

LANDSCAPE INFLUENCES ON SOIL NITROGEN SUPPLY AND WATER HOLDING CAPACITY FOR IRRIGATED CORN

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ABSTRACT

Water and nitrogen (N) supply to a crop can interact throughout the growing season to influence yield potential. The increasing availability of variable rate irrigation systems to growers in irrigated regions, along with existing capacity for variable rate fertilization, provides the opportunity for temporal and spatial management of inputs of water and nitrogen. This study was initiated in 2011 to explore interactions of landscape and soil features with water and N inputs on grain yield and water and N use efficiency. Five field locations were used across Nebraska to evaluate the effects of landscape variation, climate, and capacity for temporal and spatial management of water and N. Preliminary results in 2011 showed that at sites with significant topographic variation these features influenced grain yield as much as the rate of irrigation water or nitrogen fertilizer, indicating the importance of considering spatial variation in landscape features when optimizing rates and timing of water and nitrogen.

Keywords: Variable rate irrigation, variable rate nitrogen, landscape position, management zones

INTRODUCTION

The availability of water and nitrogen supply will interact across landscape positions within fields, even in irrigated environments. Landscape position can influence soil chemical properties (Franzen, et al., 2006) and yield potential, even in irrigated systems (Bronson, et al., 2001). Slope and relative elevation will influence the potential for rainfall to accumulate or shed from a location, and soil properties such as texture, organic matter content and topsoil depth will influence water storage and supply to crops. Areas that shed or accumulate water will differ in productivity relative to underlying soil properties and precipitation. For example, in higher rainfall or poorly drained environments low landscape positions may be low in productivity (Thelemann, et al., 2010), while in more arid or well-drained environments low positions can accumulate water and be more productive than summit positions. Soil organic matter, texture, and water availability will influence nitrogen mineralization potential and how efficiently nitrogen fertilizers are used (Noelsch, et al., 2009; Mahli, et al., 2004). All of these and other factors will interact to influence crop yield potential, which impacts total crop nitrogen demand. Variable rate irrigation systems are now available to growers which can regulate water supply spatially within fields, and growers have had the capacity for several years for variable rate nitrogen fertilization. This study was designed with the intent of evaluating landscape features with the capacity to supply water and nitrogen to crops, with the goal of providing recommendations to growers on simultaneous spatial management of water and N. This capacity for site-specific, temporal management of water and N is further enhanced by the increasing availability of sensors for real-time monitoring of soil water and crop N status. An earlier study in Nebraska (Roberts, et al., 2012) found that spatial information about soil properties, compiled into management zones, was useful in improving the accuracy of in-season N recommendations using crop canopy sensors.

PROCEDURES

Five field locations were used for the study in 2011. Two sites were at University of Nebraska-Lincoln (UNL) research laboratories – the South Central Agricultural Laboratory (SCAL) and the Brule Water Resources Laboratory (BWL). Three sites were located on cooperating producer's fields – one in Morrill County, and two in Hamilton County (Figure 1). The UNL research sites included more detailed measurements, and inclusion of treatments that were more yield-limiting than those on producer fields. Locations were situated across a rainfall and soils gradient in Nebraska, allowing evaluation of site-specific water/N management interactions over a range of annual rainfall and soil types (Table 1). Three of the sites included the use of variable rate irrigation systems and two of the sites implemented canopy sensor-based in-season N treatments.

Soil moisture was measured in specific treatments (at least two replications) every 30 cm to a depth of 120 cm. Soil matric potential was measured hourly using Watermark granular matric sensors and monitors. John Deere CropSense capacitance probes were used, to the extent available, for comparison to other methods of soil moisture determination. Additionally, neutron scattering probes were used at UNL research centers to calibrate and complement Watermark and CropSense sensors in selected treatments. From extensive soil water status measurements in spatial and temporal scales, the distribution of soil moisture under various irrigation and nitrogen regimes were determined. The crop water uptake under various irrigation and nitrogen treatments were determined using profile soil water status, irrigation, and precipitation amounts. In order to establish crop response within landscape positions relative to water supply, three levels of irrigation water were evaluated at SCAL, BWL, and the Morrill County producer site. Irrigation applications were managed based on pre-determined depletion levels of the available soil water holding capacity. This was accomplished at SCAL using pre-determined soil matric potential values to time irrigation applications. In the fully irrigated treatments, a typical value of 90-100 kPa for a silt-loam soil was used to trigger irrigation. At each irrigation event, a total of 2.5 and 1.8 cm of water was applied to fully irrigated (100%) and 75% of fully irrigated treatments, respectively. Before the tassel stage, whenever the average soil matric potential value in the top 60 cm soil layer reached 90-100 kPa, irrigation was triggered. The same procedure was used for the average of top 90 cm soil layer after tassel to account for the root water uptake in the 60-90 cm layer on irrigation management.

Soil apparent electrical conductivity (EC_a) was measured at all locations prior to planting in 2011 or in the spring of 2010 using a Veris 3100 conductivity instrument. Guided soil samples were taken at each location to determine soil organic matter, pH, conductivity, nitrate, Bray-1 phosphorus, and soil texture characteristics. Elevation data were recorded with a RTK-GPS receiver mounted to the Veris 3100. Elevation data was used to determine slope (0 to 3%, 3 to 6%, >6%) and curvature (concave, convex, linear) using ArcGIS (v. 9.2) Spatial Analyst. Slope and curvature data were categorized into landscape position (LSP) zones at locations with significant topography. Landscape position zones were classified using the following procedure:

<i>Zone</i>	<i>Slope (%)</i>	<i>Curvature</i>
1	0 – 3	concave
2	0 – 3	convex
3	0 – 3	linear
4	3 – 6	concave
5	3 – 6	convex
6	3 – 6	linear
7	> 6	concave
8	> 6	convex
9	> 6	linear

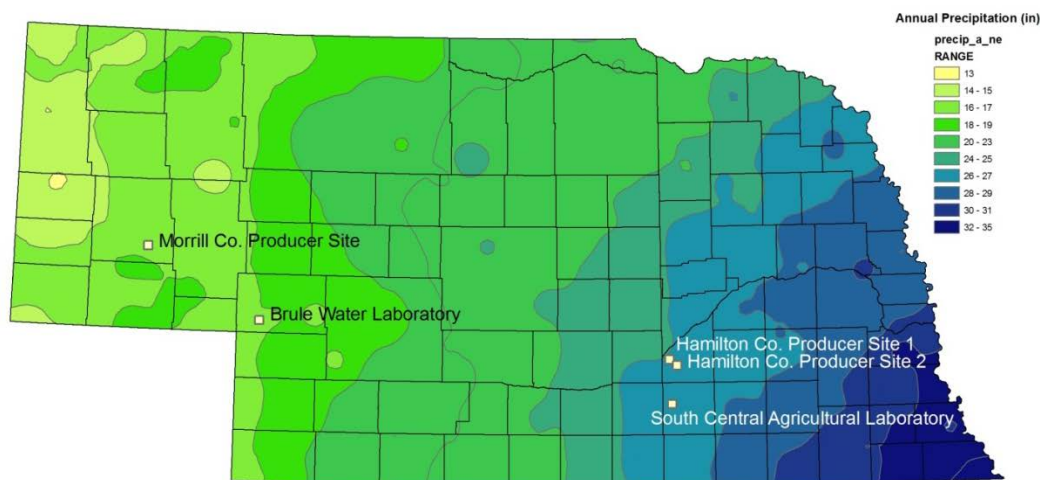


Figure 1. Study locations in 2011, with precipitation gradient across Nebraska.

Treatment design consisted of N fertilizer rates at all locations, and irrigation levels at SCAL, BWL, and Morrill Co. cooperator sites. Irrigation was delivered using either a center-pivot sprinkler system or a linear-move sprinkler system (SCAL). The SCAL site consisted of three irrigation water levels (full crop water demand-100%, 75% of full crop water demand-75%, rainfed) with five N rates (84, 140, 196, 252 kg N ha⁻¹, canopy sensor-based). Seeding rates were 74,100 and 64,220 plants ha⁻¹ for the irrigated and rainfed treatments respectively. Fixed N treatments were sidedressed on 6-7 June 2011. Sensor-based N treatments consisted of a 84 kg N ha⁻¹ sidedress on 6-7 June 2011 followed by a sensor-based application on 30 June 2011 at growth stage V8.

The Brule Water Resources Laboratory field treatment design consisted of three irrigation levels (fully irrigated-100%, 70% of fully irrigated, 40% of fully irrigated) with four N fertilizer levels (84, 140, 196, 252 kg N ha⁻¹), with four replicates of each treatment.

The Hamilton County cooperator had two fields with variable N treatments. Field site #1 had five N strip treatments (84, 140, 196, 252 kg N ha⁻¹, sensor-based) with three replications. Field site #2 had four N strip treatments (84, 140, 196, 252 kg N ha⁻¹) with three replications. Field site #2 N treatments were overlaid on 2010 N strip treatments. For the Morrill county location, three water levels (fully irrigated -100%, 125% of fully irrigated, 75% of fully irrigated) and three N rates (140, 196 and 252 kg N ha⁻¹) were imposed across differential landscape positions, with three replicates of each treatment. Nitrogen rates were applied in field-length strips crossing the range of landscape position within the field. Detailed management practices for individual locations are found in Table 2.

Table 1. Soil series and classification for 2011 sites.

Location	Soil Series	Soil Description
SCAL	Crete silt loam	Fine, smectitic, mesic Pachic Argiustolls
BWL	Satanta loam	Fine-loamy, mixed, superactive, mesic Aridic Argiustolls
	Bayard very fine sandy loam	Coarse-loamy, mixed, superactive, mesic Torriorthentic Haplustolls
	Bankard loamy sand, channeled, flooded	Sandy, mixed, mesic Ustic Torrifluvents
Hamilton Co. 1	Hastings silt loam	Fine, smectitic, mesic Udic Argiustoll
	Hastings silty clay loam	Fine, smectitic, mesic Udic Argiustoll, eroded
Hamilton Co. 2	Hastings silt loam	Fine, smectitic, mesic Udic Argiustoll
	Hastings silty clay loam	Fine, smectitic, mesic Udic Argiustoll, eroded
	Hobbs silt loam, occasionally flooded	Fine-silty, mixed, superactive, nonacid, mesic Mollic Ustifluvents
Morrill Co.	Valent loamy fine sand	Mixed, mesic Ustic Torripsamments

Table 2. Management practices for 2011 sites.

Location	Previous Crop	Hybrid	Planting Date	Seeding Rate	N Application
SCAL	corn	Pioneer 541AM	4 May	74,100 [†] seeds ha ⁻¹	6-7 June
BWL	corn	Pioneer 35-44	9 May	79,040	30 June
Ham. Co. 1	soybean	Pioneer 33-F12	10 May	71,630	10 June
Ham. Co. 2	corn	Pioneer 33-F12	10 May	71,630	10 June
Morrill Co.	corn	DKC 49-35	6 May	74,750 [‡]	13 June

[†]Rainfed treatment seeding rate was 64,220 seeds ha⁻¹

[‡]Variable seeding rate ranges from 34,000 to 83,830 seeds ha⁻¹

RESULTS AND DISCUSSION

South Central Agricultural Laboratory

Weather conditions were favorable for corn growth at this site in 2011, with above average rainfall during the growing season. Irrigation was not initiated until 27 July, with three subsequent irrigation dates: 4 August, 10 August, and 27 August. There was a significant irrigation level x N rate effect on grain yield, as well as significant main effects of both irrigation and N level (Table 3). The irrigation level x N rate interaction was largely the result of the 84 kg N ha⁻¹ treatment having a negative, linear trend in yield with increased irrigation level. Within rainfed treatments, the 84 kg N ha⁻¹ treatment yield was ~0.9 Mg ha⁻¹ greater (P=0.0185) than the fully irrigated treatment at 84 kg N ha⁻¹. Irrigation level treatments of 75% and 100% resulted in similar yield at the same N rates, with the exception of sensor-based N treatments. Sensor treatments receive 194, 145, and 210 kg N ha⁻¹ for the rainfed, 75% and 100% irrigation levels, respectively. The low N rate for the sensor treatment at the 75% irrigation level resulted from a high chlorophyll index (CI) at V8, the stage of in-season N application. Yield levels were limited somewhat at SCAL due to lower than desired plant populations (64,220 plants ha⁻¹ irrigated, 49,150 plants ha⁻¹ rainfed), resulting from residue/germination issues at planting.

With the exception of the sensor-based treatments for the 100% and 75% irrigation levels, grain yields were similar by irrigation levels (100% v. 75%). Rainfed treatments receiving >196 kg N ha⁻¹ had lower grain yield than either the 75% or 100% irrigation levels, while yields at 140 kg N ha⁻¹ were similar among all irrigation levels (Figure 2). Optimal N rates were ~200 kg N ha⁻¹ for both the 100% and 75% irrigation treatment levels.

Table 3. Statistical analysis for grain yield at SCAL, 2011.

<i>Effect</i>	<i>Num df</i>	<i>F-value</i>	<i>P-value</i>
Irrigation rate (IR)	2	4.50	0.0438
Nitrogen (N)	4	150.24	<0.0001
IR x N	8	5.40	0.0002
<i>Contrasts</i>			
Irrigation level			<u>P-value</u>
100% v. 75%			0.6844
100% v. rainfed			0.0213
75% v. rainfed			0.0432

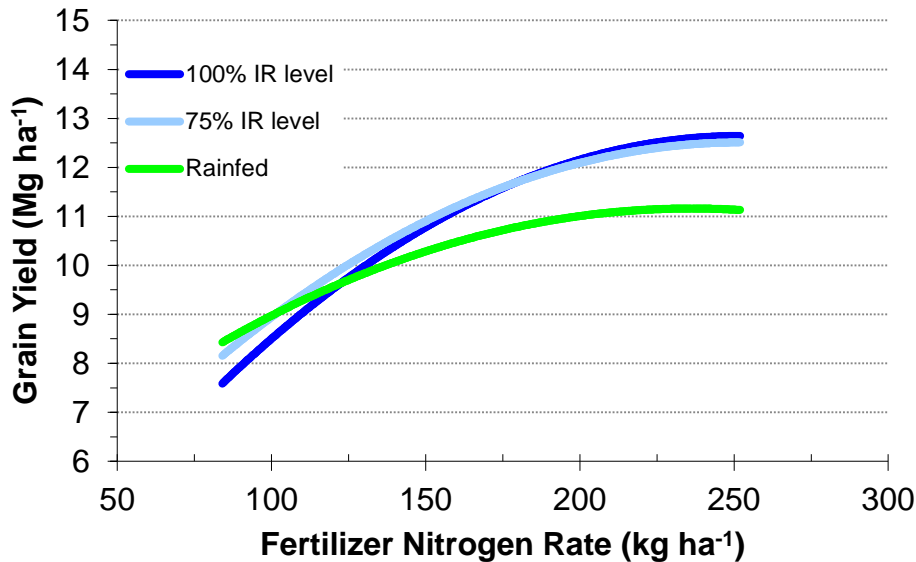


Figure 2. Grain yield response by N rate and irrigation level, SCAL site, 2011. Optimal N rates, based on a quadratic plateau model, were 174, 200, and 203 kg N ha⁻¹ for the rainfed, 75% and 100% irrigation levels, respectively.

Brule Water Resources Laboratory

Weather conditions at this site were atypical, with below-average temperatures in early summer, delaying plant growth, and greater than average growing season precipitation. A total of 19 irrigation events occurred at this site in 2011, with totals of 32.5 cm water applied for the 100% level, 22.8 cm for the 70% level, and 13 cm for the 40% level. At harvest, the harvest area was divided to account for landscape variation in the eastern portion of the field. The west end of the study was combine-harvested with a yield-monitoring combine, while the east end of the study was hand harvested for each treatment and landscape position combination. Grain yield results from this site are thus presented as either west or east areas. For the west area, treatments resulted in similar grain yield (Table 4), with no statistically significant effects on yield – yields averaged 11.6 Mg ha⁻¹ on the west area, while hand-harvested yields on the east area averaged 11.25 Mg ha⁻¹. Landscape positions with minimal slope resulted in higher yield in the west area of the study (Figures 3 and 4). In 2011, higher grain yield was generally associated with the Bayard very fine sandy loam soil. In contrast, in 2010 on the same field higher yields were generally associated with the Satanta loam soil. This suggests that yield variations driven by soil-specific supply of water and/or nitrogen can invert from year to year depending on weather conditions and associated irrigation management.

There was a significant main effect of irrigation level on grain yield for the east area of the study (Table 5), with the lowest irrigation level (40%)

resulting in the highest yield. There was no effect of N rate on grain yield for the east area of this site. There were significant effects of landscape position on grain yield. Landscape position classification varied more with soil series in the east area of the study than in the west. Yield differences by LSP were smaller for the east side of the study than the west side. For the east area of the study, grain yield was highest for 3-6% slopes with concave positions, and lowest for 3-6% slopes with convex positions. Overall, grain yield at BWL tended to vary spatially with minimal response to N treatment. Soil and landscape properties appear to be the dominate factor in yield variation, in 2011 as well as in previous years, rather than input levels of water and N.

Table 4. Statistical analysis of grain yield, west area, BWL, 2011.

Effect	Num df	F-value	P-value
Irrigation rate (IR)	2	1.72	0.1421
Nitrogen (N)	3	2.79	0.2327
IR x N	6	0.99	0.4388

Table 5. Statistical analysis of grain yield, east area, BWL, 2011.

Effect	Num df	F-value	P-value
Irrigation rate (IR)	2	4.91	0.0096
Nitrogen (N)	3	1.06	0.3709
Landscape position (LSP)	7	3.06	0.0082
IR x N	6	0.50	0.7520
IR x LSP	8	0.68	0.7077
N x LSP	17	0.44	0.9716
IR x N x LSP	16	1.57	0.0895

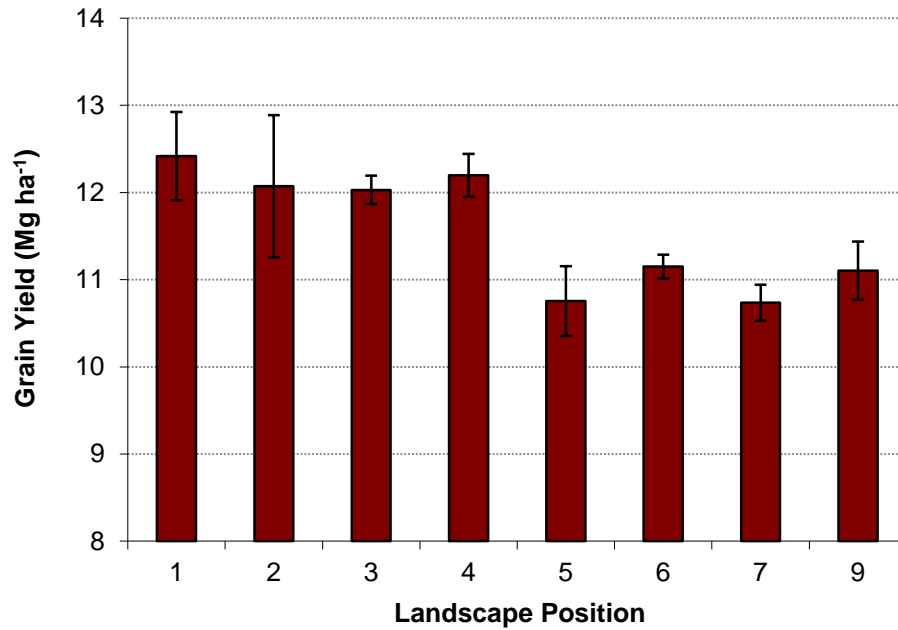


Figure 3. Grain yield for landscape positions (LSP), west area of BWL site, 2011.

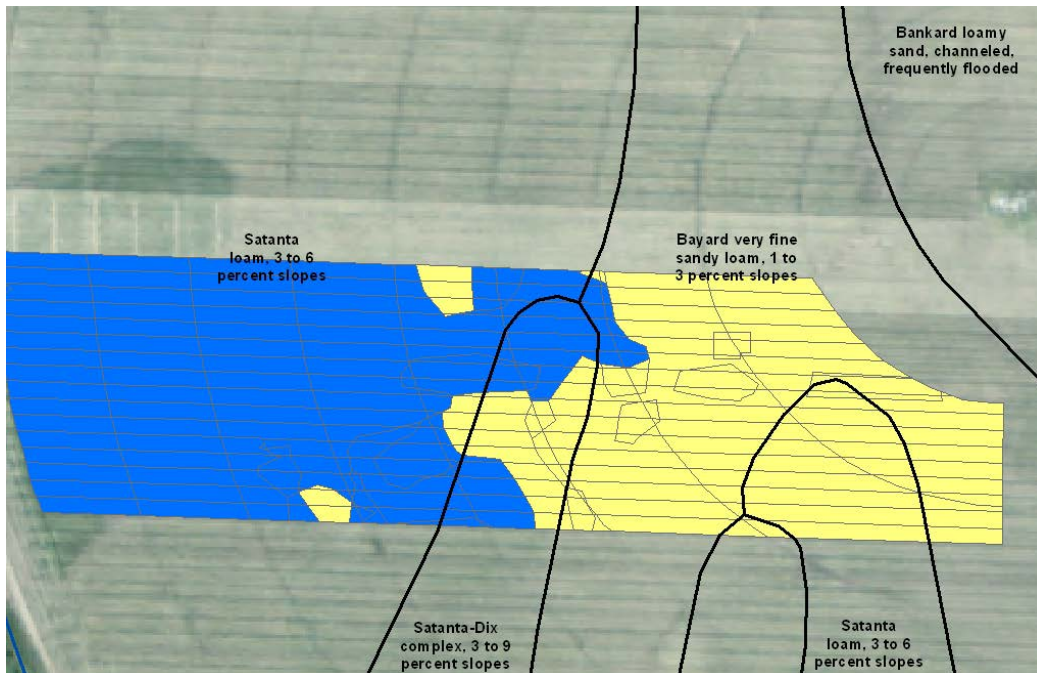


Figure 4. Grouped landscape positions, BWL west area, 2011. Grain yield was higher for LSPs associated with the Bayard very fine sandy loam (yellow), compared to LSPs associated with the Santanta loam (blue).

Weather conditions were favorable for high yield at this site, with an average yield for the study of 15.1 Mg ha⁻¹. This site had N rate treatments interacting with landscape position – irrigation was uniformly managed. There were no significant effects of N rate on grain yield, but yield differed with LSP (Table 6). Canopy-sensor based N treatment resulted in lower N rates for gently sloping LSPs (100 – 119 kg N ha⁻¹), with N rate increasing as slope increased (142 – 156 kg N ha⁻¹). In general, LSPs 1-3 had above average yield, while LSPs 5 – 8 had average to below average yield (Figure 5).

Table 6. Statistical analysis of study effects on grain yield, Hamilton Co. Site 1.

Effect	Num df	F-value	P-value
N	4	1.42	0.2651
LSP	7	17.99	0.0030
N x LSP	28	0.99	0.4770

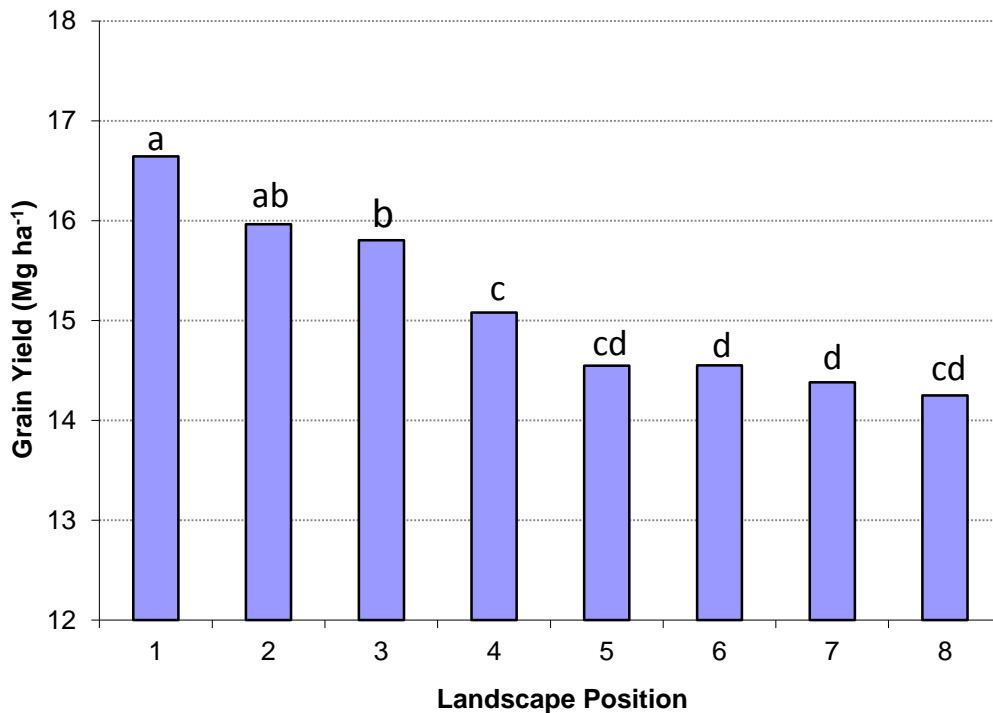


Figure 5. Grain yield by landscape position, Hamilton Co. site 1, 2011. Letters indicate statistically significant differences, P<0.05.

Hamilton County Site 2

This site was located on the same strips in a field with similar treatments in 2010. Thus, residual effects from 2010 treatments affected 2011 yield response to some degree. Yield responses by LSP were similar in 2010 and 2011. Landscape positions with level or water-accumulating positions were above

average in yield with minimal response to higher N rates, while positions with greater slope had increased yield with higher N rates. The average yield for the study in 2011 was 13.3 Mg ha⁻¹. A significant high wind event mid-summer reduced plant stand and yield potential at this site, but damage appeared to be relatively uniform across the study area. There were significant effects of both N rate and LSP on grain yield at this site, but no significant interaction (Table 7). Landscape positions 1-4 had similar yield, above the study average. Landscape positions 6 – 8 were similar in yield and below the study average.

Table 7. Statistical analysis of study effects on grain yield, Hamilton Co. Site 2.

Effect	Num df	F-value	P-value
N	3	47.9	0.0001
LSP	7	5.1	0.0047
N x LSP	21	1.2	0.2511

Morrill County Site

Multiple hail events and issues at harvest prevented statistical analysis for this site. The study field had an average grain yield of 9.8 Mg ha⁻¹.

SUMMARY

Preliminary analysis of 2011 data showed that at sites with significant topographic variation, landscape features influenced grain yield as much as the rate of irrigation water or nitrogen fertilizer. Although the mechanisms driving these landscape effects on crop water or N use efficiency are yet to be determined, these preliminary results emphasize the importance of considering the significant impact of landscape variation on management decisions that optimize rate and timing of water and nitrogen.

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