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## Abstract

A 400-ha subbasin study within the Walnut Creek watershed near Ames, IA, confirmed that using late-spring soil nitrate nitrogen ( $\text{NO}_3\text{-N}$ ) test (LSNT) fertilizer recommendations could significantly reduce  $\text{NO}_3\text{-N}$  loss in drainage water, but detailed crop response was not reported. Herein we summarize corn (*Zea mays* L.) response to the LSNT program when implemented across the Clarion–Nicollet–Webster soil association. The LSNT was used to determine the recommended N fertilizer rate that was applied uniformly across each field except on check strips where zero or nonlimiting ( $>220 \text{ kg N ha}^{-1}$ ) sidedress N was applied. Leaf chlorophyll (SPAD) readings, end-of-season stalk nitrate concentrations, and grain yield and quality (protein, starch, and oil content) showed significant year, field, soil map unit and N rate response. Average grain yield with the LSNT program was significantly lower than the nonlimiting rate in 1997 and 1998 but not in 1999 or 2000. This suggests that although watershed-scale implementation of the LSNT can reduce nitrate loss through drainage water, it may also increase producer risk, especially when above-normal rainfall occurs shortly after the sidedress N fertilizer is applied. To encourage adoption of the LSNT program for its water quality benefits, we suggest that federal, state, or private agencies develop affordable risk insurance or some other financial incentives to help producers minimize the potential crop risk associated with this program.

## Disciplines

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## Comments

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# Corn Response to Late-Spring Nitrogen Management in the Walnut Creek Watershed

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## ABSTRACT

A 400-ha subbasin study within the Walnut Creek watershed near Ames, IA, confirmed that using late-spring soil nitrate nitrogen ( $\text{NO}_3\text{-N}$ ) test (LSNT) fertilizer recommendations could significantly reduce  $\text{NO}_3\text{-N}$  loss in drainage water, but detailed crop response was not reported. Herein we summarize corn (*Zea mays* L.) response to the LSNT program when implemented across the Clarion–Nicollet–Webster soil association. The LSNT was used to determine the recommended N fertilizer rate that was applied uniformly across each field except on check strips where zero or nonlimiting ( $>220 \text{ kg N ha}^{-1}$ ) sidedress N was applied. Leaf chlorophyll (SPAD) readings, end-of-season stalk nitrate concentrations, and grain yield and quality (protein, starch, and oil content) showed significant year, field, soil map unit and N rate response. Average grain yield with the LSNT program was significantly lower than the nonlimiting rate in 1997 and 1998 but not in 1999 or 2000. This suggests that although watershed-scale implementation of the LSNT can reduce nitrate loss through drainage water, it may also increase producer risk, especially when above-normal rainfall occurs shortly after the sidedress N fertilizer is applied. To encourage adoption of the LSNT program for its water quality benefits, we suggest that federal, state, or private agencies develop affordable risk insurance or some other financial incentives to help producers minimize the potential crop risk associated with this program.

**S**UBSURFACE DRAINAGE with high  $\text{NO}_3\text{-N}$  concentrations from the U.S. Corn and Soybean Belt is one factor contributing to hypoxia in the northern Gulf of Mexico (Dinnes et al., 2002; Goolsby et al., 2001; Jaynes et al., 2004; Kalkhoff et al., 2000; Rabalais et al., 1996; Schilling and Libra, 2000). Potential  $\text{NO}_3\text{-N}$  sources include mineralization of soil organic matter and excessive application of animal waste or inorganic N fertilizer (Cambardella et al., 1999; Jaynes et al., 2001, 2004). Nitrate losses during both phases of the dominant 2-yr corn and soybean [*Glycine max* (L.) Merr.] rotation are important because of the large area planted to those crops, the high rates of N that are often applied to corn, and the inefficiency with which N is recovered during the first year after application (Balkcom et al., 2003; Randall et al., 2003).

Using appropriate N application rates, improving the synchrony (timing) between plant demand and soil N availability, and monitoring plant available N through soil and plant analyses are among the recommendations

listed by Dinnes et al. (2002) in a review of strategies for reducing nitrate loss through agricultural drainage. Implementation of the LSNT, based on the  $\text{NO}_3\text{-N}$  concentrations in the surface 30-cm layer of the soil when plants are 15 to 30 cm tall, is one specific N fertilizer management strategy that has been recommended (Magdoff, 1991; Binford et al., 1992; Guillard et al., 1999; Balkcom et al., 2003). This test has consistently shown that 20 to 25 mg N  $\text{kg}^{-1}$  soil at approximately the V6 (Ritchie et al., 1996) plant growth stage will provide an optimal supply of N for a corn crop across a wide variety of environments (Bundy and Meisinger, 1994). Coupled with end-of-season stalk nitrate analysis during the first 3 wk after blacklayer formation, these tests have been recommended as tools for improving field- and watershed-scale N management (Brouder et al., 2000; Balkcom et al., 2003).

Jaynes et al. (2004) demonstrated in a 4-yr study that implementation of the LSNT in a tile-drained subbasin of the Walnut Creek watershed in central Iowa significantly reduced N fertilizer application rates and surface water nitrate concentrations when compared with two adjacent subbasins where the farmers' standard N management practices were used. They concluded that widespread adoption of the LSNT fertilizer management program could result in a  $\geq 30\%$  decrease in nitrate concentrations in surface water. In addition to monitoring water quality effects, substantial plant data were also collected from 1996 through 2000. Our objectives are to quantify the corn crop response to the LSNT program and to determine if the response differed among soils within the Clarion–Webster–Nicollet soil association.

## MATERIALS AND METHODS

### Study Site

The 5130 ha Walnut Creek watershed located south of Ames, IA, is characterized by a gently undulating surface that has only a few meters vertical relief and a poorly defined surface drainage system. Soils within the watershed are moderately permeable, with about 33% being well drained, 10% somewhat poorly drained, 50% poorly drained, and 5% very poorly drained. A dense network of subsurface drainage tiles has been installed during the past century to accommodate intensive row crop farming (Hewes and Frandson, 1952). Corn and soybean are typically grown in rotation, with their production comprising more than 80% of the land use. Detailed descriptions of the watershed's location, geology, soils, climate, land use, and farming practices can be found in Hatfield et al. (1999) and Eidem et al. (1999).

**Abbreviations:** GPS, global positioning system; LSNT, late-spring nitrate test.

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### Tillage and Crop Management Practices

Our farmer cooperators made all tillage and crop management decisions other than the use of the LSNT fertilizer management program within the treatment subbasin. The typical corn-soybean rotation was used for almost all fields, with the exception being to rearrange their field structure (e.g., combining fields that had previously been split). Before planting soybean, corn fields were chisel-plowed in the fall by all but one cooperator. Three also chisel-plowed or used a field cultivator to till the soybean fields before planting corn. All cooperators used a field cultivator and/or disk to prepare the seedbed and incorporate herbicide and preplant fertilizer applications in the spring. Commercial yellow dent corn hybrids adapted to central Iowa were selected and planted by our cooperators in each field. All fields were cultivated once each year for weed control, usually in mid-June after the LSNT fertilizer application within the corn fields or in late June or early July for the soybean fields.

### LSNT Program

The LSNT fertilizer management program was implemented in 15 fields within a 405-ha subbasin of the Walnut Creek watershed beginning in 1997. Approximately 56 kg N ha<sup>-1</sup> was applied to each corn field at or shortly before planting each year. Soil samples were taken by dividing each field into 4-ha blocks and each block into four 1-ha subblocks when the corn plants were 15 to 30 cm tall (early to mid-June). A diagonal transect was walked across each subblock to obtain eight 30-cm-deep soil cores. Samples were taken at approximately equal distances along each transect although pothole and hilltop areas were avoided as recommended by Blackmer et al. (1997). The first core along each transect was taken within a row. The second core was taken one-eighth of the distance between two rows and the third two-eighths of the distance between two adjacent corn rows. This pattern was continued until the eighth soil core was taken seven-eighths of the distance between two corn rows. Composite samples, consisting of the eight cores from each of the four subblocks, were mixed, subsampled, extracted with 2 M KCl, and analyzed for nitrate using a Lachat flow injection analyzer (Lachat Inc., Milwaukee, WI).<sup>1</sup> Soil nitrate results were corrected for soil water content and averaged for all blocks within a field before computing a N fertilizer application rate for each field using Eq. [1]:

$$y = 1.121 \times 8 \times (25 - x) \quad [1]$$

where  $x$  is the average nitrate concentration (mg N kg<sup>-1</sup>) in the soil,  $y$  is the N fertilizer rate in kg N ha<sup>-1</sup>, the factor 8 is considered a first approximation for the conversion rate between fertilizer N application and resulting soil N concentration, 25 is the required soil N concentration for full yield (Blackmer et al., 1997), and 1.121 converts the recommendation from lbs ac<sup>-1</sup> to kg ha<sup>-1</sup>.

The computed fertilizer rate was banded using a Blu-Jet (Thurston Manufacturing Co., Thurston, NE) sidedressing machine with 32% urea ammonium nitrate (UAN) solution within 1 wk after collecting the soil samples. Each field was treated uniformly except within the field-long check strips that were 12 or 16 rows wide (depending on farmer's planter width) and strategically placed to cross all soil types. To avoid confound-

ing the watershed scale evaluation of the LSNT program, each field had only two check strips. The exception was for a 95-ha field where two sets of strips were imposed on opposite sides of the field. One strip received no additional fertilizer, thus testing the basic N rate of approximately 56 kg N ha<sup>-1</sup>, while the other received two or three times the LSNT rate so that N would be nonlimiting (i.e. >220 kg ha<sup>-1</sup>). This design enabled us to compare three N rates (≈56 kg ha<sup>-1</sup>, each field's LSNT rate, and > 220 kg ha<sup>-1</sup>) across all soil map units within each field.

### Plant Measurements

Chlorophyll meters similar to those described by Blackmer et al. (1993) and Blackmer and Schepers (1994, 1995) were used to monitor leaf N in 1997 and 1998. Approximately 90 evenly spaced measurements (Siambi et al., 1999) were taken within each field-long check strip on the most recent fully expanded leaf when corn plants were between growth stages V9 and V12 (Ritchie et al., 1996). Each measurement site was georeferenced by recording GPS waypoints so that maps could be generated to verify the N rate and determine the dominant soil type associated with each measurement.

At physiological maturity, fifteen 20-cm cornstalk samples were collected as described by Blackmer and Mallarino (1996) from every 1-ha block within each cornfield. Five additional samples were collected from the nonsidedressed and nonlimiting N check strips. The samples were dried, coarse-ground to pass an 8-mm screen using a Wiley Mill (Thomas Manufacturing, Philadelphia, PA), subsampled, and ground again to pass a 0.5-mm screen with a cyclone mill (Udy Manufacturing, Fort Collins, CO). The finely ground material was sampled, extracted with 2 M KCl, and analyzed for NO<sub>3</sub>-N with a Lachat flow injection analyzer. Samples with nitrate concentrations near or above 10 000 μg N g<sup>-1</sup> were rerun at a 400-fold dilution.

### Grain Yield and Quality

Each cooperator's combine was equipped with a yield monitor and differential global positioning system (DGPS). Personnel from a local farm cooperative helped farmers calibrate their yield monitors and ensured that each was set to record data every 2 s. The actual number of data points per block (1 ha) varied depending on operator speed but generally ranged from 20 to 50 points. Yield data were organized with ArcView (Environ. Syst. Res. Inst., Inc., Redlands, CA) geographical information system software, mapped, and prepared for further statistical analyses. Values below 0.63 or above 18.9 Mg ha<sup>-1</sup> were discarded, assuming they represented yield monitor errors associated with the beginning and end of each harvest pass or factors causing inconsistent grain flow through the combines. Yields for the adjacent no-sidedress, nonlimiting N, and LSNT check strips were extracted from the overall yield monitor data using GPS benchmarks and labels applied to the yield records by the farmers as they harvested each field.

Grain samples were collected from ears removed from the same plants that were harvested for end-of-season stalk nitrate analyses. Each 1-ha subblock was thus represented by a minimum of 15 ears, and each N treatment strip crossing selected subblocks by a minimum of five ears. The ears were dried slowly in a well-ventilated room until they could be shelled. The grain was then stored in airtight plastic bags until it could be analyzed by the Iowa State University Grain Quality Laboratory for percentage moisture, protein, oil, and starch content using near infrared reflectance spectroscopic (NIRS) procedures.

<sup>1</sup>Mention of trademark, proprietary product, or vendor is for information only. It does not constitute a guarantee or warranty or the product by the USDA or Iowa State University and does not imply its approval to the exclusion of other products or vendors that may also be suitable.

**Table 1. Predominant soil series within the Walnut Creek subbasin used to evaluate watershed-scale effects of adopting the late-spring nitrate test (LSNT) fertilizer management program in central Iowa.**

Map symbol	Soil series	Slope	Yield potential†	Surface characteristics‡				
				Depth	Clay	BD	Permeability	AWC
		%	Mg ha <sup>-1</sup>	mm	g kg <sup>-2</sup>	g cm <sup>-3</sup>	mm h <sup>-1</sup>	cm cm <sup>-1</sup>
6	Okoboji silty clay loam	0 to 1	5.27	0 to 813	350 to 420	1.25 to 1.30	5 to 15	0.21 to 0.23
28	Dickman fine sandy loam	1 to 5	3.14	0 to 406	120 to 180	1.50 to 1.55	51 to 152	0.13 to 0.15
55	Nicollet loam	1 to 3	7.28	0 to 432	240 to 350	1.15 to 1.25	15 to 51	0.17 to 0.22
90	Okoboji mucky silt loam	0 to 1	5.27	0 to 381	200 to 260	1.20 to 1.25	15 to 51	0.24 to 0.26
95	Harps loam	1 to 3	5.96	0 to 508	250 to 350	1.35 to 1.40	15 to 51	0.19 to 0.21
107	Webster clay loam	0 to 2	6.91	0 to 432	260 to 360	1.35 to 1.40	15 to 51	0.19 to 0.21
138	Clarion loam	2 to 5	6.59	0 to 330	180 to 240	1.40 to 1.45	15 to 51	0.20 to 0.22
507	Canisteo clay loam	0 to 2	6.59	0 to 584	220 to 320	1.25 to 1.35	15 to 51	0.18 to 0.22
511	Blue Earth mucky silt loam	0 to 1	6.09	0 to 559	180 to 320	0.30 to 1.00	15 to 152	0.18 to 0.24

† Expected corn yield under a high level of management (USDA-SCS, 1984).

‡ Depth refers to surface layer only; BD = bulk density; AWC = available water capacity. Values are from the Soil Survey of Story and Boone Counties in Iowa (USDA-SCS, 1981, 1984).

### Statistical Analyses

Data for leaf chlorophyll (SPAD), end-of-season stalk NO<sub>3</sub>-N concentration, yield, and grain quality from each field and from the N check strips within each were analyzed separately by year using a SAS (SAS Inst., 1990) general linear model. Individual fields, the N rate for each fertilizer strip, and dominant soil series within each block were used as the class variables. An  $\alpha$  value of 0.1 was chosen for practical application, assuming that since the LSNT program reduced NO<sub>3</sub>-N concentrations in the drainage water from the subbasin (Jaynes et al., 2004), adoption could be encouraged if there was only a 1 in 10 chance of reducing grain yield or some other variable. Least significant difference (LSD) values were calculated and used to separate mean values when the *F* values were statistically significant. Correlations among SPAD readings, stalk NO<sub>3</sub>-N, yield, protein, starch, and oil content were also computed using the SAS software. Pearson correlation coefficients were computed after averaging all data for each year, field, and N rate.

## RESULTS AND DISCUSSION

### Field-Scale Response to LSNT Management

Soils within the Walnut Creek subbasin are classified as being within the Clarion–Nicollet–Webster soil association. Within the study area, nine different soil series (Table 1) have been mapped (USDA-SCS, 1981, 1984). Subtle differences among soil series and the relative distribution of each series within the various fields are predominant factors causing significant differences in yield, stalk nitrate, and grain quality among fields and between years (Table 2).

Among years, the lowest average yields occurred in 1998 and 2000. We attribute the low 1998 yield to excessive rainfall (Fig. 1) that occurred after the LSNT-based sidedress fertilizer N application was made but before the exponential plant growth stage and rapid N accumulation. Lower yields in 2000 were attributed to the below-average rainfall beginning during the winter of 1999 and extending through the summer of 2000 (Fig. 1). The higher grain yield in 1996, before the LSNT study was initiated, is attributed to more favorable rainfall than major differences in N fertilizer rate. However, the slightly lower grain yield associated with the LSNT program was consistent with our cooperators' perceptions and verified by their self-selected comparison fields where they used

their standard (i.e., fall-applied anhydrous N) fertilizer management practices.

End-of-season stalk nitrate averages (Table 2) also showed significant differences among years. Based on interpretations suggested by Blackmer and Mallarino (1996) (i.e., <0.25 g N kg<sup>-1</sup> being low, 0.25 to 0.70 g N kg<sup>-1</sup> marginal, 0.70 to 2.0 g N kg<sup>-1</sup> optimum, and >2.0 g N kg<sup>-1</sup> excessive), the LSNT program provided optimum to excessive fertilizer N for the weather conditions

**Table 2. Year, field, and soil map unit response to watershed-scale implementation of the late-spring nitrate management program.**

	Grain yield	Stalk nitrate	Protein	Starch	Oil
Seasonal response					
1996	10.6	0.69	75.2	—	—
1997	10.1	1.49	73.2	619	37.2
1998	9.2	0.08	66.3	731	44.4
1999	10.2	1.75	65.2	629	29.4
2000	9.9	2.10	69.5	620	29.0
LSD <sub>(0.1)</sub>	0.2	0.12	1.0	1	0.3
Field response					
1	10.6	1.25	71.8	617	35.5
2	9.7	1.04	69.0	626	31.6
3	9.3	0.64	72.8	728	42.8
4	9.8	1.16	71.7	675	36.6
5	10.0	0.33	71.5	723	44.9
6	9.8	1.33	69.5	676	36.8
7	10.8	2.16	66.7	625	33.8
8	9.4	0.21	69.6	728	44.3
10	9.9	1.65	73.1	622	32.4
11	10.0	0.71	69.3	682	35.8
12	11.5	1.79	70.0	626	36.8
13	9.1	0.72	69.8	626	31.8
14	9.6	0.98	68.4	624	33.2
15	10.3	3.32	71.1	618	35.6
16	10.1	0.80	70.4	676	36.6
LSD <sub>(0.1)</sub>	0.5	0.26	2.1	2	0.7
Soil map unit response					
Okoboji sicl†	10.7	0.90	69.2	639	34.0
Dickman fsl	9.4	0.52	72.5	726	44.5
Nicollet l	9.7	1.09	69.3	662	36.3
Okoboji mucky sil	9.8	1.30	71.1	664	36.0
Harps l	9.9	1.09	69.9	650	35.7
Webster cl	10.2	1.15	69.7	654	35.6
Clarion l	9.8	1.10	70.5	661	36.2
Canisteo cl	10.0	0.98	70.3	663	36.7
Blue Earth mucky sil	10.2	1.46	75.0	616	35.4
LSD <sub>(0.1)</sub>	NS	0.44	NS	NS	NS

† See Table 1 for soil map characteristics; l = loam, sil = silt loam, cl = clay loam, sicl = silty clay loam, and fsl = fine sandy loam.

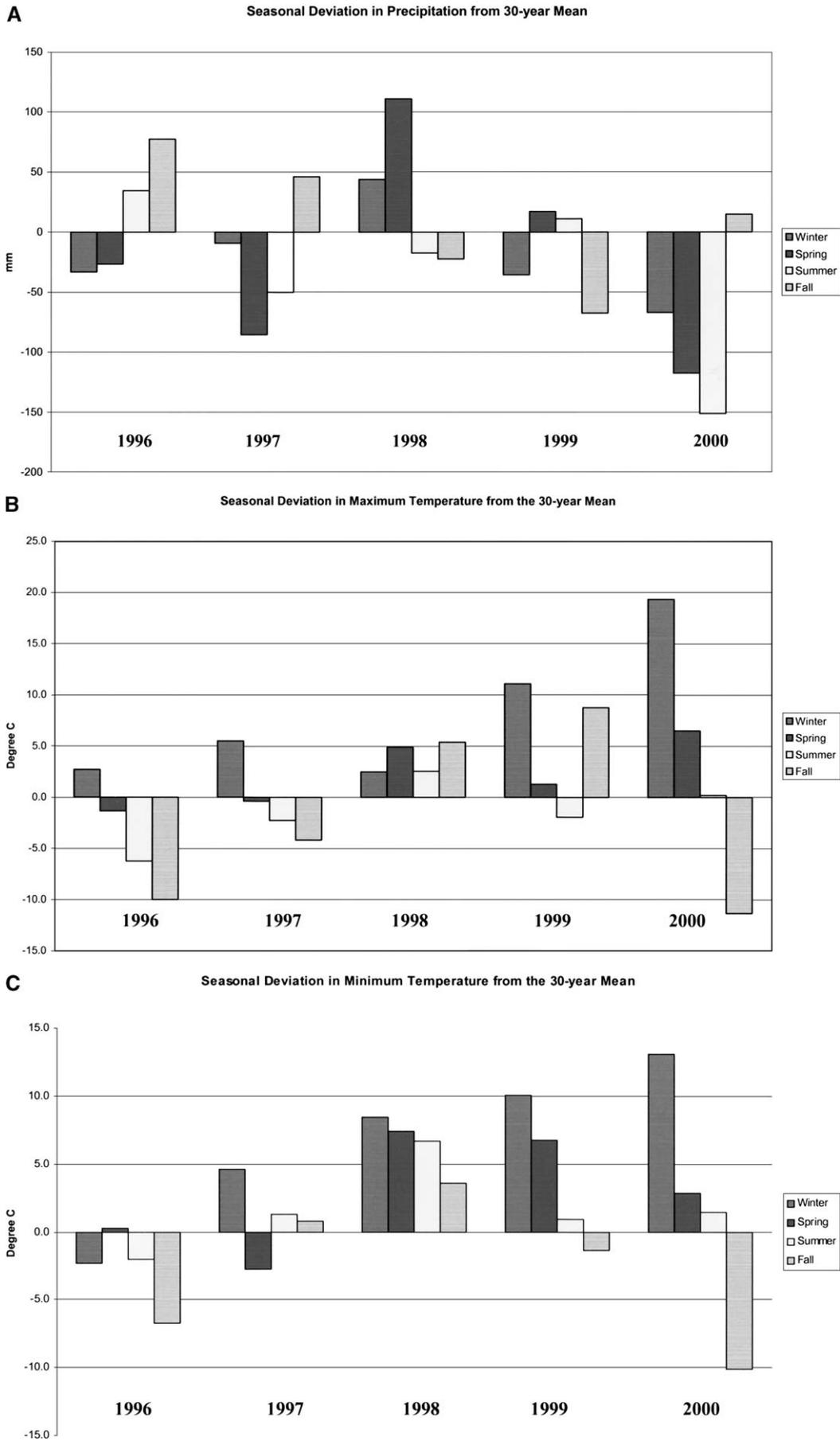


Fig. 1. (a) Seasonal deviation in precipitation from 30-yr mean, (b) seasonal deviation in maximum temperature from the 30-yr mean, and (c) seasonal deviation in minimum temperature from the 30-yr mean.

in 3 of 4 yr. However, time of N application was not evaluated, and perhaps this accounted for the slightly lower grain yields. As indicated by the lower yield, the low end-of-season stalk nitrate in 1998 was also presumably caused by N loss through leaching or denitrification following excessive precipitation in June (Fig. 1).

Protein content is currently not a major consideration with regard to market price for No. 2 yellow dent corn, but the seasonal averages, which ranged from 65.2 to 75.2 g kg<sup>-1</sup> (Table 2), showed significant differences among years. The small but steady decline in grain protein during the first 3 yr of LSNT use may reflect a lower pool of readily available plant N that also resulted in decreased nitrate loss through drainage water (Jaynes et al., 2004). During 1998 and 1999, protein concentrations in samples from the LSNT subbasin were among the lowest and most variable measured by the Iowa State University Grain Quality Laboratory. The specific factors causing the low protein content are not known but were probably associated with plant stress (e.g., available N, water, or temperature) during early grain fill.

The average grain protein content in samples from the LSNT subbasin was 2.4 g kg<sup>-1</sup> less than protein level in strip trials conducted across the state of Iowa, USA (Iowa Grain Quality Initiative, 2004). Grain protein was higher in 2000, when yields were reduced by below-normal seasonal precipitation (Fig. 1), but not as high as the average (71 g kg<sup>-1</sup>) measured before the LSNT program was imposed within the Walnut Creek subbasin (Karlen et al., 1997) or as the statewide average for grain quality strip trials (75.7 g kg<sup>-1</sup>).

The Walnut Creek watershed per se does not have a large number of livestock (Hatfield et al., 1999), but for producers who choose to adopt the LSNT program for its demonstrated water quality benefit (Jaynes et al., 2004), we suggest they also monitor for any significant decreases in grain protein. This is especially important for producers who use their corn for livestock feed. They should definitely be encouraged to develop an on-farm grain protein database rather than relying on historic farm averages or published protein values. Many feed and nutrition sources still estimate corn protein content at 85 to 88 g kg<sup>-1</sup> when determining protein supplementation needs (Hurburgh, 1997). Protein differences of 10 to 20 g kg<sup>-1</sup> could create nutrition problems if not accounted for when developing livestock rations.

Starch and oil content of the corn grain were not measured in 1996, before implementing the N management study, but were included as part of the grain quality evaluation associated with the LSNT project. Average values for 1997 through 2000 (Table 2) showed significant differences among years. Compared with the statewide strip trials (Iowa Grain Quality Initiative, 2004) where starch content for many different hybrids averaged 604, 614, 618, and 599 g kg<sup>-1</sup> for 1997, 1998, 1999, and 2000, respectively, mean starch values within the LSNT subbasin of the Walnut Creek watershed were greater during all 4 yr. Oil content in grain from the subbasin was also higher than for the strip trials in 1997 and 1998 (34.5 and 35.4 g kg<sup>-1</sup>, respectively) but lower in 1999 and 2000 (34.4 and 35.8 g kg<sup>-1</sup>, respectively).

This is attributed to increased water stress during the latter portion of grain fill in 1999 and 2000 (Fig. 1) and to hybrid differences, specifically increased use of Bt genetics within the subbasin.

### Field Variation

As expected for any watershed-scale study with multiple tracts as well as land owners and operators, there were significant differences among fields for yield, stalk nitrate, and grain quality (Table 2). Since all tillage and crop management decisions other than the use of the LSNT fertilizer management program were made by our cooperators, it is not possible to determine any specific reason for the differences. Possible causes include differences in soils, slope, and drainage characteristics; hybrid selection; and management history. With regard to hybrid differences, there were undoubtedly some since Pioneer Brand '33A14', '34B23', '34G81', '34R06', '34R07', '3489', '35N05', and '3563' were all grown during the 4-yr study. Corn suitability ratings for each field were also examined, but the four fields (1, 7, 12, and 15) with the highest average grain yields (Table 2) ranked 15th, 12th, 11th, and 9th among the 15 fields. This suggests that yield differences among fields were probably related more to the quality of field operations (i.e., weed management, tillage, plant population) than to soils or landscapes. With regard to N management, it is important to note that Field 12, which had the highest average grain yield (11.5 Mg ha<sup>-1</sup>), also had an average end-of-season stalk nitrate concentration (1.8 g kg<sup>-1</sup>) that was in the optimum range (Blackmer and Mallarino, 1996).

### Soil Series Effects

The soil series mapped (USDA-SCS, 1981, 1984) for each 1-ha block within the subbasin were superimposed on yield maps for each field to determine if there were significant differences in crop response to the LSNT program among soils. This showed that the average corn grain yield for the nine soil map units (Table 2) was 33 to 199% more than the published corn yield potentials (USDA-SCS, 1981, 1984). We attribute this to improved drainage throughout the watershed and excellent soil and crop management practices provided by our cooperators.

When analyzed by year (Table 3), yield differences among soils were significant in 1998 and 2000 but not in 1997 and 1999. We attribute this to the rotation that results in corn being planted in the same fields every other year. However, the soil series producing the highest and lowest yields in 1998 and 2000 were not the same. In 1998, the highest grain yield (9.4 Mg ha<sup>-1</sup>) was measured on Dickman fine sandy loam while in 2000, it was highest (11.1 Mg ha<sup>-1</sup>) on Okoboji silty clay loam. This response reflected differences in seasonal precipitation patterns (Fig. 1) since 1998 had sufficient rainfall to sustain the corn crop on the sandy-texture Dickman soil but too much for the fine-textured, slow-draining Okoboji soil. Winter, spring, and summer rainfall were below normal in 2000 (Fig. 1), so in that year, the clay loam soil (located in the lower landscape positions

**Table 3. Seasonal variation in corn yield, end-of-season stalk nitrate concentration, and grain protein within a subs basin of the Walnut Creek watershed used to evaluate the late-spring nitrate test (LSNT) fertilizer management program.**

Soil map unit	1997	1998	1999	2000
	Grain yield, Mg ha <sup>-1</sup>			
Okobojo sicl†	10.4	–	10.2	11.1
Dickman fsl	–	9.36	–	–
Nicollet l	9.8	9.07	10.3	9.9
Okobojo mucky sil	10.7	8.94	10.5	10.1
Harps l	10.1	9.05	10.0	10.5
Webster cl	10.1	8.85	10.2	10.0
Clarion l	9.9	9.28	10.3	9.6
Canisteo cl	10.4	9.28	10.2	10.1
Blue Earth mucky sil	10.1	–	10.4	–
LSD <sub>(0.1)</sub>	NS	0.97	NS	0.6
Stalk nitrate, g kg <sup>-1</sup>				
Okobojo sicl	0.92	–	1.48	–
Dickman fsl	–	0.22	–	–
Nicollet l	1.10	0.08	1.34	2.31
Okobojo mucky sil	1.79	0.14	1.70	3.34
Harps l	1.32	0.02	1.84	1.74
Webster cl	1.68	0.04	1.71	1.93
Clarion l	1.61	0.09	1.88	2.25
Canisteo cl	1.45	0.09	1.67	1.96
Blue Earth mucky sil	1.57	–	1.31	–
LSD <sub>(0.1)</sub>	NS	0.15	NS	NS
Grain protein, g kg <sup>-1</sup>				
Okobojo sicl	77.1	–	65.6	66.2
Dickman fsl	–	71.9	–	–
Nicollet l	72.5	65.9	67.2	65.9
Okobojo msil	79.2	64.8	64.1	69.7
Harps l	73.1	66.0	64.2	69.6
Webster cl	72.2	64.0	65.8	70.2
Clarion l	75.0	67.0	65.4	68.8
Canisteo cl	71.2	67.0	65.1	70.8
Blue Earth mucky sil	81.2	–	65.6	–
LSD <sub>(0.1)</sub>	NS	4.6	NS	NS

† See Table 1 for soil map characteristics; l = loam, sil = silt loam, cl = clay loam, sicl = silty clay loam, and fsl = fine sandy loam.

where both run-on and shallow ground water help mitigate water stress) produced the highest yield.

Consistent with the yield results, end-of-season stalk nitrate concentrations were also higher in plants growing on Dickman fine sandy loam than on any of the other soils in 1998 (Table 3) although the values were still “low” according to the ratings suggested by Blackmer and Mallarino (1996). We suggest that even though substantial rainfall occurred immediately after sidedressing, grain yield and end-of-season stalk nitrate were higher because plant available N in the Dickman soil was still recoverable and the corn plants were under less aeration stress than on the other soils. Much of the plant available N measured by the LSNT soil test or applied via fertilizer was apparently lost from the root zone through leaching and/or denitrification in the other soils. Therefore, with the exception of Okobojo mucky silt loam (0.14 g NO<sub>3</sub>-N kg<sup>-1</sup>), end-of-season stalk nitrate levels in samples for all the other soils were below 0.1 g kg<sup>-1</sup>. The very high stalk nitrate concentrations in 2000 reflect the drought stress associated with that growing season (Fig. 1).

Grain protein showed significant differences among soils (Table 3) only in 1998. Starch and oil content showed significant differences among soils and a highly significant ( $P < 0.0001$ ) field × soil interaction only in 2000 (data not presented). We suggest those differences were

**Table 4. Nitrogen rate response in strategically placed strips used to evaluate N response within the Walnut Creek watershed for 1997 through 2000.**

Fertilizer N rate kg N ha <sup>-1</sup>	SPAD	Yield Mg ha <sup>-1</sup>	Stalk NO <sub>3</sub>	Protein Starch Oil		
				g kg <sup>-1</sup>		
1997						
Minimum = 56	47	8.88	0.11	72.3	619	37.4
LSNT avg. = 168†	51	9.78	1.55	71.6	619	37.6
Nonlimiting > 220	52	10.10	2.46	72.7	619	37.1
LSD <sub>(0.1)</sub>	0.7	0.22	0.2	NS	NS	0.5
1998						
Minimum = 56	41	7.46	0.03	61.8	733	45.0
LSNT avg. = 120	45	9.09	0.12	65.3	718	43.2
Nonlimiting > 220	48	10.49	1.05	76.3	723	44.1
LSD <sub>(0.1)</sub>	2	0.49	0.13	2.3	NS	1.2
1999						
Minimum = 56	50	8.84	0.16	57.4	635	30.6
LSNT avg. = 178	52	10.23	1.88	64.7	630	28.7
Nonlimiting > 220	52	10.12	2.94	68.2	627	29.3
LSD <sub>(0.1)</sub>	0.5	0.33	0.27	1.3	2	0.7
2000						
Minimum = 56	53	9.28	0.60	62.4	625	28.5
LSNT avg. = 115	54	10.04	2.24	69.7	622	29.6
Nonlimiting > 220	55	10.05	5.39	74.8	615	29.0
LSD <sub>(0.1)</sub>	0.6	0.44	0.68	1.7	2	0.9

† LSNT = late-spring nitrate test.

caused more by water stress (Fig. 1) than a differential soil response to the LSNT program.

### Nitrogen Check Strip Response

The primary purpose for the entire project was to determine if using the LSNT fertilizer management program across a watershed could significantly reduce nitrate concentrations in drainage water (Jaynes et al., 2004). However, to confirm the LSNT program was meeting plant N requirements, 12- to 16-row check strips were strategically placed to cross as many of the soil series as possible within each field. One strip received only the preplant application of approximately 56 kg N ha<sup>-1</sup> while the other received a nonlimiting N rate (>220 kg ha<sup>-1</sup>). Yields from a third strip, adjacent to the zero and nonlimiting strips, that received the same LSNT-based rate as the entire field provided the third N treatment for N rate comparisons. The specific soil series associated with each N strip measurement was not determined because the scale of the soil maps for the watershed (USDA-SCS, 1981, 1984) was too coarse.

Within the N check strips, nearly 14 000 SPAD measurements were recorded using chlorophyll meters (Blackmer et al., 1993; Blackmer and Schepers, 1994, 1995) during the 4-yr study. Each year, the nonsidedress treatment had significantly lower SPAD values than either the LSNT or nonlimiting N treatment (Table 4). The average SPAD value for all N strips in 1998 (45) was much lower than for the other 3 yr (50, 51, and 54 for 1997, 1999, and 2000, respectively). This is attributed to the above-normal rainfall (320 mm in June 1998) that apparently resulted in substantial leaching (Kluitenberg and Horton, 1990) or denitrification.

When averaged for all fields, end-of-season stalk nitrate concentrations within the check strips showed a very significant response to N rate (Table 4). The lowest value (0.03 g N kg<sup>-1</sup>) occurred in 1998 and the highest

(5.4 g N kg<sup>-1</sup>) in 2000. In agreement with the SPAD data, end-of-season stalk nitrate values also show that the amount of plant available N was marginal in 1998 but excessive for the drought-limited yields in 2000. The LSNT fertilizer N rates in 1997 and 1999 resulted in optimum stalk nitrate concentrations of 1.6 and 1.9 g N kg<sup>-1</sup>, respectively.

Grain yield in the nonsidedressed strips was significantly lower than either the LSNT or nonlimiting N strips during each of the 4 yr (Table 4). In 1997 and 1998, average grain yield from the LSNT strips was significantly lower than for the nonlimiting N strips, but for 1999 and 2000, those differences were not significant. The yield difference in 1998 presumably occurred because the higher fertilizer application rate helped compensate for the leaching and/or denitrification losses that occurred immediately after application. Assuming the yield difference between LSNT and nonlimiting strips in 1997 (0.32 Mg ha<sup>-1</sup>, or 5 bu ac<sup>-1</sup>) was due to N, it is important to determine if the additional fertilizer increased profit. Using cost of \$0.45 kg<sup>-1</sup> N (\$0.20 lb<sup>-1</sup>) and a corn price of \$0.08 kg<sup>-1</sup> (\$2.00 bu<sup>-1</sup>), the additional 56 kg ha<sup>-1</sup> cost \$25.20 for return of \$25.60. This suggests the LSNT rate was very close to the economic optimum. Also, even though the mean yields reported by Jaynes et al. (2004) do not agree numerically with our calculations, both reports conclude that LSNT and nonlimiting N rates were not significantly different in 1999 and 2000. Furthermore, it is important to recognize the check strips were not intended to calibrate LSNT recommendations, simply to determine if there was an N response.

Grain samples from the N strips showed no significant differences in protein content in 1997. For 1998 through 2000, the differences were significant, increasing consistently as the N fertilizer rate increased from 56 to more than 220 kg N ha<sup>-1</sup> (Table 4). The consistent increase in protein as N fertilization rate increased after 1997 suggests that the residual pool of plant available N associated with the average pre-1997 fertilization rates of 150 kg N ha<sup>-1</sup> may have been reduced by implementing the LSNT fertilizer management program.

Starch content showed no significant differences due to N rate in the strip trials during 1997 or 1998, but in 1999 and 2000, it decreased significantly as N rate increased even though there was no significant yield difference between the LSNT and nonlimiting N treatments. Decreased starch content indicates stress during the latter stages of grain formation. Since both the LSNT and nonlimiting N strips had proportionally lower starch content (Table 4), N rate per se was not the cause, but perhaps an interaction between N rate and plant available water, temperature, insect damage, or other limiting nutrients stressed the plants and reduced the starch content.

Oil content showed small, statistically significant differences among N rates in grain samples from the N strips each year, but a more important difference was the substantially lower level for all N treatments in 1999 and 2000 (Table 4). As with starch content, decreased oil content is also associated with stress during the latter growth stages. However, differences in oil content among

N rates were very small compared with the 25% decrease between the first 2 and last 2 yr of the study. We suggest that hybrid differences probably caused this response, because during the last 2 yr, the percentage of Bt hybrids planted throughout the watershed increased substantially. This change also resulted in substantially more lodging during late-season storms.

Correlation analyses among the N strip measurements were done to determine if the various crop indicators responded similarly to the N rates. When averaged across fields and years, these analyses showed that SPAD readings and yield were significantly ( $P = 0.005$ ) correlated ( $r = 0.750$ ,  $n = 12$ ). SPAD readings were also positively correlated ( $P = 0.01$ ) with stalk nitrate concentrations ( $r = 0.708$ ,  $n = 12$ ) while grain yield and end-of-season stalk nitrate concentrations were also positively correlated ( $P = 0.03$ ) when averaged across fields for the 4 yr ( $r = 0.623$ ,  $n = 12$ ). Therefore, even at the watershed scale, SPAD and end-of-season stalk nitrate concentrations appear to be useful indicator tools for monitoring N effects on corn.

## SUMMARY AND CONCLUSIONS

Crop response to watershed-scale implementation of the LSNT fertilizer management program showed significant seasonal response, presumably driven primarily by rainfall and temperature. Yield differences among fields appear to have been due to management practices such as hybrid selection, plant population, or weed control rather than differences among soils or the N fertilizer rates. With the exception of stalk nitrate concentrations, differences among soil map units within the subbasin were not statistically significant.

Strategically placed check strips within each field showed significantly lower yield for the LSNT program compared with nonlimiting N rates (>220 kg N ha<sup>-1</sup>) during the first 2 yr but not in the final 2 yr. This study was not designed to optimize LSNT recommendations or for direct comparisons with the cooperator's normal practices. Therefore, any N rate below the nonlimiting treatment may have resulted in significantly lower yields in 1997 and 1998. End-of-season stalk nitrate concentrations showed a highly significant response to N rate and significant differences among years that could generally be explained by the seasonal rainfall patterns. Chlorophyll measurements (SPAD readings) on the most recently fully expanded leaf during the V9 to V12 growth stages showed a significant positive correlation with yield ( $r = 0.75$ ) and were significantly lower in nonsidedressed strips than either the LSNT or nonlimiting N strips. Grain protein, starch, and oil content showed significant statistical differences among years, fields, and somewhat to N rate. Based on this response, we suggest that if LSNT programs are to be implemented because of their effectiveness for reducing nitrate concentrations in drainage water, grain quality should also be monitored. This is especially true for producers who utilize their grain for on-farm livestock feed.

Finally, although the LSNT program was effective for reducing nitrate loss through subsurface drainage

(Jaynes et al., 2004), this study suggests that implementing it at a watershed scale may increase risk to producers. Therefore, we recommend that if the LSNT program is to be encouraged through federal or state policies, risk insurance (Dinnes et al., 2002) or other benefits should be made available to producers who adopt the practice.

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