Optimizing Nitrogen and Irrigation Timing for Corn Fertigation Applications Using Remote Sensing

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Abstract

Nitrogen (N) use efficiency in high-yield irrigated corn production systems has many economic and environmental implications. Many producers in the region rely on single pre-plant applications of granular urea or anhydrous ammonia as the primary N source in irrigated corn production systems. This practice increases the likelihood of N loss, environmental impact, and reductions in profit per acre. The increasing conversion of irrigated land in Kansas to center pivot irrigation systems presents the opportunity to develop automated systems for advanced N management through fertigation that can potentially increase nitrogen utilization, reduce environmental impact and increase profit per acre. The purpose of this study was to measure the impact of the relationship between irrigation timing, N rate, and timing of N application on corn grain yield and determine the potential for developing algorithms for fertigation systems. Results indicate that overall performance of the sensors and algorithm utilized was effective at achieving high yields but has the tendency to overestimate N requirements. In order to optimize sensor based N recommendations for fertigation systems, algorithms must be specifically designed for these systems in order to take advantage of their full capabilities, thus allowing advanced N management systems to be implemented.

Introduction

Nitrogen (N) use efficiency in high-yield irrigated corn production systems has many economic and environmental implications. In the sub-humid region of North Central and North East Kansas, risk of in-season N loss is higher than in drier irrigated corn production regions of the Central Plains. Many producers in the region rely on single pre-plant applications of granular urea or anhydrous ammonia fertilizer as the primary N source in irrigated corn production systems. These practices increase the likelihood of N loss, environmental impact, and reductions in profit per acre. The continued conversion of flood irrigated land in Kansas to center pivot irrigation systems presents the opportunity to develop automated systems for advanced N management utilizing multiple N applications through fertigation, that can potentially reduce environmental impact and increase profit per acre.

The recent developments in remote sensing technology have made it possible to improve N recommendations using hand-held or machine mounted active sensors. Sripada et al. (2005) demonstrated that remotely sensed NIR radiance could be used to estimate economic optimum N rates through corn growth stage VT. Improvements in center pivot application technology raises the possibility of using pivot-mounted sensors to control site-specific variable-rate N rates across a given field. Hence, it is necessary to understand how to best use this technology to optimize N application practices through fertigation in anticipation of widespread adoption of variable-rate center pivot equipment.

The objectives of this study were as follows:

1. Measure the impact of the relationship between irrigation timing, N rate, and timing of N application on corn grain yield.
2. Evaluate the potential for developing algorithms designed for fertigation systems.

Materials and Methods

The study was initiated in 2012 and conducted through the 2014 crop year in cooperation with Kansas producers and KSU Agronomy Experiment Fields. The Scandia and Rossville Experiment Fields were irrigated with a lateral sprinkler irrigation system while the cooperative farmer's field located outside Scandia (Scandia Site 2) was flood irrigated. Crop rotations, tillage, cultural practices, and corn hybrids utilized were representative of each area (Tables 1-3).

Each field study utilized small research plots 10 feet in width by 40 feet in length. Irrigation events were scheduled using the KanSched2 evapotranspiration-based irrigation scheduling tool (http://mobileirrigationlab.com/kansched2). Sidedress nitrogen applications were made prior to scheduled irrigation events to simulate a nitrogen fertigation system. Application timing methods implemented at each site consisted of single pre-plant application; split application between pre-plant and corn growth stage V4; and split application between pre-plant and variable treatments based on plant reflectance. Treatments were placed in a randomized complete block design with four replications.

Canopy reflectance of the corn was measured prior to each irrigation event with focus being on V-10 and R-1 growth stages respectively. The optical sensor utilized was the Greenseeker (Trimble Navigation, Ag Division, Westminster, CO. Canopy reflectance was used to calculate the Normalized Difference Vegetation Index (NDVI = NIR-visible/NIR+visible) and was averaged for each plot. The algorithm utilized to provide sensor based N recommendations was developed by Tucker and Mengel (2010).

Soil samples to a depth of 24 inches were taken by block, prior to planting and fertilization. 0-6 inch samples were analyzed for soil organic matter, Mehlich-3 phosphorus, potassium, pH, and zinc. The 0-24 inch samples were analyzed for nitrate-N, chloride, and sulfate. Fertilizer needs other than N were applied near planting.

Irrigation water was sampled at each location for NO3-N and NH4-N. Rossville and Scandia experiment stations tested with less than 1 ppm for NO3-N and NH4-N respectively and therefore would not have a large impact on the results of this study. The farmer's cooperative field near Scandia tested greater than 11 ppm NO3-N, and therefore this site was only utilized in 2012.

Grain yield was measured by harvesting an area of 5 feet by 40 feet within each plot at the Scandia and Rossville experiment stations. The farmer cooperative site at Scandia Scandia site 2) was hand harvested from an area 5 feet by 17.5 feet. All yields were adjusted to 15 percent moisture, and grain was analyzed for N content. Statistical analysis was conducting using SAS software PROC MIXED with 0.05 alpha. Blocks, locations, and years were treated as random effects during single site and pooled analysis.

Results and Discussion

Data analysis from Scandia Site 2, a farmer cooperative field, (Table 4.) shows response to applied N was low. This is likely due to the abnormally high nitrate levels in the irrigation water used at this site. Because the growing season was uncharacteristically dry, irrigation water use was above normal, giving the crop a significant N supply through the irrigation water (Figure 2.). Approximately 60 pounds of N per acre was added in 2012 through irrigation water.

There were significant N treatment effects on corn yield observed at the Scandia Station in 2012 (Table 5.). In general, the treatments that split N applications between pre-plant and in-season application resulted in the highest yields. The exception was treatment 3 (230 lb/a pre-plant). This treatment was statistically equal to the highest yielding split application treatments 5 and 6. This may be explained by the abnormally dry weather resulting in very little N loss from the pre-plant applications (Figure 1). Two of the three sensor-based N treatments (Treatments 7 and 8) yielded significantly lower than the pre-plant/V4 spilt applications (Treatments 5 and 6). The yield differences are likely attributed to the lower total N rates recommended by the sensors.

The 2013 Rossville experiment site showed a significant response to applied N also (Table 6). All sensor treatments generated the highest yield and were statistically higher than the two lowest rate preplant only treatments. This can be explained by frequent leaching losses in the early season. The soil at this location was a deep sandy loam that is prone to leaching losses if rainfall events are high and/or frequent. Figure 5 shows two rainfall events 1.25 and 2.25 inches and multiple 0.5 inch rainfall events after the preplant treatments were applied but prior to the V-4 treatment applications. Overall the yields were lower than expected at this site due to the frequent leaching events which occurred throughout the season. This indicates that fertigation systems may need to make frequent low rate N applications with limited amounts of water to satisfy N demand for high yielding corn in high N loss environments even if plant water requirements have been met or exceeded.

2013 Scandia Station experiment location showed a small response to applied N (Table 7.) Primary response was to N rate and was only significant over the check treatment. The soil at this location is a very forgiving and productive silt loam that is not prone to N loss through leaching but can suffer from denitrification loss at times. It also is capable of releasing significant amounts of mineralized N. Wet soil conditions before and after planting could have created some denitrification loss potential in late April-early May, and again in late May. Soil moisture remained high throughout June and July, near optimal for mineralizing N (Figure 3). Overall yield levels were lower than expected at this location with the highest yield being 179 bu/ac. Expected yields were 250 bu/ac, and this overall yield reduction could be attributed in part to the late planting date. The highest yielding treatment was treatment 5, a planned application of 140 pounds of N split with starter, preplant and inseason. All sensor treatments overestimated N requirements compared to treatment 5, and resulted in an unnecessary over application of N.

The 2014 Rossville experiment site produced excellent yields and a significant response to applied N (Table 8.). Figure 6 shows rainfall events in late May and June that would lead to significant N leaching losses in the sandy loam soil at the Rossville. However, in the study area a clay lens was located 24 to 36 inches deep. So despite the leaching events, N and water would be held up in the rooting area, resulting in much higher yields than at the 2013 Rossville site which lacked the clay lens. Largest yield response was to total N rate. Sensor treatments were effective at fertilizing for the 90% economic optimum, achieving 237 bu/ac from 55 lb. of applied N per acre.

2014 Scandia station achieved excellent yields and also showed a significant response to applied N (Table 9.). Rainfall and N loss was low and frequent small rain events created conditions that were good for mineralizing N (Figure 4.), which resulted in the check treatments achieving 163 bu/ac. This is a strong indication that overall site productivity was high. Sensor treatments were effective at determining the optimum N rate for high yield and profitability.

Pooled analysis of all the locations (Table 10.) shows that overall performance of the sensors and algorithm utilized was effective at achieving high yields, but has the tendency to overestimate N requirements. However, this result is not surprising as this algorithm was designed for single N applications of N at V-10 and achieving the highest yield possible rather than the agronomic optimum yield. Fertigation systems present the possibility of monitoring the corn crop throughout the growing season and making multiple applications, thus allowing the opportunity to determine the optimum N rate for a given field any given year. However, in order to optimize sensor based N recommendations for fertigation systems, algorithms must be specifically designed for these systems in order take advantage of their full capabilities, thus allowing advanced N management systems to be implemented.

References:

Sripada, R.P., R.W. Heiniger, J.G. White, and R. Weisz. 2005. Aerial color infrared photography for determing late-season nitrogen requirements in corn. Agron. J. 97:1443-1451.

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Table 1. Location information, Scandia Station

Year	2012	2013	2014
Soil Type	Crete silt loam	Crete silt loam	Crete silt loam
Previous Crop	Soybeans	Soybeans	Soybeans
Tillage Practice	Ridge Till	Ridge Till	Ridge Till
Corn Hybrid	NA	NA	Pioneer P1602
Plant Population (plants/ac)	30000	29500	33500
Irrigation Type	Lateral	Lateral	Lateral
Planting Date	4/27/2012	5/16/2013	5/5/2014
Second Treatment V-4	6/4/2012	6/19/2013	6/19/2014
Third Treatment V-8 through V-10	6/14/2012	7/3/2013	NA
Last Treatment V-16 through R-1	6/28/2012	NA	8/4/2014
Harvest Date	10/24/2012	11/1/2013	11/11/2014

Table 2. Location information, Scandia Site 2

Location	2012
Soil Type	Carr Fine Sandy loam
Previous Crop	Soybeans
Tillage Practice	Ridge Till
Corn Hybrid	NA
Plant Population (plants/ac)	32000
Irrigation Type	Flood
Planting Date	4/27/2012
Second Treatment V-4	6/4/2012
Third Treatment V-8	6/14/2012
Last Treatment V-16	6/26/2012
Harvest Date	9/25/2012

Table 3. Location information, Rossville

Year	2013	2014
Soil Type	Eudora sandy loam	Eudora sandy loam
Previous Crop	Soybeans	Soybeans
Tillage Practice	Conventional	Conventional
Corn Hybrid	Pioneer 0876	Producers Hybrid 7224 VT3
Plant Population (plants/ac)	32000	32000
Irrigation	Lateral	Lateral
Planting Date	4/29/2013	4/23/2014
Second Treatment V-4	6/3/2013	6/6/2014
Third Treatment V-10	6/25/2013	NA
Last Treatment V-16 through R-1	NA	7/8/2014
Harvest Date	9/23/2013	9/17/2014

Table 4. 2012 Scandia Farmer Cooperative Field Results

Year	Treatment	Timing Method	Starter N (lb/a)	Preplant N (lb/a)	In-Season N (lb/a)	Total N Applied (lb/a)	Yield (bu/a)	LSD Grouping
2012	4	Pre-plant/V4	20	20	20	60	209	A
2012	9	Pre-plant/Sensor	20	125	30	175	209	ABC
2012	1	Pre-plant	20	60	0	80	203	ABC
2012	2	Pre-plant	20	140	0	160	201	ABC
2012	3	Pre-plant	20	230	0	250	199	ABC
2012	7	Pre-plant/Sensor	20	40	94	154	199	ABC
2012	8	Pre-plant/Sensor	20	80	86	186	198	ABC
2012	5	Pre-plant/V4	20	80	80	180	197	BC
2012	6	Pre-plant/V4	20	105	105	230	193	C
2012	10	Check	20	0	0	20	193	C

Treatments with same letter are not statistically different at an 0.05 alpha

Table 5. 2012 Scandia Station Field Results

Year	Treatment	Timing Method	Starter N (lb/a)	Preplant N (lb/a)	In-Season N (lb/a)	Total N Applied (lb/a)	Yield (bu/a)	LSD Grouping
2012	6	Preplant/V4	20	105	105	230	188	A
2012	5	Preplant/V4	20	80	80	180	187	A
2012	3	Preplant	20	230	0	250	185	A
2012	9	Preplant/Sensor	20	125	86	231	185	A
2012	8	Preplant/Sensor	20	80	44	144	173	B
2012	2	Preplant	20	140	0	160	166	BC
2012	7	Preplant/Sensor	20	40	91	151	166	BC
2012	1	Preplant	20	60	0	80	156	C
2012	4	Preplant/V4	20	20	20	60	138	D
2012	10	Check	20	0	0	20	119	E

Treatments with same letter are not statistically different at an 0.05 alpha

Table 6. 2013 Rossville Station Field Results

Year	Treatment	Timing Method	Starter N (lb/a)	Preplant N (lb/a)	In-Season N (lb/a)	Total N Applied (lb/a)	Yield (bu/a)	LSD Grouping
2013	8	Pre-plant/Sensor	0	80	144	224	148	A
2013	7	Pre-plant/Sensor	0	40	212	252	148	A
2013	9	Pre-plant/Sensor	0	120	149	269	144	AB
2013	6	Preplant/V4	0	90	90	180	139	AB
2013	5	Preplant/V4	0	60	60	120	135	ABC
2013	2	Pre-plant	0	120	0	120	127	ABC
2013	3	Pre-plant	0	180	0	180	123	BC
2013	4	Preplant/V4	0	30	30	60	116	CD
2013	1	Pre-plant	0	60	0	60	96	D
2013	10	Check	0	0	0	0	70	E

Treatments with same letter are not statistically different at an 0.05 alpha

Table 7. 2013 Scandia Station Field Results

Year	Treatment	Timing Method	Starter N (lb/a)	Preplant N (lb/a)	In-Season N (lb/a)	Total N Applied (lb/a)	Yield (bu/a)	LSD Grouping
2013	5	Preplant/V4	20	60	60	140	179	A
2013	8	Pre-plant/Sensor	20	80	87	187	177	AB
2013	4	Preplant/V4	20	30	30	80	176	AB
2013	3	Pre-plant	20	180	0	200	173	AB
2013	6	Preplant/V4	20	90	90	200	172	AB
2013	7	Pre-plant/Sensor	20	40	123	183	172	AB
2013	2	Pre-plant	20	120	0	140	170	AB
2013	9	Pre-plant/Sensor	20	120	133	273	169	AB
2013	1	Pre-plant	20	60	0	80	167	B
2013	10	Check	20	0	0	20	149	C

Treatments with same letter are not statistically different at an 0.05 alpha

Table 8. 2014 Rossville Station Field Results

Year	Treatment	Timing Method	Starter N (lb/a)	Preplant N (lb/a)	In-Season N (lb/a)	Total N Applied (lb/a)	Yield (bu/a)	LSD Grouping
2014	2	Pre-plant	0	120	0	120	257	A
2014	6	Preplant/V4	0	90	90	180	254	AB
2014	5	Preplant/V4	0	60	60	120	248	ABC
2014	3	Pre-plant	0	180	0	180	248	ABC
2014	1	Pre-plant	0	60	0	60	239	ABC
2014	7	Pre-plant/Sensor	0	40	15	55	237	ABC
2014	9	Pre-plant/Sensor	0	120	0	120	228	BC
2014	4	Preplant/V4	0	30	30	60	225	C
2014	8	Pre-plant/Sensor	0	80	0	80	223	C
2014	10	Check	0	0	0	0	186	D

Treatments with same letter are not statistically different at an 0.05 alpha

Table 9. 2014 Scandia Station Field Results

Year	Treatment	Timing Method	Starter N (lb/a)	Preplant N (lb/a)	In-Season N (lb/a)	Total N Applied (lb/a)	Yield (bu/a)	LSD Grouping
2014	6	Preplant/V4	0	90	90	180	239	A
2014	3	Pre-plant	0	180	0	180	232	AB
2014	9	Pre-plant/Sensor	0	120	30	150	231	AB
2014	7	Pre-plant/Sensor	0	40	120	160	229	AB
2014	2	Pre-plant	0	120	0	120	223	B
2014	8	Pre-plant/Sensor	0	80	60	140	223	B
2014	5	Preplant/V4	0	60	60	120	218	BC
2014	1	Pre-plant	0	60	0	60	204	C
2014	4	Preplant/V4	0	30	30	60	189	D
2014	10	Check	0	0	0	0	163	E

Treatments with same letter are not statistically different at an 0.05 alpha

Table 10. All Site Pooled Analysis

Year	Treatment	Timing Method	Starter N (lb/a)	Preplant N (lb/a)	In-Season N (lb/a)	Total N Applied (lb/a)	Yield (bu/a)	LSD Grouping
Pooled	6	Preplant/V4	0	95	95	190	198	A
Pooled	9	Pre-plant/Sensor	0	122	71	193	194	A
Pooled	5	Preplant/V4	0	67	67	133	194	A
Pooled	3	Pre-plant	0	197	0	197	193	A
Pooled	7	Pre-plant/Sensor	0	40	109	149	192	A
Pooled	2	Pre-plant	0	127	0	127	191	A
Pooled	8	Pre-plant/Sensor	0	80	70	150	190	A
Pooled	1	Pre-plant	0	60	0	60	177	B
Pooled	4	Preplant/V4	0	27	27	53	175	B
Pooled	10	Check	0	0	0	0	147	C

Treatments with same letter are not statistically different at an 0.05 alpha

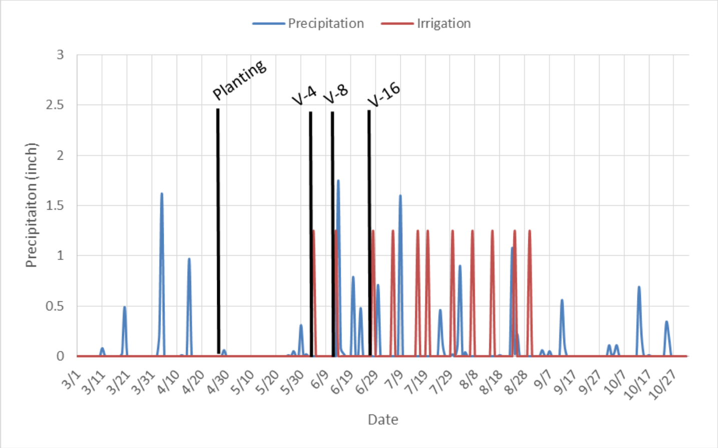

Figure 1. 2012 Scandia Station Rainfall and Irrigation

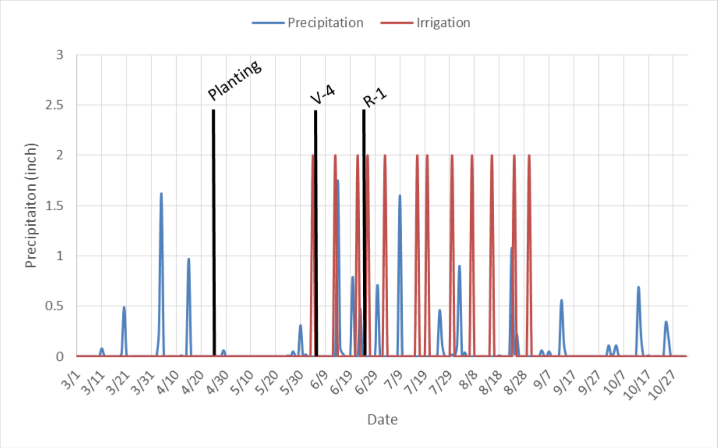

Figure 2. 2012 Scandia Site 2 Rainfall and Irrigation

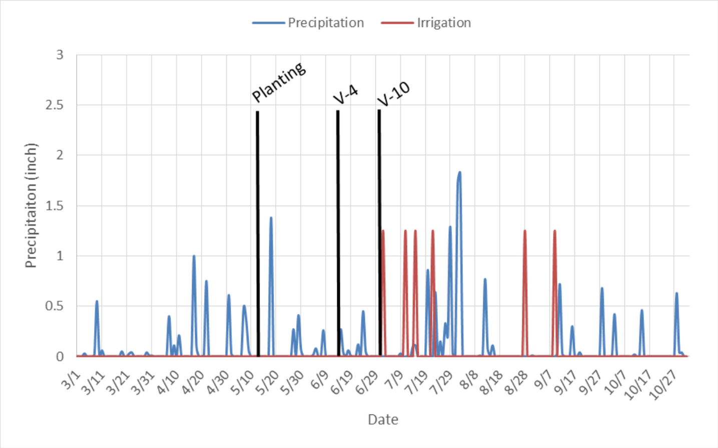

Figure 3. 2013 Scandia Station Rainfall and Irrigation

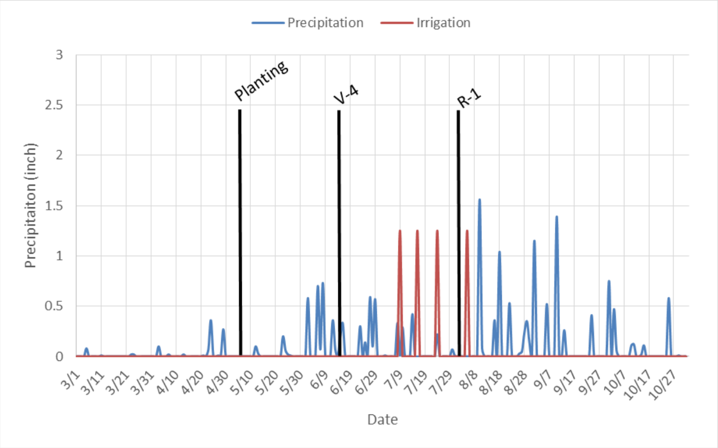

Figure 4. 2014 Scandia Station Rainfall and Irrigation

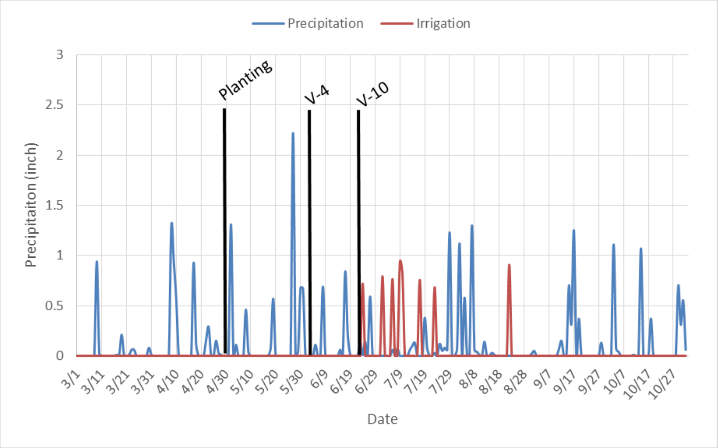

Figure 5. 2013 Rossville Rainfall and Irrigation

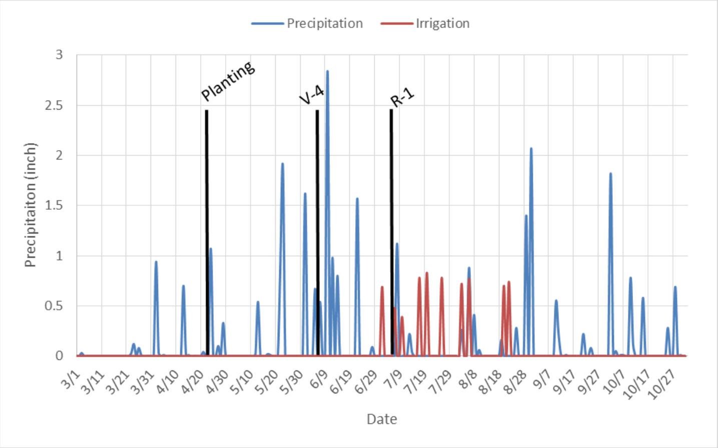

Figure 6. 2014 Rossville Rainfall and Irrigation