CONSERVATION INNOVATION GRANTS
Final Report

Grantee Name: Cinthia Johnson	
Project Title: Site-Specific N Management in an Intensified No-till Dryland Cropping System	
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Project Summary

Rationale and Objectives

Nitrogen fertilizer is traditionally applied to crops at uniform across-field rates. Yet, despite uniform application within-field variability in crop yields is a well-recognized phenomenon. Yield variability is largely due to spatial differences in soil characteristics that affect N requirements, organic N mineralization, available soil N, and yield potential. Consequently, not all areas in a field require the same level of N fertilizer, with over fertilization occurring in some areas and under fertilization in others. Grain quality is also spatially variable and the bread-making quality of wheat is limited by low and inconsistent protein concentrations controlled, in part, by available soil N.

Site-specific N management (SSN) matches N application with soil attributes and crop requirements as they vary across a site. Increasing fertilizer costs and environmental concerns stemming from fertilizer use promote SSN and Global Positioning Systems (GPS), Geographic Information Systems (GIS) for spatial analysis and mapping, and variable rate applicator technologies now make SSN feasible. Lacking is an effective, economical, and temporally consistent basis for identifying management zones. Zone maps have been attempted using sampling (soil tests) and scanning techniques (soil surveys, aerial photographs, crop yield maps, or topography). In semiarid regions intensive grid sampling is cost prohibitive and scanning methods offer the most economical basis for SSN. Unfortunately, soil surveys and topographic maps lack sensitivity while aerial photos do not detect subsurface features and are of limited use in untilled soils. Although yield maps produce a realistic picture of all factors driving yield, they do not isolate soil factors that can be managed.

One promising scanning option for identifying SSN management zones is soil electrical conductivity (EC), most simply defined as the ease with which an electrical current passes through soil. Farm fields are easily and economically mapped for EC using commercially-available sensors. Soil salinity, clay type and percentage, water content, and temperature contribute to measured EC, with one or more factors dominating in individual soils. Thus, depending on soil characteristics EC can be an indicator of salinity, moisture, clay content, and/or nitrate concentrations. In some soils, EC can also be an indirect indicator of soil productivity characteristics, thereby reflecting across-field variations in potential yield. Since across-field patterns are temporally consistent, EC has the potential to serve as a basis for SSN.

Primary objectives of this project were to: 1) establish an on-farm, farm-scale regional demonstration project for winter wheat in the Central Great Plains using EC-zone-based site-specific N management; 2) evaluate EC-based SSN for wheat crop yield, soil conservation effects (N-use efficiency) and grain quality significance – and if found to be effective, produce a procedure and analysis of economic feasibility (profit, risk, and yield) for EC-based SSN in the Central Great Plains; and 3) compare two different methods for measuring EC and delineating management zones to determine the best basis for SSN in the Central Great Plains. The two methods evaluated were: 1) direct contact EC mapping with unsupervised classification (the approach used for this project), and 2) electromagnetic radiation with response surface classification.

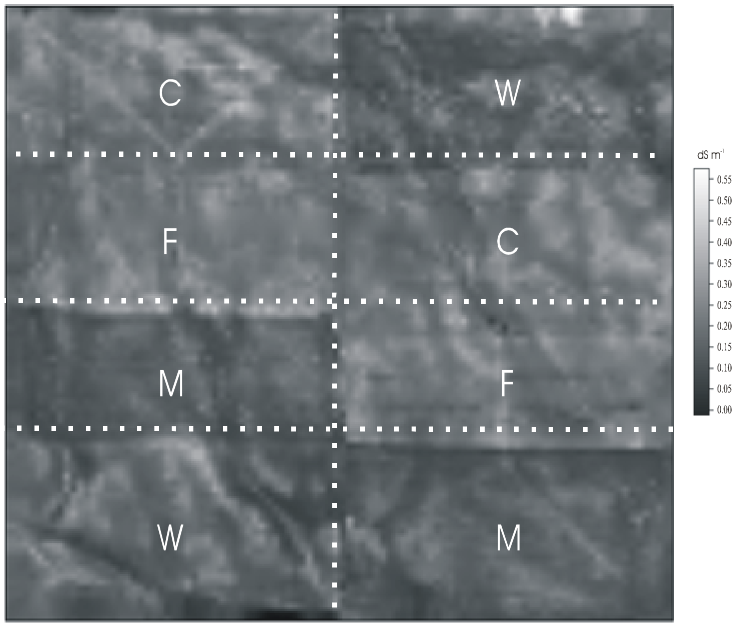
This project represents a multidisciplinary partnership between farmers (Russell, Matt and Dr. Cinthia Johnson, Sterling, CO); scientists (Dr. Dennis Corwin, USDA-ARS Riverside, CA; Dr. John Shanahan, USDA-ARS Lincoln, NE; Dr. Brian Wienhold, USDA-ARS Lincoln, NE; and Dr. Kent Eskridge (Department of Biometry, University of Nebraska, Lincoln, NE); an agricultural cooperative (Grainland Cooperative, Yuma, CO); and a county extension agent (Bruce Bosley, Colorado State University Extension Service, Sterling, CO).

Site Information

The site for the "Site-Specific N Management in an Intensified No-till Dryland Cropping System" Project was a dryland farm 19.3 km (12 mi) east of Sterling, CO in the semi-arid Central Great Plains. Highly variable rates of precipitation average 42 cm (16.5 inches) annually. Dryland farms in this region tend to be large and low input. This project was conducted for three years (2008, 2009 and 2010) at the Farm-Scale Intensive Cropping Study Site established in 1999. This contiguous section of farmland (244-ha or 610-ac) is managed in a no-till intensified and diversified winter wheat - corn - proso millet - fallow rotation (Figure 1). Crops are grown on 8 approximately 32-ha (80-ac) fields within the site such that each phase of the 4-yr rotation occurs in two fields each year.

The site was EC mapped using a Veris 3100 Sensor Cart (Figure 1) and each of the eight fields within the site was individually classified into three management zones based on ranges of EC: low, medium, and high (Figure 2). The EC maps of each field were interpolated by inverse-distance weighting and partitioned into zones using unsupervised classification, a method where spatially related EC data are grouped into natural clusters. In research foundational to this project, analysis of soil samples from an EC-zone-based sampling scheme indicated that EC delineates across-field variations in soil physical, chemical, and biological characteristics associated with productivity (Table 1). Correlations were also found between EC measured at 0-0.3 m and 0-0.91 m (0-1 and 0-3 ft) and wheat yield (1999 and 2000).

Figure 1
Farm-Scale Intensive Cropping Study Site
Project Layout and Electrical Conductivity Map



The project site is a contiguous section (610 ac) of farmland. Set in a randomized complete block design, crop treatments include two replicates (two approximately 80-ac fields) of each phase of the W=winter wheat, C=corn, M=proso millet, and F=fallow rotation each year. Treatments are superimposed on a map of electrical conductivity (EC) (0-1 ft depth) taken in March 1999. Color variations from dark to light correspond to increasing EC. Nitrogen treatments were applied to only the winter wheat phase of the rotation.

Figure 2
EC-Zone Map of One Field in the Study Site
With Superimposed N Treatments

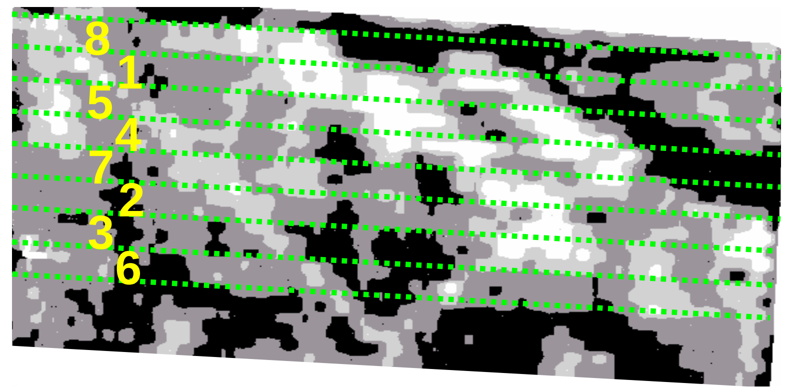


Figure 2: An EC-zone map of the field in the northeast corner of the Farm-Scale Intensive Cropping Study with superimposed N treatments. Eight nitrogen treatments will be randomly applied to two fields. They will be applied in 120-ft wide strips extending the length of each field (1/2 mi) to traverse EC zones as:

1 = 0 lb/ac N and 35 lb/ac P
2 = 30 lb/ac N and 35 lb/ac P
3 = 45 lb/ac N and 35 lb/ac P
4 = 60 lb/ac N and 35 lb/ac P
5 = 90 lb/ac N and 35 lb/ac P
6 = 120 lb/ac N and 35 lb/ac P
7 = 45 lb/ac N and 0 lb/ac P
8 = 60 lb/ac N and 0 lb/ac P

EC Zone I is shown in black, EC Zone II in gray and EC Zone III in white. EC Zone I corresponds to areas within the field with the highest production potential while EC Zone III corresponds to low-producing areas.

Table 1. Ranges of electrical conductivity (EC) and soil property means within EC zones (0-1 ft depth of measurement).

	EC Ranges	Water content	SOM ¶	Total C	Total N	P ¶	PMN ¶	Bulk density	Clay	pH
	dS m^{-1}	kg kg^{-1}	Mg ha^{-1}	Mg ha^{-1}	Mg ha^{-1}	kg ha^{-1}	Kg ha^{-1}	g cm^{-3}	%	
		---------------------- Productivity-Associated Factors -----------------						- Erosion-Associated Factors -		
EC Zone		*	**	**	**	**	*	†	*	**
Low	0.00 – 0.17	0.207	124.8	43.8	4.08	111.8	86.4	1.32	22.8	6.33
Med. Low	0.12 – 0.23	0.187	115.9	35.2	3.45	69.2	67.0	1.39	24.3	6.42
Med. High	0.14 – 0.29	0.185	110.4	32.2	3.09	27.8	59.3	1.39	27.3	6.72
High	0.18 – 0.78	0.178	112.6	32.7	3.10	26.7	54.4	1.42	28.1	6.92

¶ SOM = total soil organic matter; P = extractable Phosphorus; PMN = potentially-mineralizable nitrogen (NH_4^+).
†, *, ** Comparisons among EC zones are significant at the 0.10, 0.05, and 0.01 levels, respectively.

Project Approach

Each year for three years (2007, 2008 and 2010), eight N treatments were applied in 36.6 m by 0.8 km (120 ft by ½ mi) long strips to two 32-ha (80-ac) wheat fields, traversing EC zones (Figure 3). Six treatments, 0, 33.75, 50.62, 67.5, 101.25, and 135 kg N/ha (0, 30, 45, 60, 90, and 120 lb N/ac) were to be applied with, and two (45 and 60 lb N/ac) without, 39.38 kg/ha (35 lb/ac) P. Nitrogen was applied as liquid starter, 10-34-0, at a rate of 74.8 L/ha (8 gal/ac) with seed and/or dry urea (46-0-0) in January as needed for treatments. Placement of N strips across EC zones allowed assessment of grain yield and grain quality response to N for soils of varying yield potential and N supplying capacity. Geo-referenced sampling sites were identified within each N treatment/EC zone combination.

Composite pre-plant and post-harvest soil samples 0-7.5, 7.5-30, 30-61, 61-91, and 91-122 cm (0-3, 3-12, 12-24, 24-36 and 36-48 in) were taken from each sampling site and samples were tested for total and inorganic N to calculate N inputs and N-use-efficiencies. At wheat maturity, total above ground plant biomass was determined for two 1-m^2 hand-harvest samples of plants taken from identified sampling sites. The grain was thrashed and used to determine yield and quality (moisture, test weight, N concentration, and protein). Additionally, geo-referenced yield maps were collected from the two wheat fields using a John Deere GreenStar grain yield monitor and a Trimble AG132 D GPS. The EC-zone, N-rate, and crop-yield maps were geo-aligned for statistical comparison by Aaron Schepers (Cornerstone Mapping, Lincoln, NE) using GIS software. Analysis of variance and regression techniques were used to compare soil chemical/biological, crop residue, grain quality, and crop yield response within EC zones to various N-rates.

To allow for extreme variation in annual precipitation in the Central Great Plains, this was established as a 5-year project.

Results

Objective 1: Establish an on-farm, farm-scale regional demonstration project for winter wheat in the Central Great Plains using EC-zone-based site-specific N management.

As is typical for on-farm demonstration projects, we encountered several obstacles beyond our control in establishing this regional demonstration project. We were unable to initiate the project in 2004 because notification of the grant award came too late. The project could not be implemented in 2005, 2006 or 2009 due to an extended period of extreme drought in the Central Great Plains, resulting in poor wheat stands.

With the approval of a two year no-cost extension, we were able to impose N treatments for three years – 2007, 2008 and 2010. However, the extended period of drought in this region resulted in high residual levels of soil N and P which made it impossible to apply P treatments or low-end N treatments. Moreover, due to extremely low sub-soil moisture, particularly post-harvest, we were not able to collect deep soil samples at some sampling sites.

In addition to the original study site, we added a field (field 9) for analysis and comparison in 2010. This 64-ha (160-ac) field is located one mile south of the Farm-Scale Intensive Cropping Study site and is made up of identical soil types to those found in the original site.

Objective 2: Evaluate* EC*-based SSN for wheat crop yield, soil conservation effects (N-use efficiency) and grain quality significance.

Wheat Crop Yields:

For the Central Great Plains, whole-field mean yields at the study site were typical in 2007 (Field 5: 2970 kg/ha or 44.2 bu/ac and Field 8: 2890 kg/ha or 43.0 bu/ac), low in 2008 (Field 1: 2419 kg/ha or 36 bu/ac and Field 4: 2419 kg/ha or 36 bu/ac), and significantly above average in 2010 (Field: 4092 kg/ha or 60.9 bu/ac; Field: 4018 kg/ha or 59.8 bu/ac; and Field 9: 4704 kg/ha or 70 bu/ac). Thus, the three years evaluated in this project offer a representative cross-section of yield potential for dryland wheat in the Central Great Plains region.

As was expected, wheat yields measured by yield maps were different among years (Pr>F=0.001) and among EC zones (Pr>F=0.01). However, no significant differences were found among N treatments and there were no significant interactions between N and other treatment variables either across or within years.

Soil Conservation Effects (N-use efficiency):

For the three years of this project, no discernible relationship was found between EC management zones, N treatments and N-use efficiency. Thus, we were not able to establish optimal N treatment rates for EC zones. The most complete and reliable NUE results were found in 2008 and are presented in the graphs of N-rate treatment vs. N use efficiency for Fields 1 and 4 (composite depths of 0-12 in and 0-30 in) (Figure 3). However, these relationships are scattered and inconsistent.

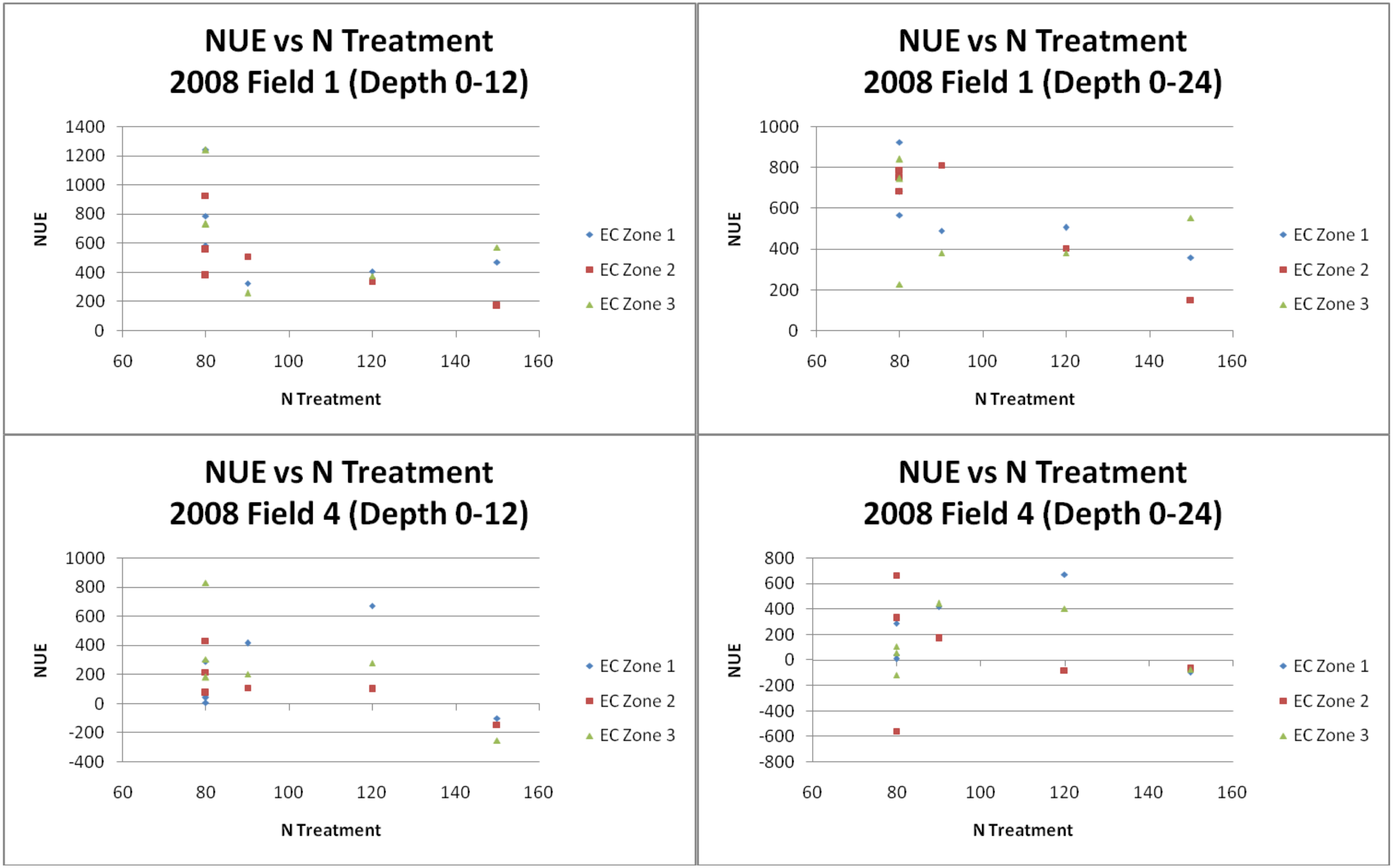


Figure 3: <u>Soil Conservation Effects</u> assessment of nitrogen-use-efficiency versus N treatments for 2008 (Fields 1 and 4). N treatments are shown in lb/ac.

Grain Quality:

Grain yields differed among years ($p < 0.001$) with yields being greater in 2010 (4.13 ± 0.05 Mg ha^{-1}) than in 2007 (2.29 ± 0.06 Mg ha^{-1} and 2008 (1.70 ± 0.06 Mg ha^{-1}). Grain yield differed among EC zones ($p = 0.02$) decreasing as EC increased (2.82 ± 0.05 Mg ha^{-1} in EC zone 1, 2.69 ± 0.05 Mg ha^{-1} in EC zone 2, and 2.61 ± 0.05 Mg ha^{-1} in EC zone 3). Grain yield also differed among N treatments ($p = 0.02$) increasing as additional N was applied (2.59 ± 0.05 Mg ha^{-1} for the 56 or 90 kg N ha^{-1} treatment, 2.64 ± 0.06 Mg ha^{-1} for the 67 or 90 kg N ha^{-1} treatment, 2.80 ± 0.06 Mg ha^{-1} for the 101 kg N ha^{-1} treatment, and 2.81 ± 0.08 Mg ha^{-1} for the 134 kg N ha^{-1} treatment). There were no significant interactions between grain yield and any of the treatment variables.

Grain N concentration exhibited a significant year by EC zone interaction ($p = 0.02$). Grain N concentration was greater in 2008 (the poorest-yielding year) than in 2007 or 2010 (average- and high-yielding years, respectively) and decreased as EC increased in each of the years (Table 2).Grain N concentration also exhibited a year by N rate treatment interaction ($p = 0.01$). Grain N concentration was similar among N treatments in 2008, the poorest-yielding year but increased with increasing N rate in 2007, an average-yielding year and 2010, a high-yielding year (Table 3).

Table 2. Grain N concentration (g/kg) as a function of year and electrical conductivity (EC) class.

	Year		
EC Class	2007	2008	2010
1	18.5 ± 0.8	24.4 ± 0.7	18.1 ± 0.5
2	18.6 ± 0.8	23.4 ± 0.7	17.1 ± 0.5
3	16.9 ± 0.8	20.3 ± 0.7	17.3 ± 0.5

Table 3. Grain N concentration (g/kg) as a function of year and Nitrogen rate (kg/ha).

	Year		
N rate	2007	2008	2010
56 or 90	15.6 ± 1.3	23.8 ± 0.9	15.7 ± 0.4
67 or 90	16.2 ± 0.9	21.3 ± 0.6	17.0 ± 0.5
101	18.0 ± 0.7	22.7 ± 0.6	17.6 ± 0.5
134	22.2 ± 0.9	23.2 ± 0.9	19.7 ± 0.7

Grain N content differed among years ($p < 0.001$) being greater in 2010 (72.5 ± 1.3 kg N ha^{-1}) than in 2007 (39.9 ± 2.2 kg N ha^{-1}) and 2008 (38.3 ± 1.7 kg N ha^{-1}). Grain N content differed among EC zones ($p = 0.03$) decreasing as EC increased (53.6 ± 1.8 kg N ha^{-1} in EC zone 1, 50.3

± 1.8 kg N ha^{-1} in EC zone 2, and 46.7 ± 1.8 kg N ha^{-1} in EC zone 3). Grain N content also differed among N treatments ($p < 0.0001$) increasing as additional N was applied (41.6 ± 2.4 kg N ha^{-1} for the 56 or 90 kg N ha^{-1} treatment, 46.7 ± 1.8 kg N ha^{-1} for the 67 or 90 kg N ha^{-1} treatment, 53.0 ± 1.6 kg N ha^{-1} for the 101 kg N ha^{-1} treatment, and 59.5 ± 2.2 kg ha^{-1} for the 134 kg N ha^{-1} treatment). There were no significant interactions between grain N content and any of the treatment variables.

Nitrogen use efficiency (%) exhibited a year by N rate treatment interaction ($p < 0.001$). In 2007 and 2008 N use efficiency was least in the lowest N rate treatment, increased as N rate increased, and then decreased slightly at the highest N rate (Table 4). In contrast, N use efficiency was greatest in the low N rate in 2010 and decreased with increasing N rate. There was also a trend ($p = 0.059$) for N use efficiency to decline as EC increased (59.6 ± 2.5% in EC zone 1, 55.2 ± 2.5% in EC zone 2, and 51.2 ± 18.2% in EC zone 3).

Table 4. Nitrogen use efficiency (%) as a function of year and N rate.

	Year		
N rate	2007	2008	2010
56 or 90	39.3 ± 8.0	22.5 ± 5.6	108.4 ± 2.8
67 or 90	46.6 ± 5.6	39.0 ± 4.0	104.3 ± 3.3
101	54.5 ± 4.6	44.8 ± 4.0	75.5 ± 3.3
134	40.1 ± 5.6	30.9 ± 5.6	61.7 ± 4.6

Objective 3: Compare two different methods for measuring EC and delineating management zones to determine the best basis for SSN in the Central Great Plains. The two methods evaluated were: 1) direct contact EC mapping with unsupervised classification (the approach used for this project), and 2) electromagnetic radiation with response surface classification.

There are two methods for EC mapping: direct contact and electromagnetic radiation – and two commonly used approaches for separating a farm field EC map into management zones: unsupervised classification and response surface classification. While direct contact EC and unsupervised classification were the basis for this demonstration project, we wanted to look at the alternative to determine its applicability for delineating soil properties associated with yield potential in the Central Great Plains.

To this end, three of the eight fields in the study site were mapped for EC using electromagnetic radiation at the 0-1 m depth (0-3 feet) and separated into management zones using response surface classification. Analysis of soil samples taken within management zones showed *no correlation* between these management zones and soil chemical, physical and biological properties associated with yield – or actual crop yields.

Conclusions

Despite major setbacks due to drought, resulting in poor wheat stands and significant soil sampling issues, we were able to establish this regional demonstration project, impose N treatments and pursue project objectives for three years (*Objective 1*). The findings of no significant difference in winter wheat yields among the various EC-zone/N treatment combinations (Wheat Crop Yields analyses) – and no relationship between EC, N treatments and NUE (Soil Conservation Effects analyses) were disappointing, to say the least (*Objective 2*).

At first glance, the results of this project do not appear to bolster the hypothesis that EC can be used as a basis for SSN in the Central Great Plains. Yet, there is significant information to be gleaned from its findings. When a by-year spatial analysis of Wheat Crop Yields was run, assuming field is a random factor and using a log-linear variogram spatial error model, N treatment was significant (Pr>F=0.1). The EC zone treatment effect produced an F value of 5.06 (Pr>F=0.3), which would have been significant had there been more than 2 degrees of freedom. Replication is clearly an issue. Given the sheer size of farm-scale experiments such as this, it is generally not practical to have more than the two or three replicates (fields).

The tremendous range in NUE calculated as part of the Soil Conservation Effects portion of this project is likely due to high local-scale variation in N levels and the importance of N contributions from the labile organic N phase. Organic N sources can be a dominant source of N for no-till fields. The high local-scale variability in N at the study site is probably a consequence of no-till management wherein N associated with plant residue is concentrated in rows for row crops and distributed more uniformly with non-row crops such as wheat. As row and non-row crops are rotated, this creates tremendous local-scale variability.

Previous work relating total N to EC measurements have shown local-scale (within 1 m) coefficients of variation (CV) of 30-60% at a range of locations throughout the southwestern USA. However, local- and global-scales of variation for total N at the Farm-Scale Intensive Cropping Study site revealed CVs of 81 and 97%, respectively. In situations where local- and global-scales of variation are nearly equal, the use of EC as a surrogate to characterize spatial variability becomes problematic and untenable unless the number of samples taken at each sampling location is sufficient to estimate a local-scale average. Optimally, five or more samples may be needed within a 1-m column of soil, at each site, in order to accurately characterize N levels (total, organic, and inorganic) and calculate NUE.

The apparent impact of high local variability is also evidenced by the fact that, for this project, significant results *were* obtained from the Grain Quality analyses. When assessed using collected grain samples, grain yields were different among years, EC zones and N treatments. Grain N concentration was also different among years, EC zones and N treatments. Moreover, NUE increased with increasing N treatments and there was a trend for NUE to decrease as EC increased. What are we to make of the major discrepancy in results between the Soil Conservation Effects and Grain Quality aspects of this project? The likely explanation is a high level of local-scale variability and the difference in sampling designs employed. Because of the quantity of soil samples collected each year (two or three fields x eight N treatments x three EC zones x five depths of measurement) only one soil core was taken per site. Conversely, two samples were taken per site for the Grain Quality analyses. It appears that N variability was mitigated and statistical significance improved by doubling the number of samples taken at each site.

Clearly, different methods for determining EC management zones do not have general applicability across regions. They must be evaluated for use within a given area. While EC measured using electromagnetic radiation with response-surface classification works well in the saline soils of irrigated systems in the arid west, direct contact measurement of EC with unsupervised EC classification at the 0-0.3 m (0-1 ft) depth of measurement appears to be most appropriate for dryland wheat systems in the Central Great Plains (*Objective 3*). Two possible explanations for this are that the 0.3-1m depth included when measuring EC with electromagnetic radiation is not suitable for the Central Great Plains because of a typically dry subsurface soil profile. Moreover, previous research using direct contact EC with unsupervised classification showed that measured EC in Central Great Plains' soils is largely driven by soil clay content – and clay content is highly correlated with soil properties associated with yield potential. In this area, variation in clay content is greatest in the top 0.3 m (1 foot) of soil.

Of all soil properties measured across the Farm-Scale Intensive Cropping Study site using electromagnetic radiation with response-surface sampling, EC correlated best with total N (r = -0.42 and -0.64 for EM_v and EM_h, respectively). This correlation indicates that the delineation of site-specific N management units using geospatial EC measurements is a viable approach. However, it is possible that the application of unsupervised classification to EC maps is not the optimal approach for delineating site-specific N management zones. As an alternative, EC could be used to develop an EC-directed sampling design which, in turn, would be used to spatially characterize N levels to define management zones. However, such an approach would be considerably more costly than the simple EC-scanning approach used in this project.

As is the case with most on-farm, farm-scale experiments, this project was a major undertaking in terms of time, management, scope, labor and analysis. Unfortunately, it was not major enough. All indications point to direct contact EC using unsupervised classification as a suitable cost-effective basis for site-specific N management in the Central Great Plains. However, a more robust experimental design, in terms of field replication and sampling will be required to provide statistical evidence for this approach.

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