High, and Very High or Excessive) were used the analysis. Only three categories (Low, Marginal, and Adequate) were used for measuring agreement between Zn soil and Zn plant tissue tests.

Analysis of whether two sampling areas, Area 1, “Nonstress” vs Area 2, “Target stress”(Fig. 2) differed in soil and plant tissue test interpretations was done by conducting ordinal logistic regression analysis. The response variable was ordered soil and plant tissue test categories of nutrient status and the independent variable was expressed as a binary categorical variable. Parameters for ordinal logistic regressions were estimated using “proc survey logistic” procedure of SAS (SAS Institute, 2005). A variable “field” or “location” was specified as a “strata” in the analysis. Slopes of ordinal logistic regression models were expressed as odds ratio values, indicating the probability to test in a lower nutrient sufficiency category. Odds ratios < 1 indicate a lower and odds ratio > 1 indicate a higher probability to test in a lower category of nutrient status for “Target stress” sampling area compared with “Nonstress” sampling area.

To identify factors that influenced soil and plant tissue category distributions, multiple ordinal logistic regression analysis was performed by regressing ordered soil or plant tissue test categories vs Manure history (no vs yes), crop stage (R3, R4, R5 for corn), N, P, K total fertilizer rates, soil pH, SOM, slope, corn suitability rating, and monthly or cumulative spring rainfall. Slope and CSR values were derived from digital soil maps (Iowa Cooperating Soil Survey, 2003) and monthly spatially interpolated rainfall data were obtained from Iowa Environmental Mesonet (Iowa Environmental Mesonet).

The best ordinal logistic regression models had all independent variables significant at $p<0.01$ level and the highest percentage of concordant pairs and the lowest Akaike Information Criteria statistical index. Two observations were considered a pair if they tested in different soil or plant tissue test categories. A pair was considered concordant if a sample that tested in a higher category was predicted to have a higher probability. A Chi-Square test for the proportional odds assumption was conducted. The assumption is that slopes of the three logistic regressions describing a set of four ordered soil or tissue test categories should be the same. The slopes were considered statistically different at $p<0.05$ level.

RESULTS AND DISCUSSION

Agreement between Soil and Plant Tissue Test Interpretations

Soil and tissue test interpretations are based on classifying the test values into several ordered sufficiency categories of nutrient status. These sufficiency categories (e.g., deficient, low, optimum/medium, high, and very high/excessive) describe the likelihood of yield increase from a nutrient. Plants testing in the below-optimal range are likely to respond with a relatively higher probability than those testing in the above-optimal range (Macy, 1936). Table 1 shows that the soil S test identified that >90% of corn and soybean samples were in the below optimal range. Plant tissue Zn test for corn, and plant tissue K and Cu tests

Table 1. Percentage of samples tested below and above the optimum range for soil and plant tissue tests for corn and soybean and agreement between ordered soil and plant tissue test sufficiency categories[#] measured by weighted Kappa statistics.

	Corn			Soybean		
	Below/above optimal range			Below/above optimal range		
Nutrient	Soil test¶	Tissue test	Weighted Kappa	Soil test	Tissue test	Weighted Kappa
	%			%		
P	10/66	38/18	0.10	15/71	55/6	0.08
K	28/45	46/28	0.22	29/47	85/3	0.11
S	91/2	46/4	0.14	95/2	46/4	0.03
Zn	11/-	91/-	0.00	13/-	62/-	0.03
Cu	18/47	46/11	-0.01	18/46	87/1	0.01
Mn	55/24	66/12	0.23	57/21	32/33	0.14
B	70/6	66/11	0.11	72/5	60/7	0.10

[#] Soil and plant tissue nutrient status was classified into 4 or 5 ordered categories such as Deficient or Very Low, Low, Medium or Optimum or Sufficient, High, and Very High or Excessive. Crop Zn status was expressed as Low, Marginal, and Adequate.

[¶] P, K and Zn soil test interpretations were based on Iowa State University recommendations, all other based on Midwest Laboratories, Omaha, NE.

for soybean identified that >85% samples had below optimal status for these nutrients. Table 1 also shows that for both crops about two-third of soil samples were tested above the optimum for P, with only about 10% of the samples testing below optimum, assuming the high subsoil P level when making P test interpretations. These results indicate that Iowa soils have a large supply of plant available P, but this large supply may carry a potentially high risk of P loss, especially in areas that are prone to water erosion.

Because both soil and plant tissue tests are used to diagnose nutrient status, the test interpretations should show some degree of agreement. However for some nutrients, a soil test showed a relatively large percentage of samples testing below the optimal range while a plant tissue test showed a relatively small percentage of samples testing below optimal. For example for soybean, the soil P test indicated 71% of samples tested in the above-optimal range while soybean P tissue test indicated only 6% of samples in the same sufficiency range (Table 1).

Comparing percentage of samples in the below and above-optimal ranges provides a relative assessment of the agreement between soil and plant tissue tests used to diagnose the same nutrient. However, it does not indicate whether one category of nutrient status based on a soil test was in the same category based on a plant tissue test or how far apart the two categories were if the soil and tissue test did not agree on the diagnosed nutrient status. The agreement between

Table 2. Differences in soil and plant tissue test interpretations between “Nonstress”[#] and “Target stress” sampling areas selected using late-season digital aerial imagery (DAI) of the crop canopy. Odds ratio values indicate the probability of testing in a lower sufficiency category for “Target stress” compared with “Nonstress” sampling areas.

Nutrient	Corn		Soybean	
	Soil test	Tissue test	Soil test	Tissue test
	Odds ratio¶		Odds ratio	
N	-	1.68**	-	-
P	1.34	1.46**	1.18	1.11
K	1.17	1.43	0.93	1.07
S	1.02	1.67***	0.86	0.97
Zn	1.92***	1.05	1.25	0.96
Cu	0.99	1.43	0.89	0.98
Mn	1.75**	1.49**	1.64**	1.16
B	0.99	1.14	0.79	0.91

[#] “Target stress” sampling areas were selected within areas where the crop canopy was lighter in color (less green), had normal plant height or where plants showed symptoms of nutrient deficiencies or within an area with a history of plant nutrient deficiencies.

¶ An odds ratio of > 1 suggests the higher probability while an odds ratio of <1 suggests the lower probability of testing in a lower

test category for “Target stress” compared with “Nonstress” sampling areas.
** Significant at $p<0.05$; ***Significant at $p<0.01$.

soil and plant tissue test can be better measured by the Kappa index.. The Kappa measures the difference between the observed and expected agreement for two categorical variables by also making adjustments for a random chance in the agreement. We used a weighted Kappa that assigned less weight to the agreement if the ordered soil or plant tissue categories were further apart than those where they were close to each other. The higher the Kappa, the better the agreement. A value of 1 indicates a perfect agreement; 0, indicates an agreement by random chance; -1, indicates a potential systematic disagreement.

The highest agreement between soil and plant tissue tests was for K and Mn in both corn and soybean, with Kappa values ranging from 0.11 to 0.23 (Table 1) and indicating a slight agreement between the two tests. The Kappa values close to 0 for Zn and Cu for corn and soybean indicated random chance in the agreement. The soil and tissue S tests partially agreed for corn (Kappa=0.14) but showed no systematic agreement for soybean.

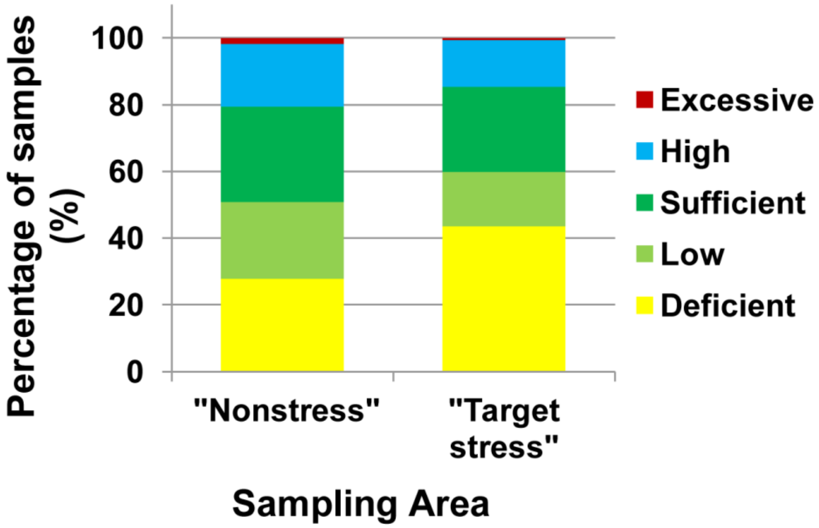

Figure 3. Percentage of corn tissue samples testing in different N test categories for “Nonstress” and “Target stress” sampling areas selected using late-season digital aerial imagery (DAI) of 505 corn fields surveyed across Iowa.

Differences between “Nonstress” and “Target stress” Areas

The value of late-season digital aerial imagery in this survey can be evaluated by testing potential differences in crop nutrient status between “Nonstress” and “Target Stress” sampling areas. The “Target stress” areas were selected where the color imagery showed the lighter color of the crop canopy or where NDVI maps showed areas with smaller plant biomass or where participants selected plants with below normal height or with some visible symptoms of nutrient deficiencies. Because soil and plant tissue test interpretations are usually expressed as ordered sufficiency categories, we used ordinal logistic regression to estimate the probability at which “Target Stress” sampling areas would test in a lower test category compared with the “Nonstress" sampling areas. Table 2 shows odds ratios of the ordinal logistic regression analysis conducted for both crops and for soil and plant tissues tests. Odds ratios of < 1 indicate a lower and odds ratios of > 1 indicate a higher probability of testing in a lower test category for “Target Stress” compared with “Nonstress" sampling areas.

For corn, only soil Zn and Mn tests showed significant differences in nutrient status categories between “Nonstress” and “Target Stress” sampling areas (Table 2). For Zn, for example, samples collected in seemingly stressed areas using the imagery were about 1.9 times more likely to test in a lower soil test category than those collected in seemingly normal areas. For soybean, both soil and tissue test (except the soil Mn test) interpretations did not differ significantly between the two sampling areas. For corn, the plant tissue test showed significant differences for N, P, S, and Mn. For N and S in corn, the “Target Stress” areas were about 1.7

Table 3. Variables that affected soil test interpretations for 505 corn (CN) fields surveyed across Iowa. Effects are expressed as odds ratios (in bold) showing the cumulative probability of testing in a lower soil test category. Odds ratios of > 1 suggest the higher probability of testing in a lower category and odds ratios of <1 suggest the higher probability of testing in a higher soil test category.

Soil test	Significant[#] variable (reference category), **odds ratio**	Percentage of concordant¶ pairs (%)
P1-Bray	Manure history (No vs Yes), **1.91**; Previous crop (SB vs CN), **1.46**; SOM, **0.70**	63
K	Manure history (No vs Yes), **1.49**; Previous crop (SB vs CN), **1.28**; SOM, **0.61**	63
S	Manure history (No vs Yes), **2.55**; Previous crop (SB vs CN), **1.40**; soil pH, **1.47;** MJRain[§], **0.96**	65
Zn	Manure history (No vs Yes), **9.90**; SOM, **0.57**; soil pH, **1.86**	78

Cu	Manure history (No vs Yes), **2.84**; SOM **0.57**; soil pH, **1.96;** MJRain, **0.93**	72

[#] Significant at $p<0.01$ level.

[¶] Two observations were considered a pair if they tested in different soil test categories. A pair was considered concordant if a sample that tested in a lower category was predicted to have a higher probability to test lower.

[§] MJRain; March through June rainfall in cm.

times more likely to test in a lower test category (Fig. 3). These observations suggest that the corn canopy color and visual assessment of plant biomass and height are more indicative of potential nutrient stress in corn than those of soybean.

Site-Specific Factors Affecting Soil and Plant Tissue Test Interpretations

The analysis in Table 2 is based on the assumption that other factors affecting soil and tissue test interpretations, except "Target stress" and “Nonstress" sampling areas, are not important or the effects of these factors cancel each other over the area of a relatively large number of fields. However, knowledge of these effects might help explain the results of test interpretations for a specific category of fields. Table 3 shows factors that influenced soil test interpretations for corn across Iowa based on categorical analysis using ordinal logistic regressions. The regressions identified factors that significantly affected the probability of testing in a lower soil test category. The slopes of the regressions were expressed as odds ratios. Odds ratios of >1 suggest a higher probability of testing in a lower soil test category and odds ratios of <1 suggest a higher probability of testing in a higher soil test category. An odds ratio of 1 suggests no preference of testing in either lower or higher test category.

Table 4. Categorical and continuous variables that affected plant tissue test interpretations of 505 corn (CN) and 376 soybean (SB) fields surveyed across Iowa. In parenthesis are odds ratios that show the cumulative probability of testing in a lower test category. Odds ratios of > 1 suggest a higher probability and odds ratios of <1 a lower her probability of testing in a lower test category.

Plant tissue test	Significant variable (reference category), **odds ratio**	Percentage of concordant[¶] pairs (%)
	Corn	
N	Previous crop (SB vs CN), **0.66**; soil pH, **1.35**; MJRain[§], **1.04**	60
K	Soil pH, **1.47;** Soil K, **0.99**	64
Zn	soil pH, **1.23,**	57
B	Manure history (No vs Yes), **0.86,** soil pH,	60

	1.21, MARain, **1.05**	
	Soybean	
P	Manure history (No vs Yes), **1.31,** Soil P Bray, **0.99**, MJRain, **1.06**	60
K	Manure history (No vs Yes), **1.52,** Soil K , **0.99**, soil pH, **1.63**	71
S	Manure history (No vs Yes), **1.43,** SOM , **0.82**, MJRain, **1.06**	58
Zn	Manure history (No vs Yes), **1.31,** soil pH, **1.29,** MARain[§], **0.96**	60
Mn	SOM , **1.30**, MARain, **1.05**	61
B	SOM , **0.69**, soil pH, **1.69**	61

[#] Significant at $p<0.01$ level.

[¶] Two observations were considered a pair if they tested in different soil test categories. A pair was considered concordant if a sample that tested in a lower test category was predicted to have a higher probability to test lower.

[§] MJRain; March through June rainfall. MARain; March through August rainfall.

For corn, fields with no history of manure applications were more likely to test in a lower soil test category than those that had manure applications in the past (Table 3). For the soil Bray1 test, fields that received some manure applications were 1. 9 times more likely to test in a higher soil test category than those that did not receive manure in the past. The odds ratios for the factor of manure history ranged from 1.5 for soil K to 9.9 for soil Zn tests (Table 3). The average effect of manure applications on soil P test values is also shown in Figure 4. A median soil P value with the manure history was about 15 mg P_2O_5 kg^{-1} higher than that without the manure history.

For P, K, and S soil tests, fields planted to corn after soybean tended to have a lower nutrient status that those planted to corn after corn (Table 3). Odds ratios for SOM for P, K, Zn, and Cu

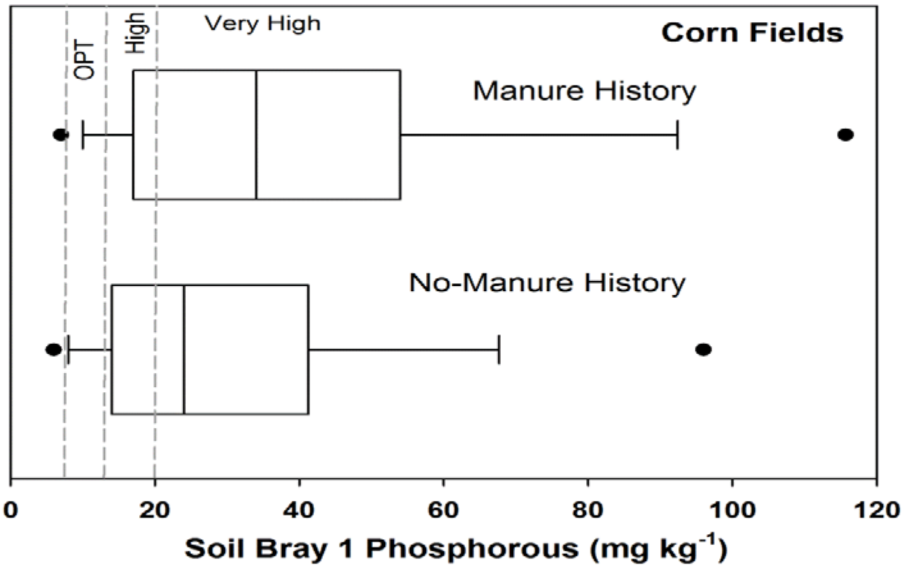

Figure 4. Box plots summarizing distributions of Bray 1 soil test for 505 corn fields across Iowa with and without history of Manure applications. Soil P test interpretations were based on the assumption that the majority of soils in Iowa have high subsoil P levels.

soil tests were <1, indicating a higher probability of testingin a higher sufficiency category with higher SOM. Soil samples collected in corn fields with higher soil pH tended to have a lower soil Zn status. The best ordinal logistic regression models indicated that from 63 to 78% soil sample pairs were concordant. A concordant pair is defined when a sample that tested in a lower test category is predicted with a higher probability to test lower and vice versa. Regression models with 50% of concordant pairs would indicate a random chance for predicting soil or tissue test categories using a given set of explanatory variables.

Table 4 shows factors that influenced corn and soybean tissue test interpretations. Corn tissue samples from corn after corn fields were more likely to test in a higher N sufficiency category than those from corn after soybean fields. With an increase in one soil pH unit and increase in one cm of cumulative March through June rainfall (MJRain), the probability of testing in a lower category increased by 1.35 and 1.04 times, respectively. Additional analyses showed that the corn N tissue test identified 15% more samples in the Deficient and Low categories than the corn stalk nitrate test did (data are not shown). Moreover, the corn N tissue test identified only a few samples as Excessive, suggesting that the corn tissue N test might have underestimated corn N status.

Manure applications tended to shift tissue test interpretations to higher test categories for nutrients such as P, K, S, and B in corn and Zn in soybean (Table 4). Also, higher cumulative March through June rainfall increased the likelihood of testing in a lower S category in soybean. Similar effects were from higher cumulative March through August rainfall (MARain). However, both these effects were relatively small considering that some parts of the state had below normal rainfalls in August of 2011.

A noticeable feature in Table 4 is the significant effect of soil pH on plant tissue test interpretations. An increase in soil pH increased the likelihood of testing in lower tissue test categories for N, K, and Zn in corn fields, and for K, Zn, and B in soybean fields. It is not clear why K availability tended to decrease with an increase in soil pH, but it is common that micronutrient availability decreases with higher soil pH. For both crops across the state, a medium soil pH was 6.6, with about 25% of samples having soil pH of< 6.0 and with 25% of samples having soil pH of >7.0. However for individual landform areas, the soil pH effect on plant tissue test interpretations might be overestimated because high pH, calcareous soils are only confined to the Des Moines Lobe, landform area in central Iowa (Fig. 1). Limiting analyses to only 85 soybean fields within the Des Moines Lobe Area showed that some significant effects of soil pH on soil and tissue test interpretations have disappeared. Therefore, having a sufficient number of fields, it could be possible to identify site-specific factors that influence soil and tissue test interpretations within Landform Areas that are characterized by a unique combination of soil types and weather conditions.

Additional analyses showed that 110 corn fields that received some S, Zn, Cu, or B applications (in different fertilizer forms at planting or as foliar applications) did not have a higher status of these nutrients (except for S) than those fields not receiving S, Zn, Cu or B applications. Therefore, applications of these nutrients were not effective for increasing corn nutrient status. This may also imply a low probability of economic yield response to these micronutrients in these corn fields.

CONCLUSIONS

A statewide survey was conducted to characterize corn and soybean nutrient status of the four essential (N, P, K, S) and several (Zn, Cu, Mn, B) micronutrients across Iowa in 2011. Late-season DAI was used to select "Target stress" (higher crop canopy reflectance and smaller plant biomass) and "Nonstress" areas to collect two soil and plant tissue samples within each of 505 corn and 376 soybean fields. The results showed that across the state >50% of soil or tissue samples had below optimal status for S, Mn, and B for corn and K, S, Cu and B for soybean. About 65% of the soil samples tested above optimal for P based on Bray 1 soil test interpretations. Also, about 25% of soil samples had a pH<6.0 and the same percentage of samples had a pH>7.0.

This study established benchmark (reference) distributions of soil and plant tissue test values and classified these distributions into crop nutrient status categories. These distributions can be used to monitor changes in nutrient status over time and identify factors responsible for these changes. Based on the soil and plant tissue tests for both crops, fields with manure history tended to have a higher nutrient status than fields with no history of manure applications. For some nutrients, soil and plant tissue samples collected in areas with higher SOM or lower soil pH tended to have a higher nutrient status than those collected in areas with lower SOM or higher soil pH values.

An interpretation of the results of this study was limited because the tissue samples were collected at different crop growth stages and at slightly later timing than it is usually recommended for some nutrients. Although the tissue test interpretations were adjusted for differences in growth stage, sampling all fields at the same crop growth stage would likely increase the accuracy of soil and plant tissue test interpretations. The results also revealed large disagreements among soil and tissue test interpretations recommended by commercial and public (university) soil and plant testing laboratories.

This statewide survey will help to design and conduct additional controlled on-farm studies for measuring yield responses to nutrients that are often identified in below-optimal ranges and for verifying and adjusting the currently used soil and plant tissue test calibrations.

ACKNOWLEDGEMENTS

The study was partially funded by the Iowa Soybean Association with soybean checkoff dollars and by the Integrated Farm Livestock Management Project from Soil Conservation Division of the Iowa Department of Agriculture and Land Stewardship. We are very thankful to all growers, agronomists, and technical providers who participated in the study. This study would not have been possible without the On-Farm Network staff who contributed numerous hours to this project.

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