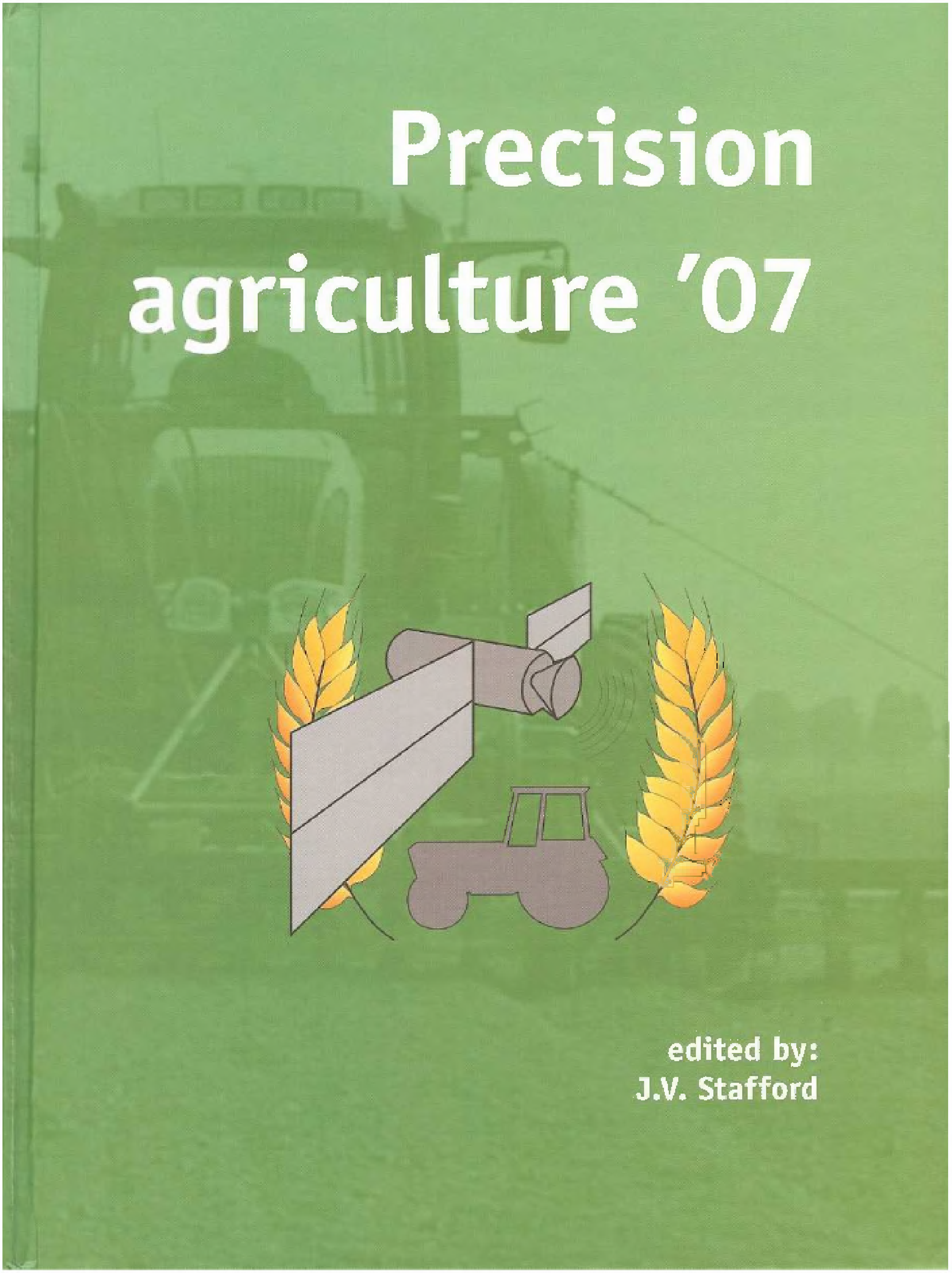
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Site-specific management of pH-induced iron chlorosis of maize

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Abstract

A study was conducted over nine site/years in Nebraska, USA between 2004 and 2005 to evaluate the potential to predict chlorosis-prone areas within fields which are relatively stable in space and time. The study also investigated the potential benefits of site-specific cultivar management according to chlorosis pressure. Sites were mapped for soil apparent electrical conductivity (ECa) at two depths (0-30 cm and 0-90 cm), and soil pH at a depth of 10 cm. Sites were also sampled by hand on a regular grid to a depth of 20 cm and analyzed for a range of soil properties. Sites were evaluated in-season with natural color and near-infrared imagery, and at the end of the season by yield mapping. In all or a portion of each field, replicated paired strips of two maize cultivars were planted, one considered susceptible to iron chlorosis (P34N42), another with similar characteristics but tolerant to iron chlorosis (P34B99). Detailed evaluation of the ability to predict iron chlorosis-prone areas was conducted over 3 site/years. Management zones were delineated using combinations of yield data, ECa and vegetation indices derived from aerial imagery. Across all locations, grid sampled pH ranged from 6.1 to 9.1; on-the-go pH ranged from 4.9 to 9.2; shallow ECa ranged from 0.1 to 39 mS/m; deep ECa ranged from 0.2 to 152 mS/m. For one field, planted to maize one year and soybean the next, two chlorosis management zones were consistently delineated both years, with similar spatial relationships. For another field, soil water holding capacity was a larger yield limiting factor than iron chlorosis and management zones for iron chlorosis could not be delineated. For 8 site/years where paired strips of chlorosis-prone or tolerant cultivars were planted, no distinct advantage of site-specific maize cultivar management was found based on yield response of the two cultivars evaluated. Generally P34B99 yields were superior to P34N42 regardless of the level of chlorosis pressure. This study found spatial information on factors conducive to iron chlorosis can be useful in delineating chlorosis-prone areas within fields. However, other yield limiting factors may confound delineation of zones strictly for chlorosis management. Successful spatial cultivar selection for iron chlorosis management will require the use of cultivars with response characteristics which differ more than those used in this study.

Keywords: iron chlorosis, soil pH, soil electrical conductivity

Introduction

Iron chlorosis can be a significant yield limiting factor for maize and other sensitive crops and is especially an issue on soils high in pH. Many of the soils in the Great Plains of the US are derived from calcareous parent material, which results in carbonate accumulations which raise soil pH and inhibit plant availability of nutrients such as iron and manganese (Kaspar *et al.*, 2004; Thomas, 1996). Soils which are poorly drained can also be conducive to iron chlorosis, because reducing conditions inhibit iron uptake and utilization in the plant. Selection of cultivars tolerant to iron chlorosis is often the most cost-effective practice for crop production on these soils, as the application of iron fertilizers, either to the soil or crop foliage, is unpredictable and expensive (Hansen *et al.*, 2003). Often soils prone to iron chlorosis, either due to their calcareous nature or poor drainage, are interspersed in fields with soils that are less conducive to iron chlorosis. Thus, the uniform planting of chlorosis-tolerant cultivars in fields which contain areas which are chlorosis-prone may reduce productivity in areas less conducive to chlorosis. Site-specific cultivar management is one potential solution to optimize productivity across highly variable fields.

In order to utilize site-specific cultivar management, chlorosis-prone areas within fields must be relatively stable and predictable. Various methods have been used to assess chlorosis-prone areas, including soil apparent electrical conductivity (Hartsock *et al.*, 2000; Williams and Hoey, 1987), and aerial imagery (Stoner *et al.*, 1980; Bastiaanssen *et al.*, 2000), as well as soil sampling, either on a grid basis, directed according to yield maps, or on-the-go pH mapping (Adamchuk *et al.*, 2004).

The primary objectives of this study were: (1) evaluate methods to delineate chlorosis-prone areas in fields. (2) explore the feasibility of planting cultivars optimized for soil conditions within chlorosis-prone and relatively chlorosis-free areas of fields.

Materials and methods

The study was conducted over nine site/years between 2004 and 2005 in Nebraska. Sites were located in central and southwestern Nebraska, generally representing the range of soils and climates in which iron chlorosis can impact crop production. Sites were mapped prior to each growing season using a Veris® Mobile Sensor Platform (MSP; Veris Technologies, Inc., Salina, Kansas, USA), which measured both apparent soil electrical conductivity (ECa) at depths of approximately 0-30 cm and 0-90 cm, and soil pH at a depth of approximately 10 cm. Samples were collected at densities of approximately 7-12 samples ha^{-1} for pH, and 106-190 measurements ha^{-1} for ECa. In addition, grid soil samples were collected to a depth of 20 cm at a density of approximately 1 sample ha^{-1}. Two maize hybrids were selected for comparison at all sites in collaboration with Pioneer Hi-Bred International, Inc. (Johnston, Iowa, USA) agronomists as well as cooperators. The hybrids were selected to be as comparable as possible in traits with the exception of tolerance to iron chlorosis. Hybrid P34N42 (2650 growing degree units [GDU] to maturity) was selected as most productive in non-chlorosis prone areas, and hybrid P34B99 (2590 GDU to maturity) was selected as most productive in chlorosis-prone areas of fields. Hybrids were planted in paired field length strips with at least nine replications. Due to seed limitations, at some sites only parts of the field were planted to hybrid strips, with the remainder of the field planted with another hybrid. In these cases, treatment areas were oriented to cover the range of chlorosis conditions present within the field. Site/year 9 (SY 9) was planted to soybean with a single cultivar in 2005 rather than corn. Aerial photographs (RGB and NIR) were collected at each site during the growing season after tassel emergence. Grain yield was mapped with the cooperator's combine. Yield data was processed with Yield Editor 1.01 software (USDA-ARS Cropping Systems and Water Quality Unit, University of Missouri, Columbia, MO, USA) to remove outliers. Cleaned grain yield, ECa, Veris pH and grid sample pH data were interpolated using ordinary kriging. Delta yield maps were created by subtracting the kriged surface of P34N42 yield (chlorosis-susceptible) from the kriged surface of P43B99 yield. Output datasets of grain yield, grid sample pH, Veris pH, and ECa were created using common X and Y origins with a standard grid interval of 10x10 m.

Aerial photographs were re-sampled from 0.3 to 1 m resolution, and three vegetation indices were calculated: normalized difference vegetation index, NDVI (NIR-red)/(NIR+red); green normalized difference vegetation index, GNDVI (NIR-green)/(NIR+green); and visible atmospherically resistant index, VARI (green-red)/(green+red-blue). Vegetation indices (VI) were then calculated at the same 10x10 m grid as grain yield, pH and ECa. Management zones were created using various combinations of spatial data over years with Management Zone Analyst software (MZA 1.0.1, University of Missouri, Columbia, MO, USA). Grain yield, ECa and VI were normalized to a mean of 0 and standard deviation of 1 for management zone delineation.

For statistical analysis of grain yield relationships to mapped soil properties, 30 m buffers were created from uninterpolated data in ArcGIS (v. 9) to extract grain yield, Veris pH, and ECa around grid sample points. Values within the buffer range were averaged and exported for correlation analysis.

Results

Management zone delineation

Management zone delineation was only attempted on site/years 1, 5 and 9, due to more detailed information being available on those sites. Site/years 1 and 9 were the same field – SY 1 planted to maize in 2004, SY 9 planted to soybean in 2005. Figure 1 provides maps of various properties over the two years at this site. The field was furrow-irrigated, with irrigation pipe laid about 200 m from the south end of the field, allowing water to flow in both northerly and southerly directions from the pipe.

In general, pH and ECa were higher in the northern part of this field. Soils in this portion of the field were mapped as Caruso series, which is a poorly drained silty clay loam; Gayville series, which is a sodic poorly drained silty clay loam; and Gibbon series, which is a somewhat poorly drained loam soil. Areas in the field with deep ECa generally greater than 100 mS m^{-1} are sodic, with salt deposits and dissolved soil organic matter present on the surface. Patterns of ECa were the most stable of mapped parameters between years, while Veris pH was not well-correlated between years. Heavy crop residue in the spring of 2005 from the previous maize crop made sample collection difficult, and thus results between years may not be directly comparable. Veris pH collected in 2004 was highly correlated ($r=0.92$) with grid sampled pH. There was generally good correlation between ECa patterns and NDVI or GNDVI. Maize yield in 2004 shows streaks in part of the field due to the hybrid strips, but generally yield was lower in the northern part of the field for both maize in 2004 and soybean in 2005. We found management zones delineated from yield, deep ECa, and NDVI to most closely relate to observed chlorosis in the field (Figure 2). There did not appear to be any advantage to including two years data in the zone delineation process, as the zones created were similar whether one or two years data were included. Management zone 2 (chlorosis-prone) generally corresponded to the Caruso/Gayville complex (Cg and Gc) and Gibbon (Gg) soils, while management zone 1 (non-chlorosis-prone) corresponded to the better drained Janude sandy loam (Jm), Leshara silt loam (Le) and Novina sandy loam (Nv) soils.

Site/year 5 had areas of the field in which low yield correlated with high pH, high ECa and high reflectance from aerial photographs (data not shown). However, chlorosis management zones could not be successfully delineated on this field, at least from one year's data. Areas of low yield also coincided with well-drained, sandy loam soils with low shallow and deep ECa. These areas of low yield were identified as water-stressed during the growing season. The low water holding capacity of these soils could not adequately meet crop evapotranspiration demand during the season, even though irrigated. Thus areas of the field with low water holding capacity were confounded with chlorosis-prone areas in terms of their effects on yield, and resulting management zones corresponded more to areas of water stress than chlorosis.

Site specific hybrid management

Paired maize hybrid strips were included at eight of the nine site/years – site/year 9 was planted to soybean in 2005. This approach is also termed a split planter design (Doerge and Gardner, 1999), since it can easily be implemented by producers filling half the grain boxes on a planter with one cultivar, and the rest with a different cultivar. When harvested with a yield mapping combine, the resulting delta yield map can illustrate areas within the field where one or the other cultivar excelled. The chlorosis-tolerant hybrid (P34B99) produced greater yield than the chlorosis-susceptible hybrid (P34N42) regardless of soil properties in all site/years. For most of the sites, there were areas of depressed or elevated yield unrelated to chlorosis pressure – most often due to coarse-textured soils

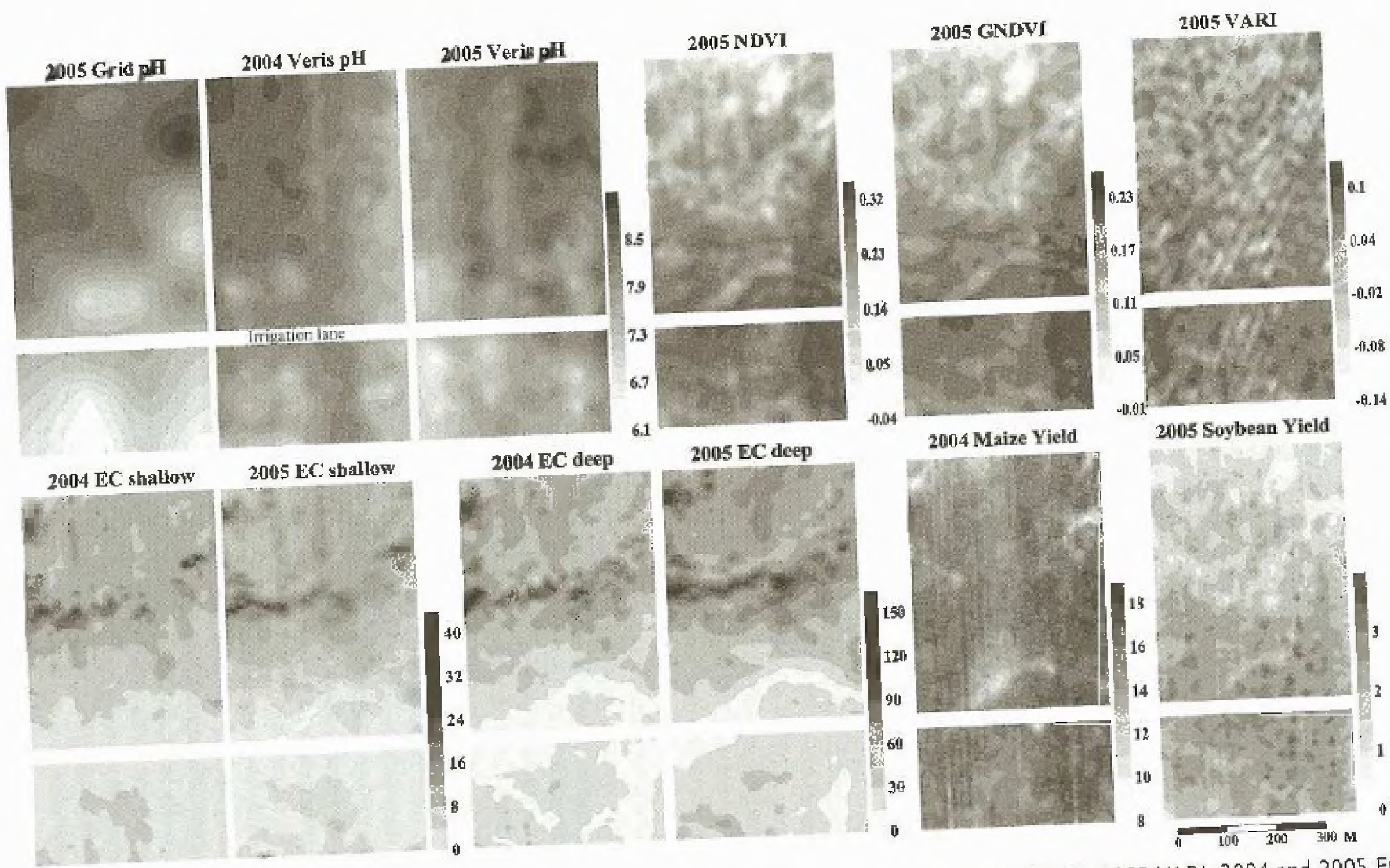

Figure 1. Site/years 1 and 9 (same field): 2005 grid pH, 2004 and 2005 Veris pH, 2005 NDVI, 2005 GNDVI, 2005 VARI, 2004 and 2005 ECa shallow (mS m^{-1}), 2004 and 2005 ECa deep (mS m^{-1}), 2004 maize yield (Mg ha^{-1}), and 2005 soybean yield (Mg ha^{-1}).

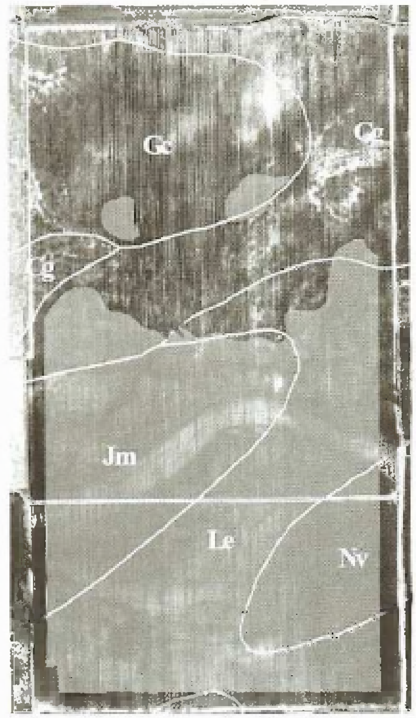

Figure 2. Management zones for site/year 1 and 9. Gray-shaded areas are MZ 1, classed as non-chlorosis prone. Non-shaded areas are MZ 2, classed as chlorosis-prone. Management zones are based on combined 2004 and 2005 yield, deep ECa and NDVI. The background is the natural color aerial photograph from 2005 and mapped soil series boundaries.

with low water holding capacity, with resulting water stress during the growing season leading to reduced yield – even with irrigation. Table 1 shows the significant correlation coefficients for mapped soil properties related to yield of both hybrids. Apparent soil electrical conductivity was significantly correlated to yield at three of the eight sites. Grid sampled pH was significantly correlated to yield

Table 1. Significant Pearson correlation coefficients between mapped soil properties and grain yield of two hybrids over eight site/years. Values not shown were not statistically significant.

Site/Year	Shallow ECa		Deep ECa		Grid pH	
	P34B99	P34N42	P34B99	P34N42	P34B99	P34N42
1						
2						
3			0.58	0.63	-0.53	-0.64
4			0.76	0.71		
5						
6						
7						
8	0.66	0.62	0.69	0.65	0.53	0.50

at only two sites – once positively, once negatively. There were no significant correlations between grain yield and Veris pH, even though Veris pH was significantly correlated to grid pH at five of the eight sites. Site/year 3 did have areas of very shallow soil, with rock outcroppings, in which the delta yield map showed higher yield for P34B99 (chlorosis tolerant) than P34N42 (chlorosis-susceptible). There were corresponding areas at this site where the chlorosis-susceptible hybrid yielded better than the chlorosis-tolerant hybrid, but these were unrelated to soil pH.
Yield reduction due to iron chlorosis was observed only at site/year 1 and 5, and in these fields other yield limiting factors also existed – primarily soils with low water holding capacity. In spite of the high potential for iron chlorosis at other sites, soil properties were not adequately divergent to generate substantial yield differences between hybrids. Other yield limiting factors superseded iron chlorosis at site/year 3, 4, 7 and 8.

Conclusion

The use of spatial information to delineate areas in fields prone to iron chlorosis seems feasible. In our case, the use of deep ECa, yield and aerial imagery were useful in identifying chlorosis-prone areas for one of the two fields evaluated These zones generally corresponded to mapped soil series known to be conducive to iron chlorosis. A geo-referenced aerial photograph taken during a growing season in which iron chlorosis pressure is occurring may be a relatively inexpensive means of identifying chlorosis-prone areas which can be correlated to yield. Delineation of chlorosis-prone areas in fields can be confounded if other yield-limiting factors exist as well. Further evaluation of the use of aerial imagery, ECa, for chlorosis zone delineation is warranted. It will be important to assess the stability of zones over years with varying climatic conditions.
Based on eight site/years of comparison in our study, the chlorosis-tolerant hybrid (P34B99) appeared to be the better hybrid regardless of soil pH and ECa conditions. Thus, there was no advantage for these sites to planting different hybrids in different areas of the field. For site-specific hybrid management to be beneficial, greater differences in soil characteristics may be required, or hybrids which are more widely divergent in their response to soil conditions, or both.

References

Adamchuk, V.I., Hummel, J.W., Morgan, M.T. and Upadhyaya, S.K. 2004. On-the-go soil sensors for precision agriculture. Computers and Electronics in Agriculture 44 71-91.

Bastiaanssen, W.G.M., Molden, D.J., and Makin, I.W. 2000. Remote sensing for irrigated agriculture: Examples from research and possible applications. Agricultural Water Management 46 137-155.

Doerge, T.A. and Gardner, D.L. 1999. The Pioneer split-planter comparison method. Site-Specific Management Guide 10. International Plant Nutrition Institute, Norcross, GA, USA.

Hansen, N.C., Schmidt, M.A., Anderson, J.E. and Strock, J.S. 2003. Iron deficiency of soybean in the Upper Midwest and associated soil properties. Agronomy Journal 95 595-1601.

Hartsock, N.J., Mueller, T.G., Thomas, G.T., Barnhisel, R.I., Wells, K.L. and Shearer, S.A. 2000. Soil electrical conductivity variability. In: P.C. Roberts, R.H. Rust, and W.E. Larson, eds. Proceedings 5th International Conference on Precision Agriculture. American Society of Agronomy misc. pub., Madison, WI, USA [CD-ROM]

Kaspar, T.C., Pulido, D.J., Colvin, T.S., Jaynes, D.B. and Meek, D.W. 2004. Relationship of corn and soybean yield to soil and terrain properties. Agronomy Journal 96 700-709.

Stoner, E.R., Baumgardner, M.F., Biehl, L.L. and Robinson, B.F. 1980. Atlas of soil reflectance properties. Agricultural Experiment Station Bulletin 962, Purdue University, IN, USA.

Thomas, G.W. 1996. Soil pH and soil acidity. Methods of Soil Analysis: Part 3 – Chemical Methods. Soil Science Society of America book series no. 5, Madison, WI, USA, pp. 475-490.

Williams, B.G. and Hoey, D. 1987. The use of electromagnetic induction to detect the spatial variability of salt and clay content of soils. Australian Journal of Soil Research 25 21-27.