Using N Timing to Enhance Yield and Nitrogen Use Efficiency in High Yielding Dryland and Irrigated Corn

A.R. Asebedo and D. B. Mengel
Kansas State University, Manhattan, KS

Abstract

Nitrogen (N) management is becoming one of the more complex aspects of modern corn production. Changes in plant genetics, earlier planting dates, larger farm size, equipment innovations, increasing fuel and N costs, as well as concerns with potential environmental contamination create a combination of opportunities and pitfalls that contribute to this complexity. Balancing time and financial resources in an effort to maximize yield and profitability, while still being a good environmental steward has become difficult for producers. The purpose of this study was to evaluate the effects of different N management systems, particularly time of application, on yield and Nitrogen use efficiency (NUE). The study was conducted on widely different soils and management systems, and the rainfall patterns differed greatly between the two years at most locations. The primary focus was on N loss caused by leaching or denitrification. Results to date indicate that increased N efficiency and grain yield can be achieved by optimizing the time, rate, and number of N applications used to coincide with corn N demand and the potential for N loss, particularly as influenced by soil properties. This work indicates that appropriate N management practices such as N timing will differ with N loss potential of specific soils, and climate patterns.

Introduction

Nitrogen management is becoming one of the more complex aspects of modern corn production. Changes in plant genetics, earlier planting dates, larger farm size which compresses time available for field work per acre, equipment innovations, increasing fuel and N costs, new and alternative N sources and additives designed, as well as concerns with potential environmental contamination all contribute to this increased complexity. Balancing time and financial resources in an effort to maximize yield and profitability, while being a good environmental steward, has become a difficult challenge for many producers.

In the Midwestern portion of the U.S., many states use a system for making N recommendations which focuses on the average economic response to N across a defined geographic area, adjusting a general response function for changes in N and corn price (Sawyer et al, 2006). The developers of the system recognize that differences in soil organic matter (SOM), as a source of mineralizable N, soil texture and drainage and their impact on N loss, in season temperature and precipitation, and how and when fertilizer is applied to the crop, all change the shape of the response function. These factors are addressed by using response functions specific to states or soil regions within states (Camberato, Nielsen, Miller and Joern, 2012). While these approaches are a definite improvement for growers managing the crop on a rate per field basis over traditional "rules of thumb" of 1.1 or 1.2 pounds of N per bushel of yield, they don't provide guidance on how to adjust rates for differences in drainage, texture or SOM found in different management zones within a field.

Other states, such as Kansas, take a more mechanistic approach to making N recommendations and try to adjust "rule of thumb" recommendations for residual soil N in the profile, SOM content and resulting mineralized N, previous crop grown and other N sources such as manure or N in irrigation water (Leikam, Lamond and Mengel, 2003). These approaches are more easily applied to a management zone or "on the go" application system, but still have limits, as most do not reflect changes in NUE due to drainage or soil physical properties impact on N loss, or changes in N utilization efficiency (Moll et al, 1980) and resulting changes in N need per bushel of response as yields increase.

A considerable body of information exists in the literature on the impact of soil properties, such as SOM and crop residue levels, soil drainage and texture, fertilizer source, urease and nitrification inhibitors, as well as method and time of N application on nitrogen fertilizer recovery, required N rate and corn yield (Trembley et al, 2012; Stamper, 2010; Weber, 2010).

The concept of the 4-R's, applying the right source, at the right rate, at the right time and in the right place sounds simple enough, but the devil is in the details, as all the factors interact making that right rate a moving target (IPNI, 2010). Rate is a function of each of the other three variables and the efficiency associated with that choice/decision, as impacted by yield level, soil properties, soil N supply and climate. The key is to understand how all of these factors interact and to design a management system which can respond to changes in these factors throughout a given field to enhance yield, NUE and farmer profits without adding additional risk or complexity to the management system.

The objectives of this study were as follows:

1. Measure the impact of N rate and time of application (N management system) on yield, profitability and nitrogen use efficiency in high yielding corn production.

2. Determine if the use of split application systems utilizing crop sensors or professional agronomists judgment of N need late in the growing season, can improve NUE compared to a fixed rate system using current N rate recommendations applied early in the growing season.

Materials and Methods

Experiments were established at four locations in Kansas during 2013 in cooperation with Kansas producers and KSU Agronomy Experiment Fields. The experiments were continued in 2014 and are planned to continue again in 2015. The Scandia, Partridge, and Rossville locations are all KSU Agronomy Department Experiment Fields and are irrigated using center pivot or lateral move sprinkler systems, while the Sterling location was a cooperating farmer's field and was rain fed. Crop rotations, tillage, cultural practices, and corn hybrids utilized were representative of each area (Table1.). Each field study utilized small research plots 10 feet in width by 40 feet in length. Seventeen treatments consisting of five N rates that were applied in single or split applications at different times during the growing season with UAN as the N source were used. Starter fertilizer materials were APP based, with UAN or other nutrients added as needed, based on current soil tests. Treatments were placed in the field using a randomized complete block design with four replications.

Soil samples to a depth of 24 inches were taken by block, prior to planting and fertilization to estimate residual nitrate-N present at planting. 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 sulfur. Any fertilizer needs other than N were applied near planting as indicated by the soil tests.

Canopy reflectance of the corn was measured multiple times throughout the growing season with V-4, V-6, V-10, and R-1 being key targeted growth stages for measurement. Optical sensors used were the Greenseeker (Trimble Navigation, Ag Division, Westminster, CO), the CropCircle ACS-470 (Holland Scientific, Lincoln NE), and Rapid Scan (Holland Scientific, Lincoln NE). Wavelengths in nanometers (nm) utilized were as follows: 660, 670, 700, 710, 735, 760, 770, and 780. Canopy reflectance was used to calculate the Normalized Difference Vegetation Index (NDVI0. NDVI = NIR-visible/NIR+visible and was averaged across multiple measurements for each plot.

Ear Leaf tissue samples were taken at silking and whole plant samples at half to 3/4 milk line and analyzed for N content. Plant biomass was also measured to allow calculation of total N uptake in both stover and grain. Grain yield was measured by harvesting an area of 5 feet by 40 feet within each plot at the Partridge, Scandia, and Rossville locations. Harvest area for the Sterling location consisted of 5 feet by 17.5 feet. Yields were adjusted to 15 percent moisture, and grain was analyzed for N content. All analyses were conducted by the KSU Soil Testing Lab using procedures recommended by the NC Committee on Soil Testing. Statistical analysis was conducting using SAS software PROC GLM with mean separations made using a 0.1 alpha.

Results and Discussion

Results from this experiment are summarized in Tables 2 through 5. The Sterling location soil consisted of deep, fine sands, contained low organic matter with low water holding capacity and high potential for nitrate leaching. During the 2013 growing season, initial conditions were dry, with initial germination and emergence slowed by the dry conditions. However, during the vegetative growth period of June and early July, when the majority of the N is taken up by corn, two high rainfall events occurred which likely resulted in some leaching loss (Figure 1). A second dry period occurred during late vegetation and pollination, which severely impacted yields. Only a limited response to N was observed (Table 2), but differences in observed yield and N uptake were likely due to differences in water availability across the plot area caused by soil variation. Despite distribution in rainfall not being ideal, average yields for this dryland site were obtained across all treatments with a yield range of 110-133 bu. ac^{-1}. No statistical response to applied N was observed, however there was a strong trend for yield increase with higher N rates and later applications of N.

The 2014 season provided much more favorable growing conditions and excellent yields. Yields at this location in 2014 ranged from 144 to 164 bu. ac^{-1} (Table2). Like 2013, initial conditions were dry. However shortly after planting a series of timely showers provided adequate moisture for emergence and early growth. During vegetative growth rainfall intensified, with an intense storm supplying approximately 2.5 inches of precipitation on June 9, shortly after the V-4 applications were made. This likely resulted in some nitrate leaching from early applied fertilizer treatments. As has been seen many times in this area, good moisture not only supported crop growth but also resulted in a flush of mineralization, as indicated by the check plot yield of 144 bushels per acre. Despite conditions conducive to N leaching, only limited response to applied N was observed. A trend to later applications of N resulting in higher yields was observed again at this site in 2014.

Moderately high yields and good response to applied N were observed at Partridge in 2013 (Table 3). The soils at this site were slightly heavier textured, with greater water holding capacity and lower N leaching potential. The highest yields were observed from single applications at high rates at V-4 and from split applications receiving N as starter, at V-4 and at R-1. Delaying N applications until V-10 and total at-planting N applications resulted in lower yield. The at-planting treatments resulted in lower yields and decreased efficiency likely due to the time of N application not matching crop demand and resulting in increased N loss. A rainfall event of almost 3 inches occurred May 30 prior to V-4 which could lead to nitrate leaching and account for the decreased efficiency of the “at-planting” treatments (Figure1). The V-4 180 lb. ac^{-1} treatment 7 was able to carry enough N in the soil profile to obtain the third highest yield, thus showing a marked improvement in yield by shifting the N application time to more closely coincide with N demand. The R-1 120 lb. ac^{-1} treatment 14 obtained the highest yield, but was not statistically different from treatment 7. Sensor treatments at the V-10 and R-1 time underestimated N need considerably, thus resulting in severe reductions in yield. The Agronomist estimation made a good assessment of N need and achieved high yield for the site.

In 2014 yields were severely impacted by alternating episodes of wet and dry weather. Heavy rainfall events in mid-May, mid-June and early July resulted in significant N loss and enhanced weed pressure. A significant response to treatment was observed, with the later N applications producing higher yields. Sensors again failed to provide good estimates of N needs under these conditions, as did the Agronomists late season estimates of N need. An additional treatment of broadcast 50% urea-50% ESN urea was added in 2014 at this site. Its performance was not better than later timed UAN treatments at a similar N rate.

Excellent yields and a moderate response to applied N was observed at Rossville in 2013 (Table 4.). Weather was excellent, and though blessed with adequate rain, only one event, occurring on May 30, likely resulted in leaching loss. There were no statistical differences in yield between at-planting, V-4, and split rate N treatments at comparable N rates. Yields in excess of 230 bushels per acre were obtained with only 120 pounds of applied N. However, waiting to apply N until V-10, or roughly waist high corn, did lower yields. This was likely due to N stress during earsize determination starting at V-6. Thus the lack of a starter N application, or the 60 pound N application at V-4 which the split application treatments received, was critical at this site in this year. The sensor treatment which received 60 pounds of N at V-4 and sensed at R-1 again indicated no additional N was needed, and that proved to be correct. The Agronomist visual assessment utilized more N than the sensor but resulted in similar yields. The sandy loam soil at the Rossville location creates an environment that is prone to nitrate leaching losses. However, rainfall distribution was excellent during 2013 with only one rainfall event exceed 2 inches (Figure 3.). Therefore weather conditions were not conducive for nitrate leaching and which explains the respectable performance of the at-planting treatments compared to treatments with delayed N applications.

Conditions in 2014 were not as favorable for yield or N loss at Rossville. During the period from planting to V-10, five rainfall events over 1 inch, with 4 in excess of 1.5 inches and one of 2.5 inches were recorded at this site. As a result, yields were reduced and N loss was significant. A twenty pound N application as starter fertilizer was made immediately after planting using a surface band of UAN. This likely proved beneficial, since as a general trend, the later N was applied, from planting to V-10 in a single application, the higher the resulting yield. Split applications utilizing V-4 and R-1 application times gave the best responses at this site in 2014.

Although moderate yield and N response was observed at the Scandia location (Table 5.), severe weed pressure resulted in increased variance and decreased yields in 2013. This was the result of extremely dry weather reducing the effectiveness of most herbicide programs. Statistical response to applied N was only observed over treatments 2, 1, and 11. Weather conditions were not conducive for nitrate leaching or denitrification in the silt loam soils of the study area (Figure 4). Sensor treatments underestimated N need and therefore resulted in reduced yield.

Conditions were still dry in 2014 at Scandia, however timely showers and stored soil moisture maintained acceptable conditions until early July when irrigation water became available. An N rate response was observed, with highest yields obtained with the V-4 applications of 120 or 180 pounds of N or V-10 with 180 pounds of N. Split application of N also performed well. With only limited precipitation N loss potential was limited at this site, so most management systems performed well.

The N loss potential observed at these sites due to both inherent soil characteristics and annual rainfall patterns are similar to those faced by many Kansas producers across their farm. Sidedress applications at V-4 or split application systems can offer a significant yield and NUE advantage at locations with higher loss potential and intense rainfall events. Importantly, no adverse effects were observed to sidedressing or split application systems when conditions were not conducive to N loss. The split application options can also allow adjustment of application rates up or down in response to that years conditions.

It is unfortunate that the crop sensor systems used in this study did not perform as well as hoped. However, this emphasizes the need to further develop the algorithms crop sensors utilize so these systems can be more effective at providing optimal N recommendations. The judgment of a competent agronomist was shown to have value. However, additional tools are available to agronomists, such as the chlorophyll meter and fired leaf counts. In other research studies, these tools have been shown to be effective for guiding late season N applications, but take considerable more time to implement when compared to crop sensors.

This research to date has clearly shown the importance of proper early season N management. The application of adequate levels of N early in the season is critical to ensure the corn crop doesn’t come under N stress during earsize determination when using delayed or split application systems. Otherwise permanent reductions in yield will result that cannot be recovered by a high rate of N later in the growing season.

Further research will continue to evaluate the effects of the N application timing and N management strategies under different weather conditions and soil types to determine their applicability in corn production. The authors also intend to continue work on sensor based algorithms to enhance the value of this potential tool.

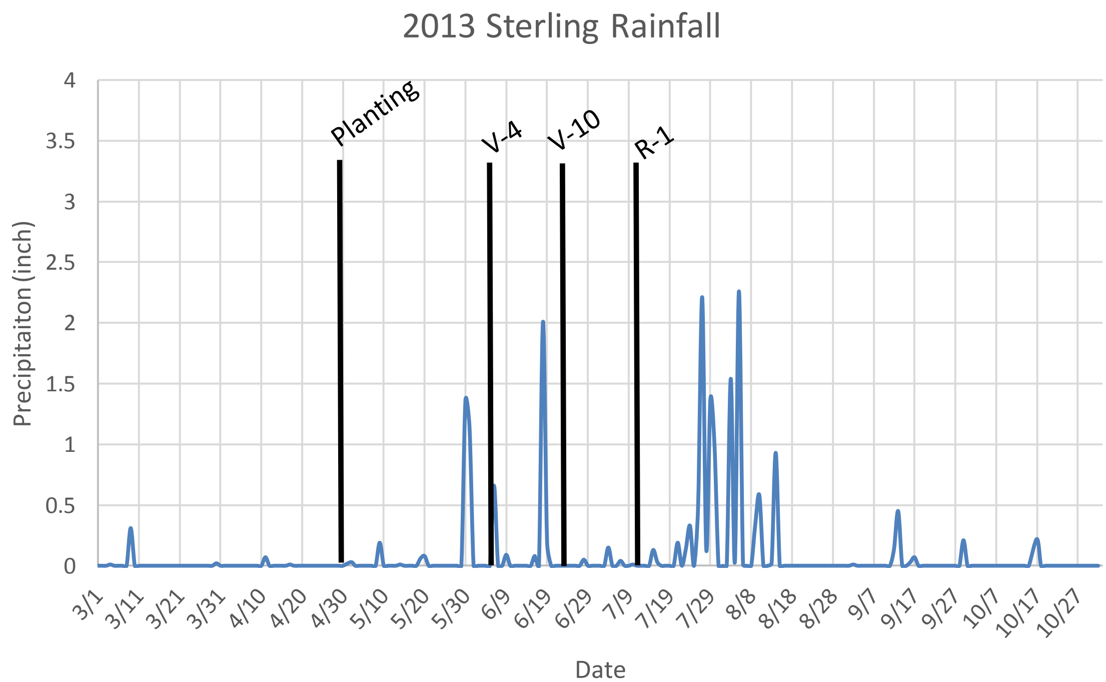
Table 1. Location information, 2014

Location	Sterling	Partridge	Scandia	Rossville
Soil Type	Saltcreek and Naron Fine Sandy loams	Nalim loam	Crete silt loam	Eudora sandy loam
Previous Crop	Soybeans	Soybeans	Soybeans	Soybeans
Tillage Practice	No-till	Conventional	Ridge Till	Conventional
Corn Hybrid	Pioneer 35F-50 Refuge	DK 64-69	Pioneer P1602	Producers H9138 3000GT
Plant Population (plants/ac)	19,000	27,300	33,500	30,400
Irrigation	No	Yes	Yes	Yes
Residual NO_3 lb. N ac^{-1}	26	24	48	46
Planting Date	4/20/14	4/30/14	5/5/14	4/23/14
First Treatment V-1	5/14/14	5/21/14	5/30/2014	4/29/13
Second Treatment V-4	6/6/14	6/6/14	6/16/14	6/6/14
Third Treatment V-10	6/24/14	6/24/14	7/1/14	6/24/14
Last Treatment R1	7/3/14	7/2/14	8/4/2014	7/8/14
Harvest Date	9/1/14	10/16/14	11/11/2014	9/17/14

Table 2. Effects of Nitrogen application timing on corn grain yield, 2013 and 2014, dryland, Sterling, KS

Treatment	Starter N	Planting N	V-4 N	V-10 N	R-1 N	Total N applied	Grain Yield 2013	Grain Yield 2014
	---------------------pounds N per acre					--------------------	------ bu/acre-----	
1	7	0	0	0	0	7	110 c	144 f
2	7	60	0	0	0	67	118 bc	154 bcd
3	7	120	0	0	0	127	115 bc	155 bcd
4	7	180	0	0	0	187	118 bc	157 abc
5	7	0	60	0	0	67	117 bc	148 ef
6	7	0	120	0	0	127	125 ab	160 abc
7	7	0	180	0	0	187	116 bc	155 bcd
8	7	0	0	60	0	67	118bc	157 abc
9	7	0	0	120	0	127	120 abc	154 bcd
10	7	0	0	180	0	187	118 bc	160 abc
11, 13 Sen	7	0	60	0	0	67	133 a	----
11, 14 Sen	7	0	60	0	0	67	----	148def
12	7	0	60	0	180	247	129 ab	161 ab
13	7	0	60	0	60	127	115 bc	158 abc
14	7	0	60	0	120	187	121 abc	159 abc
15, 13 Sen	7	0	0	110	0	117	124 abc	----
15, 14 Sen	7	0	0	0	0	7	----	153 cde
16, 13 AG	7	0	60	0	0	67	119 abc	----
16, 14 AG	7	0	60	0	0	67	----	160 abc
17 U/ESN	7	0	0	120	0	127	----	164 a
CV, percent							8.6	4.5

Figure 1. Rainfall distribution at the Sterling location in 2013 and 2014.



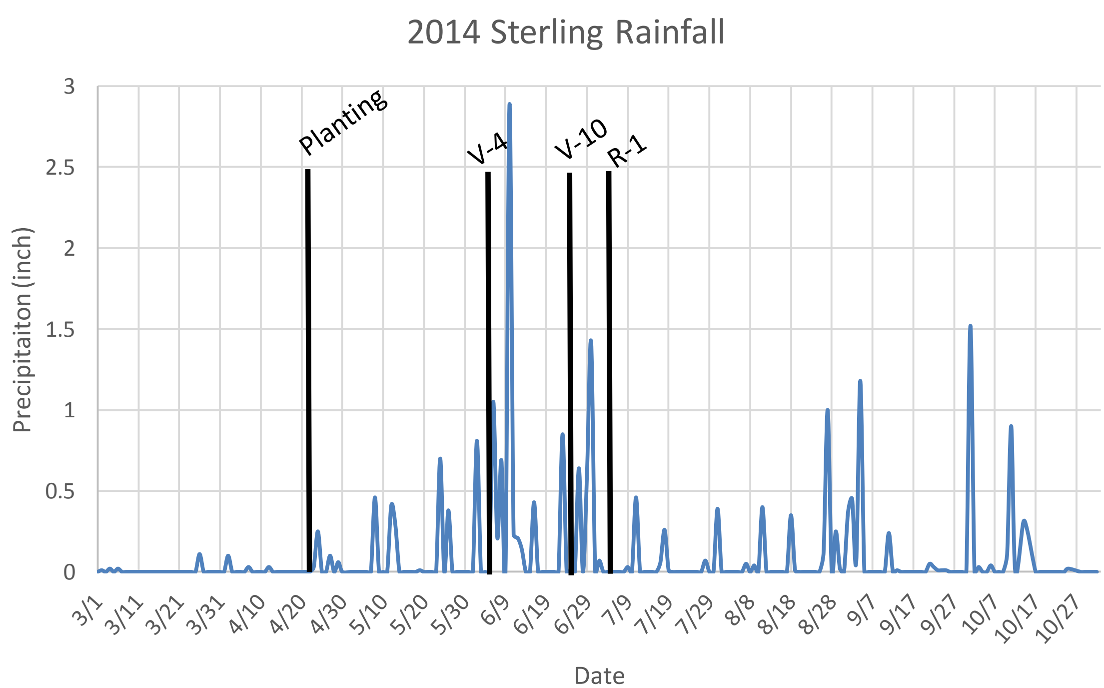


Table 3. Effects of Nitrogen application timing on corn grain yield, 2013 and 2014, irrigated, Partridge, KS

Treatment	Starter N	Planting N	V-4 N	V-10 N	R-1 N	Total N Applied	Grain Yield 2013	Grain Yield 2014
	------------------- pounds N per acre					-----------------	---- bu per acre ----	
1	20	0	0	0	0	20	154 e	85 hi
2	20	60	0	0	0	80	162 e	96 fgh
3	20	120	0	0	0	140	173 d	94 fghi
4	20	180	0	0	0	200	180 c	96 fghi
5	20	0	60	0	0	80	173 cd	86 ghi
6	20	0	120	0	0	140	176 cd	101 def
7	20	0	180	0	0	200	190 ab	99 defg
8	20	0	0	60	0	80	159 e	104 cdef
9	20	0	0	120	0	140	181 bc	128 a
10	20	0	0	180	0	200	180 cd	125 ab
11, 13 SEN	20	0	0	92	0	112	156 e	-----
11, 14 SEN	20	0	0	0	0	20	-----	82 i
13	20	0	60	0	60	140	179 cd	111 bcd
14	20	0	60	0	120	200	192 a	111 bcd
12	20	0	60	0	180	260	191 a	118 abc
15, 13 SEN	20	0	60	0	0	80	161 e	-----
15, 14 SEN	20	0	60	0	0	80	-----	97 efgh
16, 13 AG	20	0	60	0	130	210	190 a	-----
16, 14 AG	20	0	60	0	0	80	-----	94 fghi
17, U/ESN	20	0	0	120	0	140	-----	116 abc
CV, percent							4.2	11.5

Figure 2. Rainfall distribution at the Partridge location in 2013 and 2014.

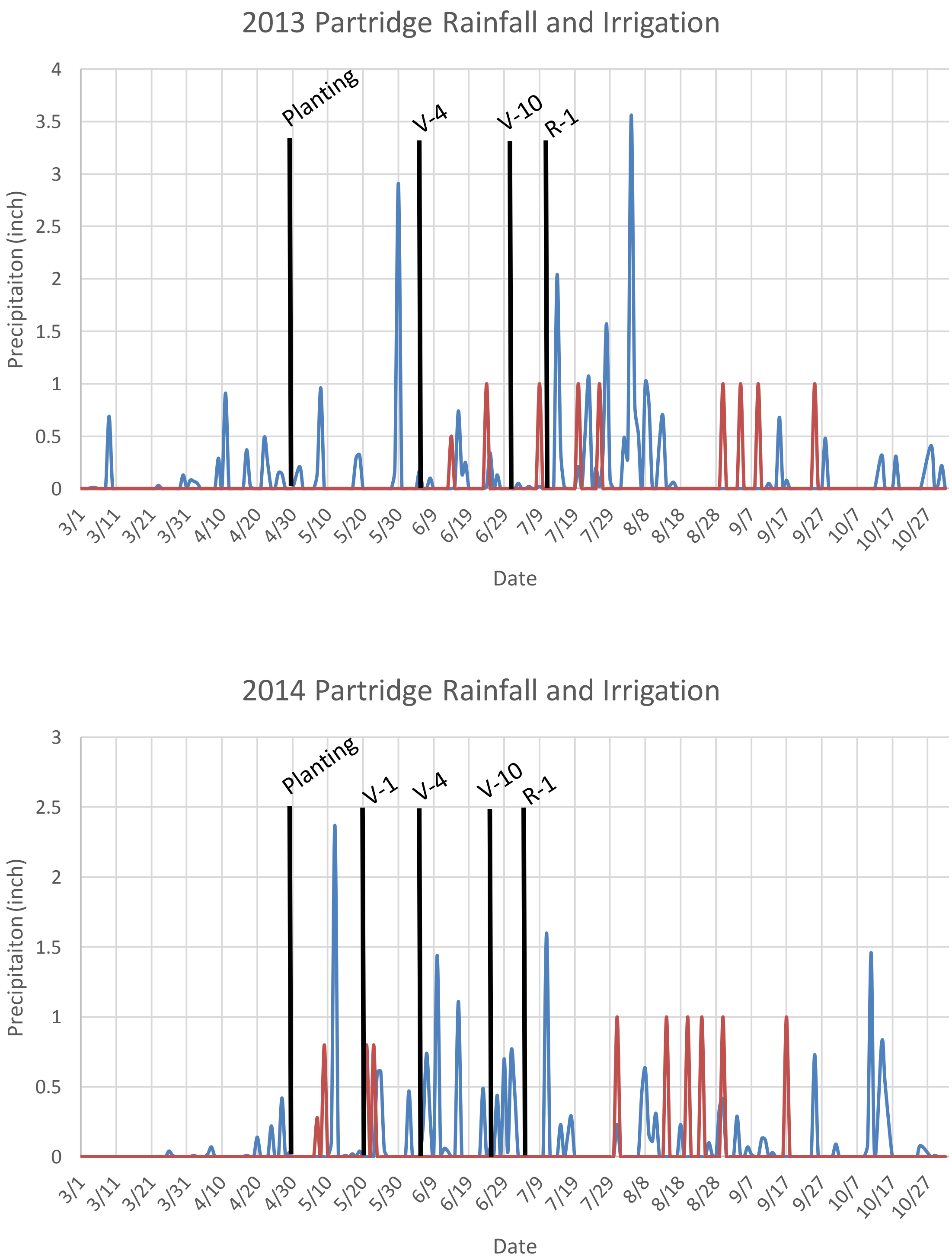
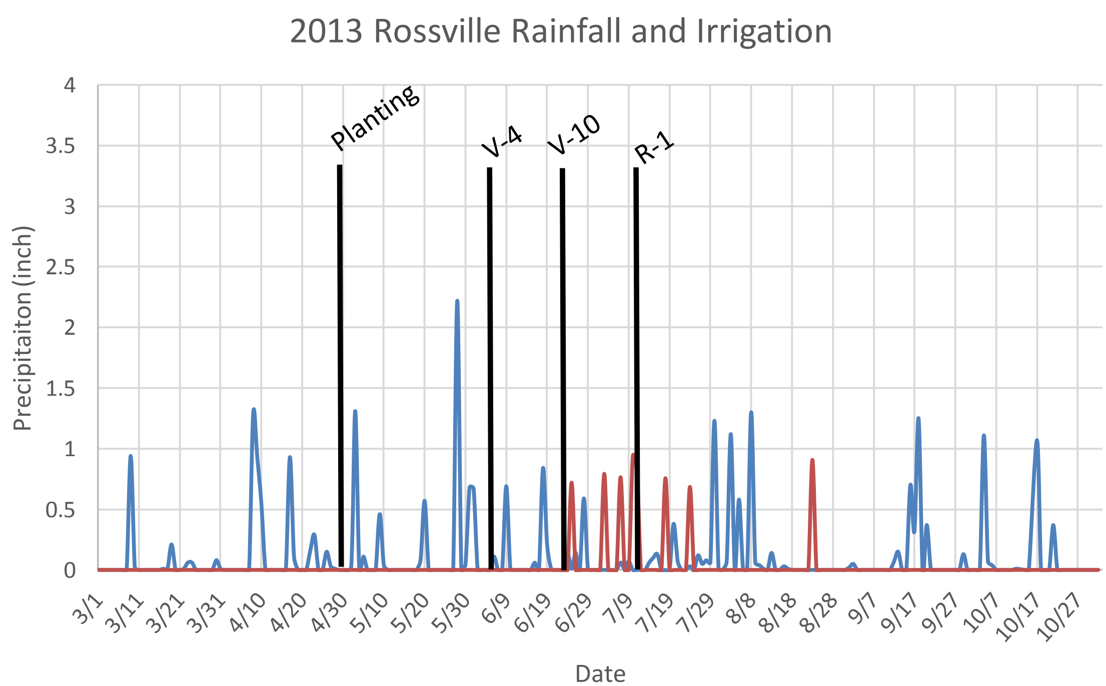


Table 4. Effects of Nitrogen application timing on corn grain yield, 2013 and 2014, irrigated, Rossville, KS

Treatment	Starter N*	Planting N	V-4 N	V-10 N	R-1 N	Total N**	Grain Yield 2013	Grain Yield 2014
	------------------ pounds N per acre ------------------						---- bu per acre ----	
1	0	0	0	0	0	0	194 g	97 e
2	0	60	0	0	0	60	217 def	165 bcd
3	0	120	0	0	0	120	235 abc	151 dc
4	0	180	0	0	0	180	234 abcd	175 abc
5	0	0	60	0	0	60	219 cdf	139 d
6	0	0	120	0	0	120	240 a	168 bc
7	0	0	180	0	0	180	239 ab	187 ab
8	0	0	0	60	0	60	221cdef	154 cd
9	0	0	0	120	0	120	215 ef	172 ab
10	0	0	0	180	0	180	207 fg	188 ab
11, 13 SEN	0	0	0	198	0	198	212 de	-----
11, 14 SEN	0	0	0	0	0	0	-----	111 e
12	0	0	60	0	180	240	230 abcde	197 a
13	0	0	60	0	60	120	231 abcde	183 ab
14	0	0	60	0	120	180	224 bcdef	192 ab
15, 13 SEN	0	0	60	0	0	60	230 abcde	-----
15, 14 SEN	0	0	60	19	0	79	-----	167 bc
16, 13 AG	0	0	60	0	60	120	222 bcdef	-----
16, 14 AG	0	0	60	0	45	105	-----	174abc
17, U/ESN	0	0	0	120	0	120	-----	186 ab
CV, percent							5.3	13.8

*No starter applied 2013, 100 lbs 20-20-0 starter applied 2014
** does not include 20 pounds starter fertilizer N applied in 2014

Figure 3. Rainfall distribution at the Rossville location, 2013 and 2014.



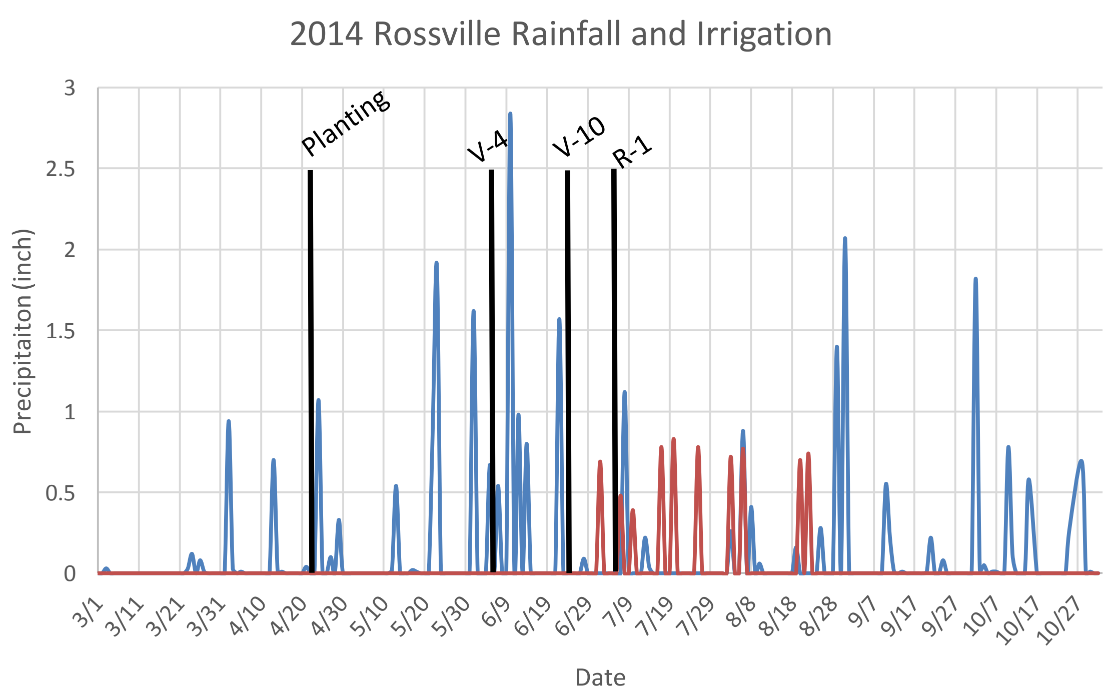


Table 5. Effects of Nitrogen application timing on corn grain yield, 2013 and 2014, irrigated, Scandia, KS

Treatment	Starter N	Planting N	V-4 N	V-10 N	R-1 N	Total N Applied	Grain Yield 2013	Grain Yield 2014
	----------------------- pounds N per acre -----------------						---- bu per acre ----	
1	20	0	0	0	0	20	161 cd	160 h
2	20	60	0	0	0	80	167 bcd	192 g
3	20	120	0	0	0	140	180 ab	211 ef
4	20	180	0	0	0	200	181 ab	216 de
5	20	0	60	0	0	80	178 ab	202 fg
6	20	0	120	0	0	140	178 ab	229 abc
7	20	0	180	0	0	200	190 a	230 ab
8	20	0	0	60	0	80	179 ab	195 g
9	20	0	0	120	0	140	178 ab	216 de
10	20	0	0	180	0	200	183 ab	229 abc
11, 13 SEN	20	0	0	0	0	20	158 d	----
11, 14 SEN	20	0	0	0	0	20	----	148 def
12	20	0	60	0	180	260	175 abc	233 a
13	20	0	60	0	60	140	184 a	218 cde
14	20	0	60	0	120	200	176 abc	223 abcd
15, 13 SEN	20	0	60	46	0	146	179 ab	----
15, 14 SEN	20	0	60	30	0	110	----	221 bcde
16, 13 AG	20	0	60	0	0	80	184 a	----
16, 14 AG	20	0	60	0	30	110	----	210 ef
17, U/ESN	20	0	0	120	0	140	----	225 abcd
CV, percent							6.5	4.3

Figure 4. Rainfall distribution at the Scandia location, 2013 and 2014.