Fluid JOURNAL

Official Journal of the Fluid Fertilizer Foundation

Spring 2015 • Vol. 23, No. 2, Issue #88

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ARTICLES

THE FLUID JOURNAL - MISSION

The Fluid Journal is published by the Fluid Fertilizer Foundation. The FFF is a non-profit organization committed to researching and providing information about fluid fertilizer technology. Since its formation, the FFF has funded over $3 million in fluid fertilizer research. We have accumulated thousands of pages of research data. The main goal of the Fluid Journal is to transfer this technical information into easy to read form to farmers and dealers so they may be better informed as to the technological advancements that the fluid fertilizer industry has achieved.

FOCUS

The Fluid Journal is focused on disseminating fluid fertilizer technology to universities, dealers, equipment manufacturers and fertilizer producers. Our editorial matter focuses on several areas:

- Evaluate the agronomics of fluid fertilizers in the production of maximum economic crop yields
- Evaluate application techniques for fluid fertilizers.
- Investigate and inform our readers of innovative uses of fluid fertilizers under varied cultural, pest control and water management practices.
- Evaluate the efficiencies and conveniences of fluid fertilizer systems.
- Evaluate methods of controlling environmental problems with fluids.

From The Publishers

The Powerful Grip of Tenacity

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The Fluid Journal, and its parent organization the Fluid Fertilizer Foundation (FFF), are offsprings of the National Fluid Solutions Association (NFSA), together an aggregation that dates back 61 years to 1954. Their founders, independent fluid fertilizer dealers, were dedicated to the proposition that fertilizers in the fluid form are the most efficient and productive way to feed crops.

Over the years, there have been some consolidations and changes in the world of agriculture that have required foresight and determination of those in the world of fluid fertilizers to adjust to the times and carry on.

By the early nineties the FFF was operating as its own entity when the NFSA discontinued operation. At the time, the FFF was being revitalized. The Fluid Journal was formed to replace Solutions Magazine, which had been the primary source of spreading word about fluid fertilizers under the auspices of the NFSA.

"Never forget the tenacious efforts"

Today, the Fluid Journal is read worldwide over a website stretching across 104 countries and regions, informing its readers about the FFF and the advantages of fluid fertilizers in crop management and producing higher yields.

While the FFF continues on, thanks not only to ag companies who've contributed their time and skills and the leadership of the FFF's President Dale Leikam, it should never forget the tenacious efforts over the years of the principals who would never say quit.

A powerful grip, indeed.

24th Fluid Forum Offers Broad Agenda

Insights provided on a wide range of research showing the advantages of fluid fertilizers in improving yields.

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Talking Stick was again the site for the 24th Annual Fluid Forum held from February 15 to 17 in Scottsdale, Arizona as researchers and ag people from the United States and overseas gathered for two days of sharing the latest in field research to improve crop yields. Information-packed sessions, led by leading researchers funded by the Fluid Fertilizer Foundation, headquartered in Manhattan, Kansas, spoke to packed sessions on the latest developments in improving yields using fluid fertilizers.

Opening the first session Monday afternoon was Russell French of Dupont/ Pioneer who spoke on "Implementing Research and Adapting for High-Yield Agriculture." The opening day sessions ended with a talk assessing the potentials for drip irrigation and fertigation, delivered by Dr. Fred Below of the University of Illinois.

An FFF board-sponsored reception in Talking Stick's spacious Garden Atrium followed the afternoon session, treating a crowd of 121 registrants to a multi-tabled array of gourmet delights.

Steve Keller, Chair of FFF Board of Directors, calling the 2015 Annual Meeting of the FFF to order.

Ed Krysl receiving the Distinguished Service Award for his 50 years of service to both the National Fluid Solutions Association (NFSA) and the Fluid Fertilizer Foundation. Standing next to him is his wife Neta, another long-time dedicated worker for the FFF. Presenting the award is Steve Keller, Chair of the FFF Board of Directors.

Following a Continental Breakfast the next morning, the discussion was an hour presentation by Dr. Peter Mansoor of Ohio State University on the formation and activities of ISIS, the vile acts they perform and the effect they are having worldwide. This was followed by a broad range of subjects covering the latest in fluid technology reports by ten researchers speaking on such topics as irrigation timing in corn fertigation, a recap on 4R nutrient stewardship, environmental challenges, and improving cotton production efficiency.

The noon annual meeting of the FFF was a festive occasion that included a multi-course luncheon followed by an annual report concerning FFF business, including Board of Directors reports.

Recognition was given by Board Chair Steve Keller to those members who have regularly provided FFF support, plus eight new companies who have recently joined in their support of the Foundation.

He also briefly discussed some of the subjects brought up at the recent Board of Directors meeting.

Dale Leikam also made the President's Report, offering thanks to supporting members, recognizing FFF board companies who have served as sponsors, researchers, and program speakers. He also brought members up-to-date on the FFF's finances and any new research projects.

This was followed by a presentation of the Researcher of the Year award which went to Dr. Tony Vyn of Purdue University for his outstanding fluid fertilizer research contributions to agriculture.

The prestigious Werner Nelson Award was presented to Dr. Carrie Laboski of the University of Wisconsin for her outstanding contributions to wise use of fertilizer to maximize crop yields and profits.

Fluid Fellow Awards, given in recognition of leadership in the fluid fertilizer industry, were presented to: Waddy Garrett of VitAg, Carl Bruice, of Wilbur-Ellis, Cliff Snyder of IPNI, and Tom Fairweather of Tessenderlo-Kerley. At the close of the meeting, the gavel was passed from Board Chair Steve Keller of Morral Companies to Dr. Terry Tindall of J.R. Simplot Company.

The Tuesday afternoon sessions began with a testy look at the regulatory and environmental challenges facing this country and the opportunities we have in dealing with those challenges. Following this was an array of research updates that provided the very latest in fluid fertilizer research and technology.

In 2016, the 25th Annual Fluid Forum will again be held at Talking Stick Resort in Scottsdale, Arizona. Dates are February 15 to 16, 2016. Be sure and put this on your calendar.

Calcium Offers Most Crop Per Drop

Of key importance in promoting water-use efficiency

Dr. Bill Easterwood

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Summary: *Amongst the tools we have available for effective crop production is calcium fertilization. Its beneficial effects in terms of crop yield, fruit quality, and plant health are well known. Most importantly, it increases water use efficiency (WUE) and can be incorporated into a drought stress management plan.*

In previous Fluid Journal editions, we were informed about current water scarcity problems and the challenges created for production agriculture. This topic is very timely since it is elementary that plants and fertilizer will neither survive nor function without water. In these articles, the authors suggested increasing the efficiency of our water use via:

1. Optimum irrigation systems
2. Limiting water loss during delivery to the systems.

But, can we optimize plant water usage as well? Can specific nutrients applied during fertilization maximize available water uptake/usage by plants?

Recent research during the past few decades indicates that nutrients can play a vital role in plant (WUE). Specifically, calcium fertilization will be the focus of our attention here.

Calcium's role

We learned long ago that calcium is essential for cell wall development/ thickness, plasma membrane structure/ water regulation as well as nutrient uptake, and cell division or mitosis. We now know that calcium and calmodulin (calcium modulated protein—CaM) act as a messenger molecule to initiate plant protection mechanisms, aid in hormone responses and control plant water relationships. How then, does calcium/ CaM help increase a plant's (WUE)?

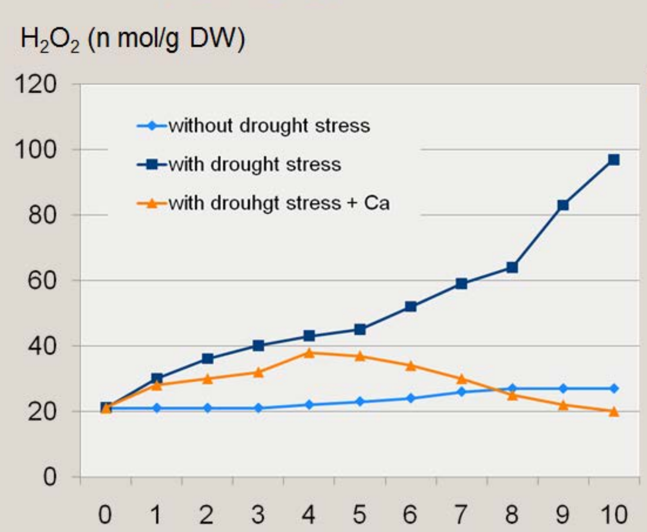
Growth under drought

In the chloroplasts of plant cells, oxygenated radical compounds are formed during photosynthesis. Under normal growing conditions, these compounds are eliminated by the plant. But during drought stress, they can accumulate and attack and damage the plasma membranes of cells, causing water and nutrient leakage at the cellular level.

To control these radical compounds, the plant releases mobile Ca stored in vacuoles to stabilize and maintain plasma membrane integrity, as well as control oxygenated radical concentrations.

Therefore, we can observe the effect of calcium mitigating oxygen radical (H_2O_2- hydrogen peroxide) concentrations in plants under drought stress (Figure 1).

Figure 1. Ca lowers the concentration of oxygen radicals (e.g. H_2O_2) in the cell at drought stress



Method: In a cell tissue culture of a traditional Chinese medical crop (Liquorice), water stress was induced by addition of 10 % polyethylene glycol (PEG) with and without 40 mM/l Ca.

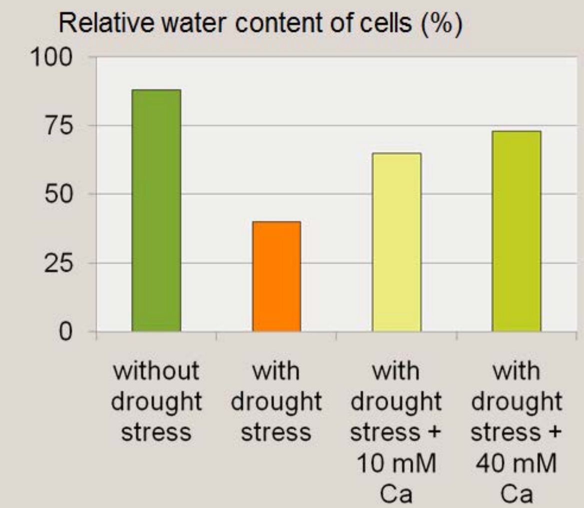
Maximizing cellular water content with minimal damage to the plasma membrane is the result (Figure 2). Without water soluble calcium availability to the plant, damage to the plasma membrane can:

- greatly reduce the water content of plants during drought stress
- reduce plant growth
- limit yield.

Water uptake

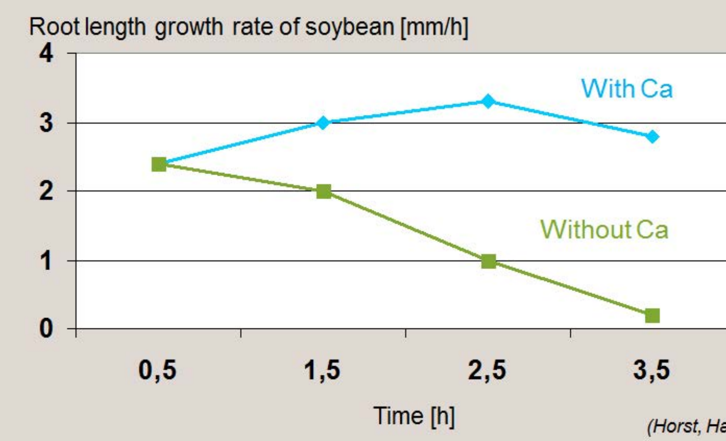
To maximize water uptake efficiency, plants growing under drought conditions will require a large healthy rooting system for maximal root surface area to extract available water from the soil. So a large root mass with a large number of root hairs is beneficial. The root hair zone is the most water permeable in the rooting system and increases the root diameter, promoting increased water uptake.

Figure 2. Ca maintains the water content of cells under drought stress



Method: In a cell tissue culture of a traditional Chinese medical crop (Liquorice), water stress was induced by addition of 10 % polyethylene glycol (PEG). Different Ca concentrations were applied to the growth medium (10 and 40 mM/l Ca)

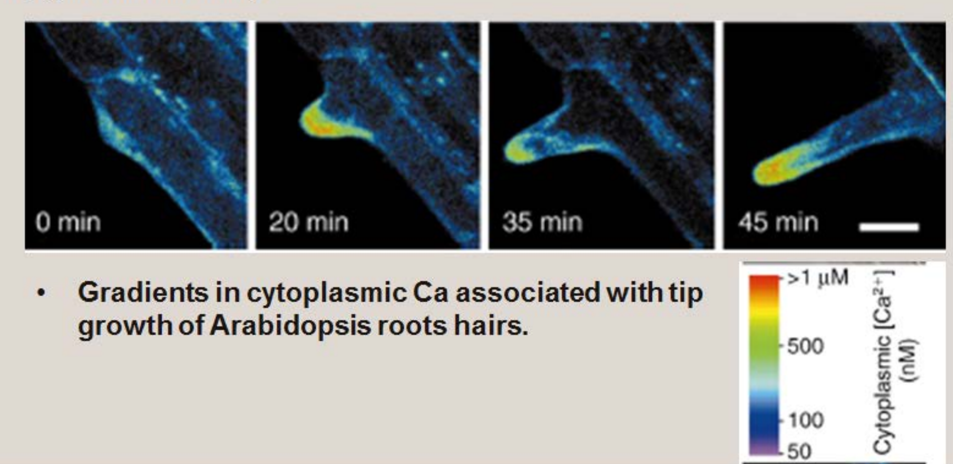
Figure 3. Root growth is strongly depending on sufficient Ca supply by the soil



(Horst, Hannover University)

Figure 4. Ca is essential for root hair growth

A tip-focused Ca gradient in root hairs is a pre-requisite for root hair growth; Here Ca leads the direction of tip growth and is a crucial component of the tip-growth machinery.



- **Gradients in cytoplasmic Ca associated with tip growth of Arabidopsis roots hairs.**

Calcium plays a vital role in root (Figure 3) and root hair production (Figure 4), since it is a major nutritional component of roots and aids in cell division during root and root hair development.

With the increased production of larger roots and root hair with calcium application, rooting systems have greater surface area and become significantly more effective in increasing available water uptake by 55 percent in a sandy soil on a theoretical basis (Figure 5).

During drought stress, plants release abscisic acid (ABA), a hormone that increases water conductivity (movement of water from roots to shoots) in the plant. With or without ABA, Ca also increases water conductivity. With ABA and Ca, water conductivity is significantly increased (Figure 6).

So, water uptake efficiency, maximal root and root hair mass, and optimal water conductivity are necessary for strong healthy productive plants during drought. Calcium plays a vital role in both plant mechanisms.

Transpiration

Stomata. Available soil water is taken up by plant roots and translocated to the xylem, which moves the water in a continuous flow into leaves. Water is converted to water vapor near the stomata and when open, escapes into the atmosphere as the plant acquires CO_2 and releses O_2. Stomatal transpiration, as described, accounts for 90 to 95 percent of the water transpired through the leaves.

The ability of the plant to regulate its stomatal opening and closing is imperative in order to obtain a carbon source for photosynthesis and to limit water loss from tissue and prevent desiccation. Tissue damage or plant death can occur when plant tugor is low and the stomata are open.

It is well known that potassium is key

in stomatal regulation. Potassium ions are actively transported (requiring biochemically derived energy) into guard cells around the stomata. With the change in osmotic potential, an influx of water hydrates and expands the guard cell, resulting in a "swelling" and closing of the stomata. But we also know that increasing calcium concentration in the apoplast near the guard cells leads to stomata closure and a decreasing calcium concentration leads to opening of the stomata (Figure 7).

So, calcium also plays a role in plant water efficiency, like potassium, but we do not know unequivocally the mechanism involved. Some hypotheses include calcium signaling the initiating of ATP formation and energy production for active transport of potassium into the guard cells. Regardless of mechanism, it is certain that calcium controls stomatal openings. Plants with a low available calcium status cannot fully close their stomata, which results in tissue desiccation pictured in the potato photo shown at the lead of this article.

Cuticle. The cuticle is a waxy resinous material covering the epidermis of leaves and other plant parts. As water vapor moves through the leaf, approximately 5 to 10 percent of the water transpired by the leaf is lost through breaks in the cuticle and is termed cuticular transpiration. Some plant species, growing in a desert environment, have thick cuticles while others do not. Generally, the thickness of the cuticle decreases the amount of water vapor lost. However, when stomata are closed, higher rates of cuticular transpiration can occur.

Plant-available calcium helps reduce cuticular transpiration. Stronger thicker cell walls create a barrier to reduce water loss. Wrapper leaves of lettuce, for example, exhibit a significant water loss reduction through the cuticle with increasing calcium concentration (Figure 8).

Summing up

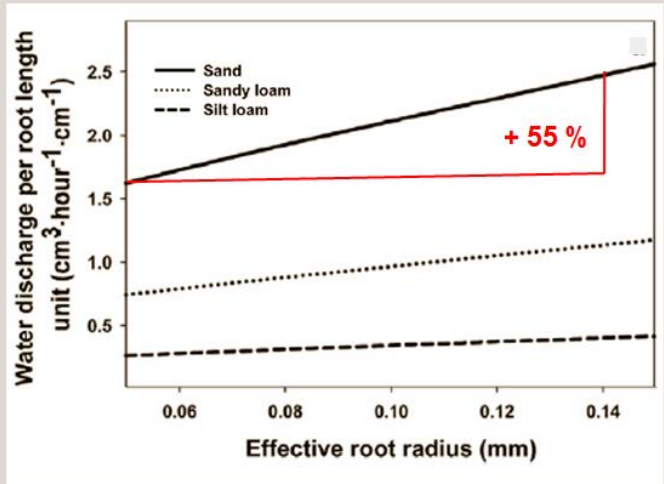
Considering all of the beneficial effects of calcium nutrition in terms of yield, fruit quality, and plant health, it is also appropriate to consider that sufficient calcium supply to plants is necessary to increase plant WUE and be incorporated into a drought stress management plan. We have observed that:

- Calcium protects cell membranes against drought-induced oxidative stress
- With calcium, water content of stressed cells is maintained
- Calcium improves water uptake and transport to the shoot
- Calcium reduces transpiration losses.

Given the challenge of water scarcity, we must use all of our tools to address the challenge. A crop with good drought stress management will produce greater harvest per given amount of water, resulting in higher WUE or, in European terminology, "most crop per drop." Calcium fertilization is one of our important available tools.

Dr. Easterwood is Director of Agronomic Services at Yara North America, Inc. in Tampa, Florida.

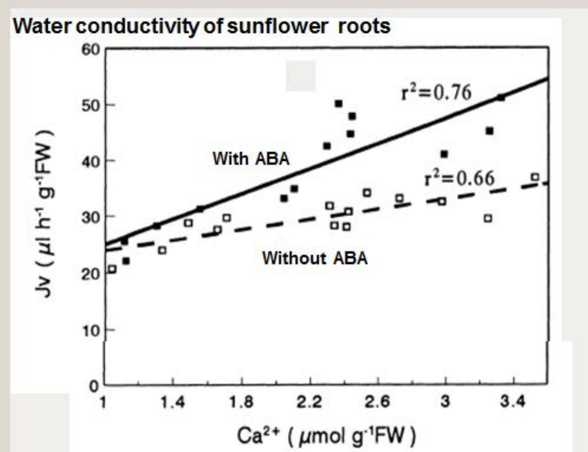
Figure 5. Root hair enhances effective root radius, which improves water uptake



Simulation of water uptake per unit root length at different root diameters.

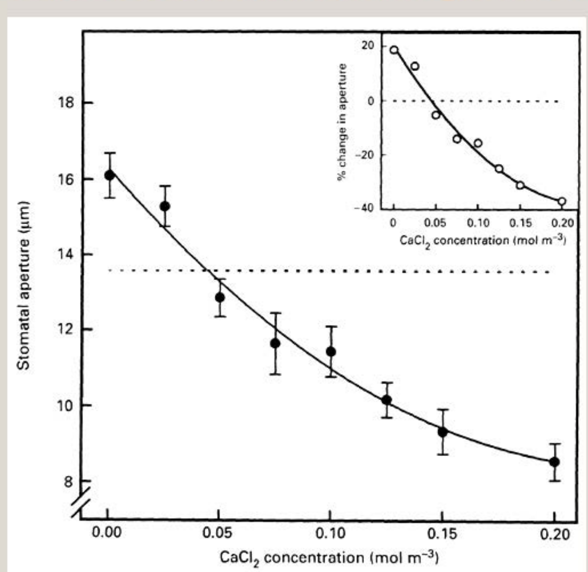
e.g. a single root 1 mm in diameter with root hairs 1 mm in average length, growing in sand, will improve the water uptake rate per unit root length by 55%.

Figure 6. An adequate Ca status improves water conductivity of roots and its sensitivity to ABA (abscisic acid, a stress hormone)



- Increasing the water conductivity of roots appears to be a plant adaptation to drought stress. Water conductivity increases with abscisic acid (ABA), a stress hormone produced and released by the plant during drought stress.
- Increasing Ca supply enhanced
  - water conductivity of sunflower roots.
  - their sensitivity to ABA.

Figure 7. Stomata opening is controlled by Ca concentration outside the guard cells (apoplast)



Response of open stomata in epidermis cells of C. communis to Ca in the incubation medium after 3 hours; main figure = absolute stomatal aperture; inserted figure = relative change compared to initial value

Figure 8. A good Ca status reduces the water losses through the cuticle

- **Ca helps the plant to reduce transpiration losses during the night, when the stomata are closed.**

Transpiration in relation to leaf area [g H_2O/m^2xh]

What About Late Season Application of Foliar N?

Post flag leaf has been too variable to draw conclusions.

Drs. Brian Arnall, Brad Seaborn, Jeremiah Mullock, and Mr. Brandon Burgess

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Summary: *In our studies across the six site years, late-season foliar nitrogen (N) never impacted yield in either a positive or negative manner when compared to the standard fertility treatment. The response to overall measured variables, which included protein, mix tolerance, and loaf volume, was very variable and not consistent. Oklahoma's post-flag leaf environment may be too variable to say, conclusively, that late-season foliar application would improve the baking and milling qualities of hard red winter wheat.*

In the fall of 2010 the Kansas Board of Trade proposed and passed quality standards on No. 2 Hard Red Winter Wheat, in which any wheat that fell below 10.5 percent would be considered undeliverable. This new standard significantly increased the interest of late-season N applications to increase grain protein in the Southern Great Plains. It has been a practice widely used and accepted in the Northwest and Eastern US, relative to spring wheat production.

However, in the Southern Great Plains, late-season N applications are not widely used. Average yield levels of the region often do not support additional trips over the field. In a 2002 field study by Woolfolk, et al., it was reported that when UAN and ammonium sulfate were applied to winter wheat pre- and post-flowering, grain N concentration was increased. However, producers in the region are commonly making fungicide applications during flag leaf stage. This presents an opportunity to apply fertilizer N with no additional application cost.

To this point, many producers are putting one to two gallons of low salt N products in with the flag leaf fungicide application in hopes of either improved yield or increased grain protein levels.

Trial specifics

Evaluation. This trial was established to evaluate the use of two N sources applied flag leaf (FL) and post anthesis (PA) to improve Great Plains hard red winter wheat grain yield, protein, and milling and baking characteristics.

Sources. The two sources evaluated were UAN 28-0-0 and CoRoN 25-0-0. CoRoN (which is labeled as being derived from urea, methylene diurea, and methylene urea) was selected due to its low salt level and wide availability within the region.

Rates. Protein levels were maximized at a rate of 34 kg N ha^{-1} (Woolfolk et al., 2000). However, the greatest majority of the low salt N fertilizers is not being recommended at a rate above 18 L ha^{-1} or as, in the case of CoRoN, 7.6 hg N ha^{-1}. Therefore, it was important to evaluate rates below that which Woolfolk looked at. Both N sources were applied at three rates (6.7, 13.4, and 26.8 kg N ha^{-1}) at the two timings FL and PA.

Applications were made using a CO_2 pressurized backpack sprayer. All treatments were supplied at a flow rate of 93.8 L ha^{-1} with water as the carrier. Typically, FL applications occurred in mid-April while PA applications were made in mid to late May. The constant flow rate was chosen to ensure uniform application of the fertilizer. All treatments, excluding the non-fertilized check, received 45 kg N ha^{-1} pre-plant and 45 kg N ha^{-1} at top-dress. Unlike the Woolfolk work, where treatments were applied in the cool of the morning to reduce the likelihood of tissue burn, the treatments for this study were all applied mid-day. However, the use of water as a carrier likely reduced tissue burn, at least for the lower N rates.

Location. The trials were established at two locations: Lahoma and Lake Carl Blackwell (LCB). Figures 1, 2, and 3 document the deviation in plant-available water, average daily temperature, and relative humidity from the long-term average values for each year of the study at the Lahoma site.

Treatments. Our study consisted of 14 treatments, which included a non-fertilized and a fertilized control arranged in a RCBD.

Plot size measured 3m by 6m.

Harvest. At maturity, the grain was harvested from the center 1.5 m of each plot with a Massey 8XP combine.

Evaluation. All grain from each plot was retained and sent to the USDA ARS Baking and Milling lab in Manhattan KS for evaluation of milling and baking qualities.

Samples. It should be noted that all samples from the 2013 harvest were lost when packaging was damaged during the shipping process. Therefore, for the 2013 crop year, only yield data are available.

Baking, milling variables

Recommended Quality Targets (RQT) are set by the HWW Quality Target Committee. The purpose of RQT for Hard Red Winter Wheat (HRWW) is to provide specific quality goals for the breeding community, water producers, and marketing programs in order to assist and guide the decisions needed to maintain the consistency and end-use quality of the U.S. HRW market class. Variables are:

- Test Weight > 60 lb/bu-1
- Protein > 12.0
- Mixing tolerance: ranked value with a score from 0-6; values above 3 are preferred
- Mix time: 3 to 5 minutes
- Loaf Volume > 850 cc

Flour yield was also measured. The greater the percent yield the better.

2011 crop year

The 2011 crop year was characterized by a late spring warm-up with good winter moisture but a dry spring with below average relative humidity levels during the FL and PA application window.

Yields. At both locations the yield of the check was not significantly different from any other treatment documenting a non-responsive crop season. Yields at Lahoma, however, were significantly higher than LCB with ranges of 4.0 to 5.4 Mg ha^{-1} and 1.7 to 2.2 Mg ha^{-1} respectively.

Protein. While yield was not affected at either location, protein was increased above the non-fertilized control at LCB. There was no significance in protein at Lahoma across all 14 treatments and no significant differences in protein at LCB for any treatment that received fertilizer N. At Lahoma, the 13.4 kg N ha^{-1} PA application resulted in the highest protein content. Five of the six treatments with the highest protein content at LCB were PA applications.

Baking/milling. Of the baking and milling qualities measured, only mixing tolerance was impacted by the late-season N applications at Lahoma, with all UAN treatments resulting in significantly higher values than CoRoN at 3.67 and 2.94, respectively.

Loaf volume. At LBC, loaf volume was the only variable significantly impacted. All late-season N treatments resulted in a 55cc increase in loaf volume over the fertilizer control.

Samples. All samples fell below the 850cc target.

2012 crop year

The 2012 crop year was characterized by good soil moisture through winter and the onset of a severe drought in June. Early spring temperatures and relative humidity values were above average; however, May saw relative humidity values drop below the long-term average.

Yields. The favorable spring weather led to slightly higher maximum yields at Lahoma and significantly high maximum yields at LCB, with ranges of 3.9 to 5.9 Mg ha^{-1} and 1.8 to 3.9 Mg ha^{-1}, respectively.

Protein. At both locations, the majority of the treatments increased protein levels above that of the fertilized controls. At Lahoma the 13.4 kg N ha^{-1} rate of CoRoN applied PA was the only treatment that was statistically higher than the fertilizer control, while 13.4 and 26.8 kg N ha^{-1} UAN applied at FL, as well as the 26.8 kg N ha^{-1} UAN applied PA treatments, all had statistically higher protein content. A comparison of N source at LCB showed that UAN had a significantly higher protein level at 11.58 percent than CoRoN had at 11.18 percent.

Mix time. The same trend was seen in mix time as the average mix time of treatment receiving UAN was longer than that for those receiving CoRoN. Flour yield was significantly impacted by timing of application. Treatments receiving N at PA had an average yield of 72.9 percent while those receiving N at FL had an average yield of 72.2 percent.

2013 crop year

As was previously mentioned, all samples were damaged in transport to the lab in Manhattan KS. Therefore, the only variables that can be reported are yield and test weight. The 2013 crop year was characterized by an extremely dry winter with the month of March bringing below normal temperatures, timely rains, and average relative humidity.

Yields. The poor winter with a following favorable spring led to average yields at Lahoma and LCB, with ranges of 4.0 to 4.9 Mg ha^{-1} and 3.2 to 3.8 Mg ha^{-1}, respectively. It is hypothesized that

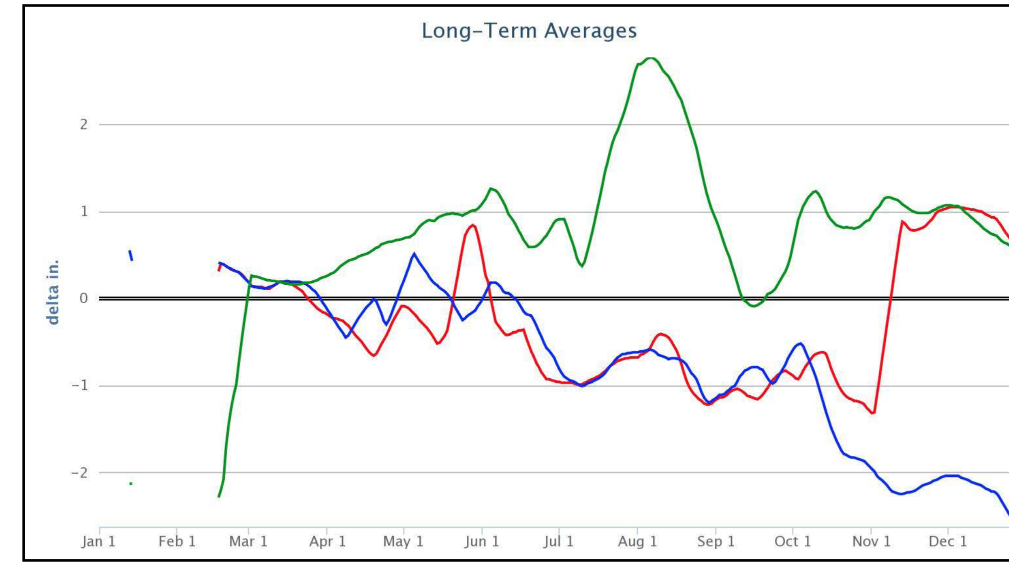

Figure 1. *The deviation from 2000 to 2014 average of plant available water (inches) in the top 16 inches of soil profile for the Lahoma Research Station in 2011, 2012, and 2013.*

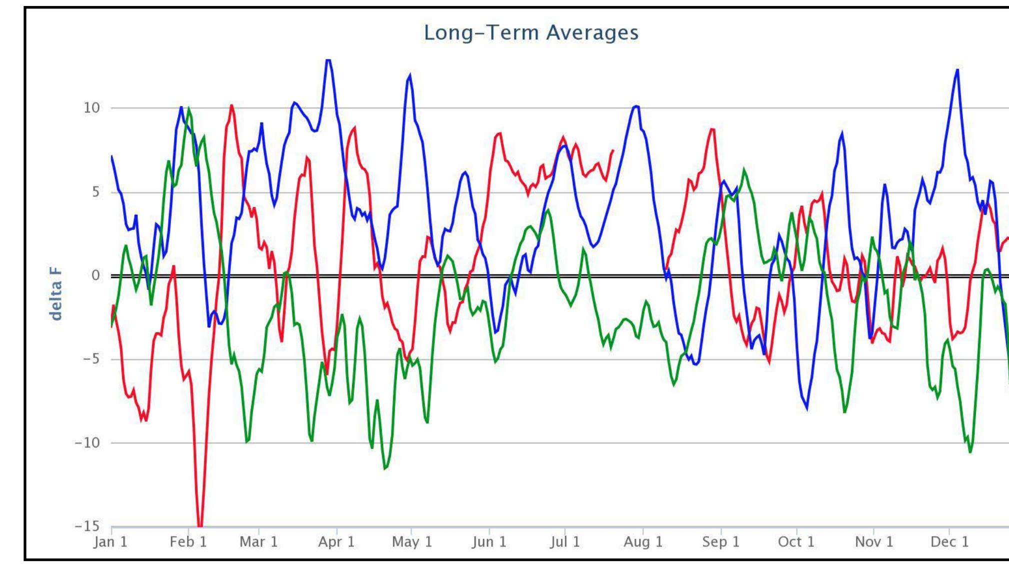

Figure 2. *The deviation from 2000 to 2014 average of daily air temperature (degrees F) for the Lahoma Research Station in 2011, 2012, and 2013.*

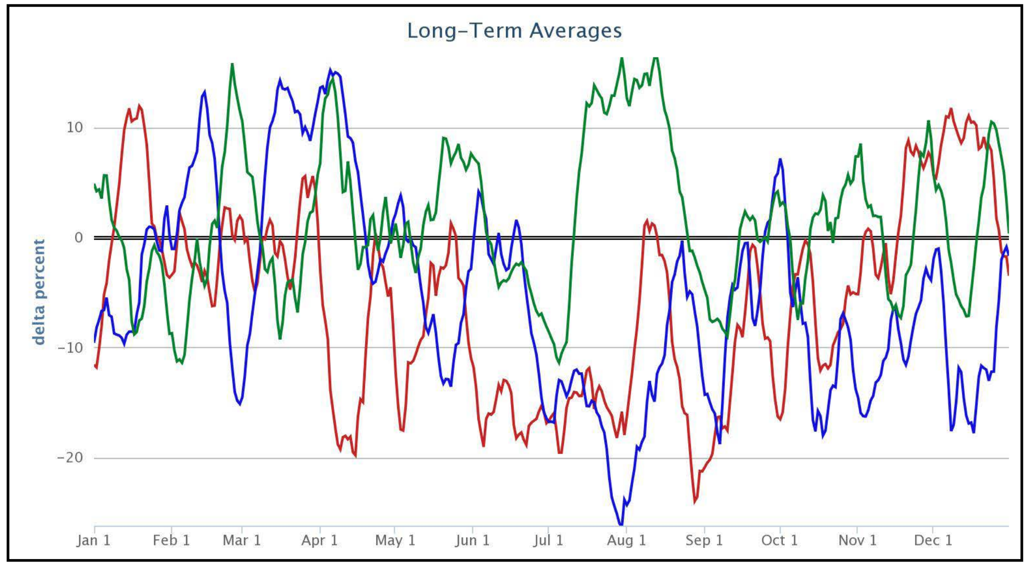

Figure 3. *The deviation from 2000 to 2014 average of percent relative humidity for the Lahoma Research Station in 2011, 2012, and 2013.*

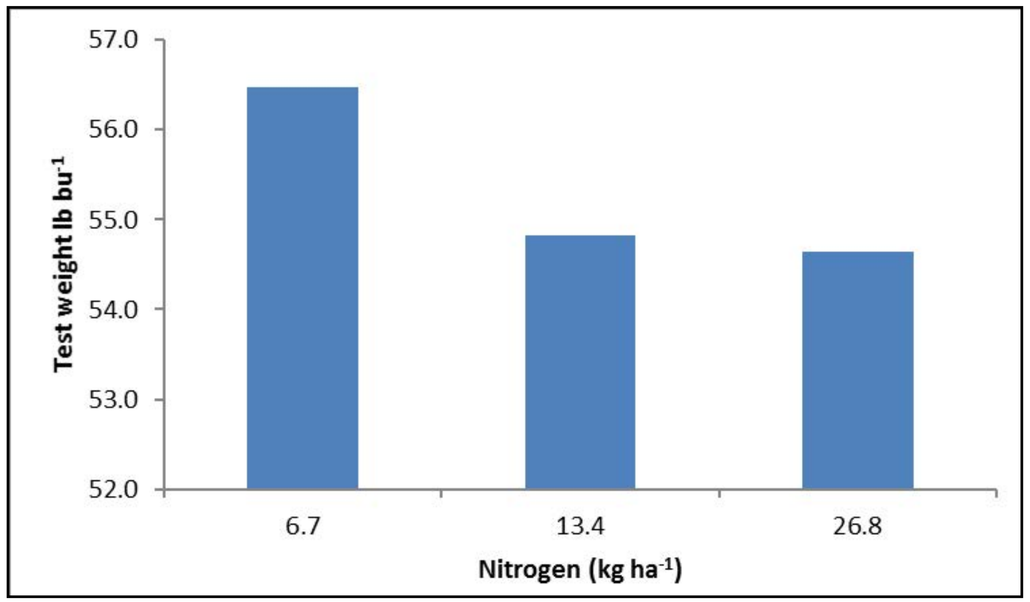

Figure 4. *At Lahoma, the N rate of 6.7 kg N ha^{-1} had a significantly greater test weight than the 26.8 kg N ha^{-1}.*

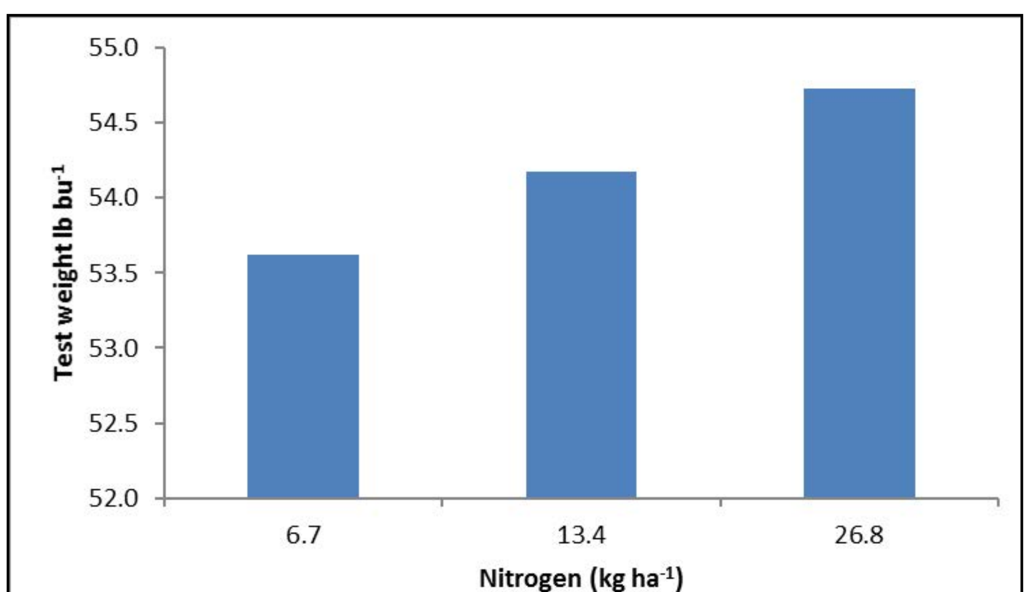

Figure 5. *At LBC the 26.8 kg N ha^{-1} rate was significantly greater test weight than the 6.7 kg N ha^{-1} treatment.*

delayed mineralization, induced by the drought, decreased the response to fertilizer N, which can be noted with the average yield range of each location being less than 1 Mg ha^{-1}.

Test weight, for the first time during the evaluation of the study, was significantly impacted by treatment. It is important to note that harvest was delayed at both locations due to rain, and because of that, overall test weight was negatively impacted. The test weight results from 2013 are a good summation of the overall study (Figures 4 and 5). At Lahoma, the N rate of 6.7 kg N ha^{-1} had a significantly greater test weight than the 26.8 kg N ha^{-1}, while at LCB the 26.8 kg N ha-1 rate was a significantly greater test weight than the 6.7 kg N ha^{-1} treatment. A final result of the 2013 crop year showed that at Lahoma CoRoN treatments resulted in significantly greater test weights than UAN, 56 and 54.6 respectively. Yet at LBC, while there was no significant difference, the average test weight of UAN treatments was 54.4 and the average test weight of CoRoN treatments was 53.9.

Take home

Regardless of the source rate or late season environment--flag leaf and beyond--applications never positively impacted yield and therefore should not be recommended as such. However, the FL and PA application did, at times, impact grain protein, test weight, flour yield, mix tolerance, mix time, and loaf volume.

What variable was impacted, and to what degree, was not consistent across treatment or environments. The confounding result of the 2013 crop year test weights is a perfect example. The application of N post-anthesis did impact these variables more often than did flag leaf application.

The source of the PA application was seldom significant, indicating that the cheaper source, UAN, was just as effective if not more so as the low salt controlled-release source, CoRoN.

The greatest take-home may be that if the field is properly fertilized to reach maximum yield potential, an economical return on late-season N applications is unlikely. Currently, work is being performed to estimate the impact of these late-season N applications in situations where N is limiting.

Dr. Arnall is associate professor, Dr. Seaborn is supervisor and research chemist, Dr. Mullock is soil fertility agriculturalist, and Mr. Burgess is M.S. student in charge of project at Oklahoma State University.

Nitrogen, Irrigation Timing Key To Higher Corn Yields

Performance of remote sensors is essential in achieving high yields.

A.R. Asebedo, E.A. Adee, and D. B. Mengel

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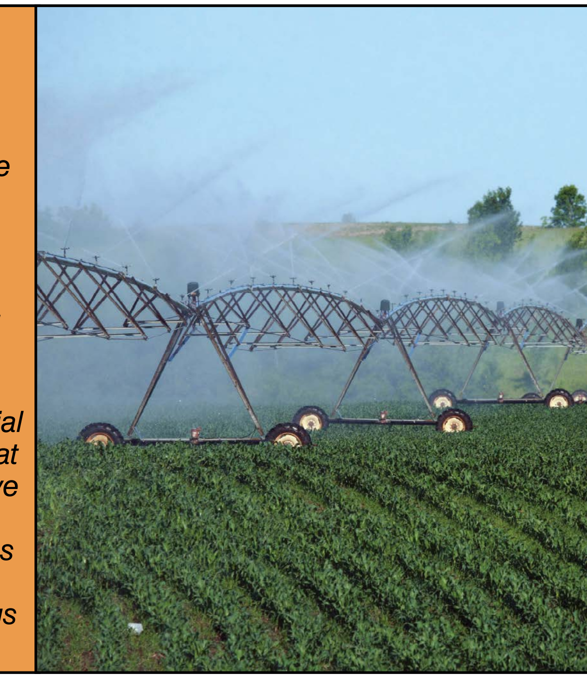
***Summary:** Nitrogen use efficiency (NUE) in high-yield irrigated corn production systems has many economic and environmental implications. Many producers in the region rely on single pre-plant applications of granular urea or anhydrous ammonia as the primary N source in irrigated production systems. 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 NUE, 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 algorithms used 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.*



Nitrogen use efficiency (NUE) 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 use of multiple N applications through fertigation, which 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 raise 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.

Objective

The objectives of this study were to:

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

Methodology

The study was initiated in 2012 and conducted through the 2014 crop year in cooperation with Kansas producers and Kansas State University 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 used were representative of each area.

Plots. Each field study used 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).

Applications. Sidedress N applications were made prior to scheduled irrigation events to stimulate an N fertigation system. Application timing methods implemented at each site consisted of single pre-plant application, split application between pre-plant and corn growth stage V-4, and split application between pre-plant and variable treatments based on plant reflectance. Fertilizer needs other than N were applied near planting.

Design. Treatments were placed in a randomized complete block design with four replications.

Canopy reflectance of corn was measured prior to each irrigation event with focus being on V-10 and R-1 growth stages, respectively. Canopy

Table 1. 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 2. 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 buA	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

reflectance was used to calculate the Normalized Difference Vegetation Index (NDVI = NIR-visible/NIR+visible) and was averaged for each plot. The algorithm used to provide sensor-based N recommendations was developed by Tucker and Mengel (2010).

Sensor. The optical sensor used for canopy reflectance was the Greenseeker (Trimble Navigation, Ag Division, Westminster, CO).

Sampling. Soil samples, to a depth of 24 inches, were taken by block, prior to planting and fertilization. Samples (0 to 6 inches) were analyzed for soil organic matter (Mehlich-3 phosphorus, potassium, pH, and zinc). The 0 to 24-inch samples were analyzed for nitrate-N, chloride, and sulfate. Irrigation was sampled at each location for NO_3-N and NH_4-N. Rossville and Scandia experiment stations tested with less than 1 ppm for NO_3-N and NH_4-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 NO_3-N, and therefore this site was used only in 2012.

Yields. Grain yield was measured by harvesting an area of 5 feet by 40 feet within each plot at the Scandia and Rossville experimental stations. The farmer cooperative site at Scandia site 2 was hand harvested from as 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 conducted 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

2012. Data analysis from Scandia Site 2, a farmer cooperative field (Table 1), show 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. Approximately 60 pounds of N per acre were added in 2012 through irrigation water.

There were significant N treatment effects on corn yield observed at the Scandia Station in 2012 (Table 2). 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 lbs/A pre-plant). This treatment was statistically equal to the highest yield 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. Two of the three sensor-based N treatments (treatments 7 and 8) yielded significantly lower than the pre-plant/V4 split applications (Treatments 5 and 6). The yield differences are likely attributed to the lower total N rates recommended by the sensors.

2013. The 2013 Rossville experiment site showed a significant response to applied N also (Table 3). All sensor treatments generated the highest yield and were statistically higher than the two lowest rate pre-plant-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 1 shows two 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

"Algorithms must be specifically designed"

Table 3. 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 4. 2013 Scandia Station Field Results

Year	Treatment	Timing Method	Starter N lb/A	Preplant N lb/A	In-Season N lb/A	Total Napplied (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

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.

In 2013, the Scandia Station experiment location showed a small response to applied N (Table 4). 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 2). Overall, yield levels were lower than expected at this location with the highest yield being 179 bu/A. Expected yields were 250 bu/A, and this overall yield reduction could be attributed, in part, to the late planting date. Highest yielding treatment was #5, a planned application of 140 pounds of N split with starter, pre-plant and in-season. All sensor treatments overestimated N requirements

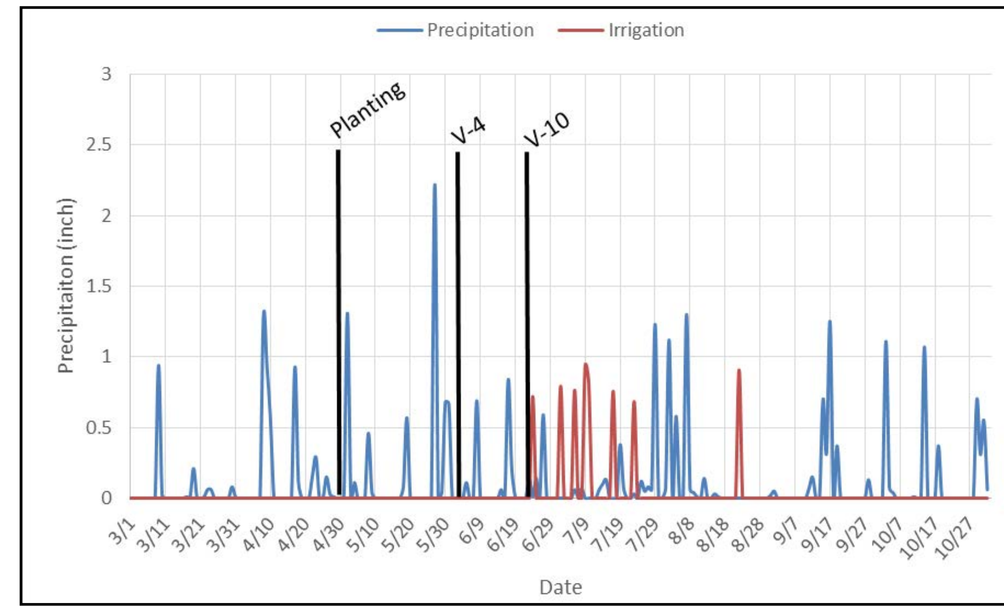


Figure 1. *2013 Rossville Rainfall and Irrigation.*

compared to treatment 5, and resulted in an unnecessary over application of N.

2014. The Rossville experiment site produced excellent yields and a significant response to applied N (Table 5). Figure 4 shows rainfall events in late May and June that would lead to significant N leaching losses in the sandy loam soil at Rossville. However, in the study area, a clay lens was located 34 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 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 percent economic optimum, achieving 237 bu/A from 55 lbs of applied N per acre.

Scandia station achieved excellent yields and also showed a significant response to applied N (Table 6). Rainfall and N loss was low and frequent small rain events created conditions that were good for mineralizing N (Figure 3), which resulted in the check treatments achieving 163 bu/A. 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.

Summing up

Pooled analysis of all locations (Table 7) shows that overall performance of the sensors and algorithm used was effective at achieving high yields, but has the tendency to overestimate N requirements. However, this result is not surprising as the 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 particular year. However, 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.

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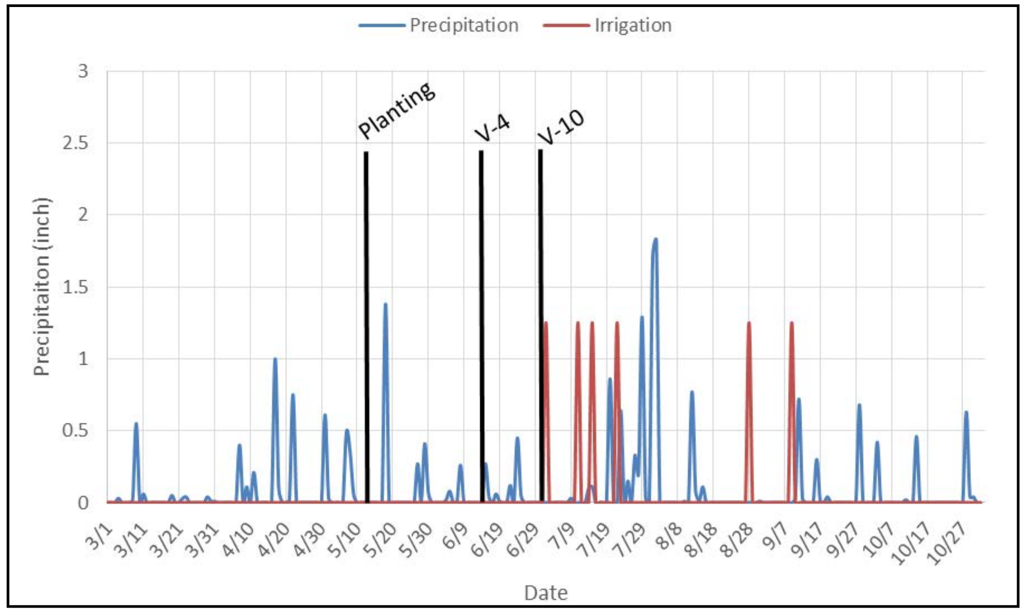

Figure 2. *2013 Scandia Station Rainfall and Irrigation.*

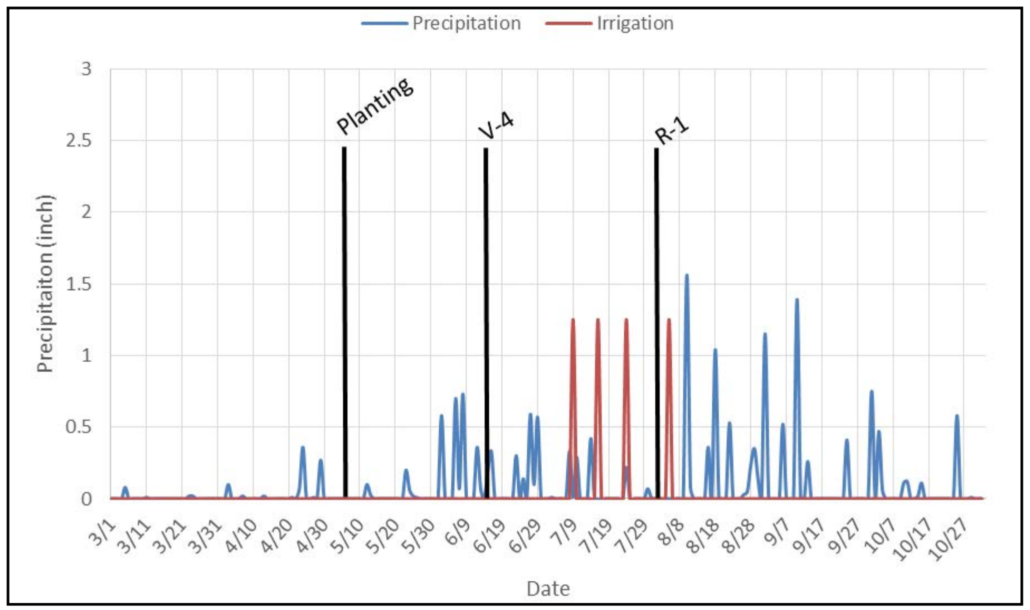

Figure 3. *2014 Scandia Station Rainfall and Irrigation.*

Table 5. 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 6. 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 (lbA)	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 7. 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