# EFFICIENT MANAGEMENT OF WATER AND NUTRIENT RESOURCES: ASSESSING THE POTENTIAL FOR DRIP IRRIGATION AND FERTIGATION

Fred E. Below, Tryston Beyrer, Adriano Mastrodomenico and Juliann Seebauer
Crop Physiology Laboratory, Department of Crop Sciences, University of Illinois
1201 West Gregory Drive, Urbana, IL 61802
Presented at the Fluid Fertilizer Forum February 16, 2016, Scottsdale, AZ

## ABSTRACT

The industry-wide initiative of doubling corn (*Zea mays* L.) grain yields by 2030 is required to feed a growing world population. The use of precision irrigation and fertilizer application technology may serve as a promising venue for producers to increase yields sustainably. Therefore, our primary objectives were to, 1) investigate subsurface drip irrigation (SDI) as a possible strategy to improve the efficiency of nutrient uptake and use when liquid nutrients are applied at key growth stages in corn and soybean (*Glycine max* (L.) Merr.), and 2) understand how drip irrigation and fertigation can be optimized in a high yield agronomic system with complementary agronomic management practices including hybrid and variety selection and crop protection. Across five corn hybrids and four planting populations, yield improvements by as much as 69 bu /acre were obtained at Champaign, IL due to season-long fertigation of N, P, K, S, and Zn in 2015. Fertigation increased total nutrient accumulation in corn over a base fertilizer application for N (+53%), $P_2O_5$ (51%), $K_2O$ (+36%), and S (+36%). Fertigation of corn led to nutrient recovery efficiencies of approximately 65% for N and 25%, 31%, and 38% for P, K, and S, respectively. Fertigation maximized corn hybrid yields to approximately 246 bu/ acre regardless of plant population of 32,000 to 50,000 plants/ acre. Nutrients were also fertigated in soybean (N, P, K, S, and Zn) and, with foliar protection, improved grain yield by as much as 8 bu/acre in 2015. Varietal differences in response to fertigated nutrients suggest that this tool may be used to classify soybean varieties for their responsiveness to agronomic management. The 2015 findings highlight significant yield improvements associated with adequate nutrient availability in corn and soybean, and how innovative liquid nutrient sources and delivery methods (i.e., SDI) can be used as a strategy to supply nutrients efficiently for maximum yields and less nutrient loss.

## INTRODUCTION

To feed a growing human population on less land, greater yields are necessary. While the average U.S. corn yield is approximately 170 bushels per acre, greater yields are possible, as shown by the 2015 National Corn Growers Contest winners all exceeding 300 bushels per acre, and a third of them exceeding 400 bushels per acre. The world record for corn is now well over 500 bushels per acre. In growing a 260 bushel per acre corn crop, our laboratory has determined that weather conditions account for over 27% of those bushels, while controllable crop management factors of nitrogen fertilizer, hybrid, previous crop, plant population, tillage and plant growth regulators, each account for, on average, 26%, 19%, 10%, 8%, 6%, and 4%, of yield respectively (Ruffo et al., 2015). These yield estimates are based on prerequisites of drainage, pest and weed control, proper soil pH, and adequate P and K based on soil tests. Conversely, soybean (*Glycine max* (L.) Merr.) yield increases over time have lagged behind corn and providing soybean with adequate phosphate, along with planting a longer relative maturity variety in narrower rows, and using a fungicide and insecticide each can increase yields approximately 3.5 to 5 bushels per acre (unpublished data). Yield increases in corn in the past 30 years in the U.S. have paralleled increases in planting density. However, this increased plant density leads to less roots per plant, and a greater need for more precise nutrient supply.

A series of studies conducted over the past three years has identified the fertility requirements for high-yielding corn (Bender et al., 2013) and soybean (Bender et al., 2015; Table 1). Total nutrient requirements for soybean are similar to those of corn, despite the misconception among farmers that nutrient management in soybean is less critical because of N-fixation as well as the notion that fertilizer supplied to a corn crop will also meet subsequent soybean fertility requirements. Nutrient harvest index values (i.e., the portion of total nutrient uptake represented in grain tissues) of N, P, S, and Zn in both corn and soybean are generally between 60-80%; which suggests that soil test levels will quickly decline if provided inadequate crop nutrition. This may partially explain the decreases in P, K, S, and Zn levels reported by a recent IPNI summary of soil fertility levels (Fixen et al., 2010). Current corn and soybean fertility recommendations are based on expected (corn) yield for N, and soil test levels for P and K. However, in the future, maximizing yields while also sustaining the productivity of soils requires a comprehensive season-long fertility plan designed to meet the uptake needs of well-managed corn and soybean crops.

Sub-surface drip irrigation (SDI) has traditionally been used in the production of high-value vegetable and fruit crops such as tomato. More recently, it has been adapted for commodity row crops such as corn, soybean, and cotton as an alternative to center-pivot or flood irrigation. The benefits of a SDI system relative to other traditional irrigation forms include reduced water use brought about by up to a 50% reduction in evaporation losses (Lamm and Trooien, 2003), and the ability to adapt to any field size, geometry, or topography (Netafim, 2010). Additionally, SDI provides the opportunity to increase the efficiency of nutrient applications through the practice of fertigation (i.e., liquid fertilizer sources supplied with irrigation water). Fertigation of nutrients directly into the root microenvironment, particularly during periods of rapid uptake, can minimize nutrient losses associated with immobilization, volatilization, or surface run-off (Hartz and Hochmuth, 1996). Currently, fertigated corn and soybean acreage in Illinois is limited in scope (90,000 acres or less than 1 % of total crop acres as of a 2013 survey) (USDA-NASS, 2015a & 2015b). However, factors may accelerate fertigation and SDI system adoption in traditionally non- irrigated parts of the Corn Belt, including 1) high commodity and input prices, 2) catastrophic weather events such as the 2012 drought, and 3) the demand for increased agricultural productivity in response to world population growth.

**Table 1.** Mineral nutrition required to produce 230 bu $acre^{-1}$ corn (adapted from Bender et al., 2013) and 60 bu $acre^{-1}$ soybean (adapted from Bender et al., 2015). 'Maximum Uptake' (total nutrient uptake), 'Removal with Grain' (nutrient content of grain), and 'Harvest Index' (portion of total nutrient uptake residing in grain) are three key measures used to estimate nutritional needs in a cropping system.

| **Nutrient** | **Maximum Uptake** | | **Removal With Grain** | | **Harvest Index** | |
|---|---|---|---|---|---|---|
| | Corn | Soybean | Corn | Soybean | Corn | Soybean |
| | ———lb $ac^{-1}$ ——— | | ———lb $ac^{-1}$ ——— | | ——— % ——— | |
| N | 256 | 245 | 148 | 179 | 58 | 73 |
| $P_2O_5$ | 101 | 43 | 80 | 35 | 79 | 81 |
| $K_2O$ | 180 | 170 | 59 | 70 | 32 | 41 |
| S | 23 | 17 | 13 | 10 | 57 | 61 |
| Zn (oz $ac^{-1}$) | 7.1 | 4.8 | 4.4 | 2.0 | 62 | 44 |

Macronutrient accumulation varies considerably among crop and mineral nutrient. In corn, the majority of N and K accumulation occurs before flowering compared to uptake of P, S, and Zn, which primarily occurs during grain-filling (Bender et al., 2013). Because nutrient applications for corn production primarily supply nutrients in a bulk, dry granular form prior to planting, most nutrients are prone to chemical conversion or are fixed into unavailable forms before plant uptake. The potential for nutrient fixation or environmental pollution occurs for soybean as well, with an estimated 118, 19, and 48 lb $ac^{-1}$, respectively, of N, $P_2O_5$, and $K_2O$ uptake required after the initiation of pod-filling (Bender et al., 2015).

In our initial studies using fertigation in 2014, we observed that even when water from irrigation is not needed, corn yields can be increased by 30 bushels per acre and soybean yields by 5 bushels per acre by better timing nutrient availability with plant needs. The importance of supplying nutrients at key growth stages may be more crucial for intensively managed corn and soybean production systems where other factors such as germplasm, pest control, plant density, and row spacing have been optimized. This project is designed to be forward-looking and assess how drip irrigation and fertigation might be used in the future to increase corn and soybean yields while also improving nutrient use efficiency.

**WORK PLAN**

***Site characteristics and cultural practices***

Experiments were conducted at Champaign, IL using adjacent plots maintained in a corn-soybean rotation. The fertigation plots are situated on a Drummer Flanagan soil (silt loam, 3.6% organic matter; 21.1 meq/100g CEC, 5.8 pH, 22 ppm P, 99 ppm K, and 9.5 ppm S using Mehlich-3 extraction) that is tile-drained. The subsurface drip irrigation (SDI)- fertigation system was installed in the spring of 2014, and consists of 48 equally-sized zones that can be regulated for differential application of irrigation and fertigation. Using programmable controllers, each zone can precisely supply varying rates of nutrients at specific growth stages, according to plant needs. The dripper-lines are buried approximately 14 to 16 inches below the soil surface with 30-inch spacing between lines. The SDI system covers ten acres total, divided equally between corn and soybean. Plots were maintained weed- and disease-free.

***Research approach***

Five corn hybrids (Channel 214-45 Stx-RIB, Croplan 7087 VT2P, DeKalb C61-54, DeKalb C64-87, and NK 74R-3000GT) were planted on 28 April 2015. Using a precision plot planter (SeedPro 360, ALMACO, Nevada, IA), four population intensities were evaluated (32,000, 38,000, 44,000, and 50,000 plants per acre). Corn plots were four rows wide and 37.5 feet in length with 30 inch row spacing.

For soybean, 17 varieties were evaluated, representing four different seed brands (Asgrow, Hi-Soy, Syngenta, and Croplan) and maturity groups, ranging from 2.9 to 3.8 (AG2935, AG2933, AG3634, AG3832, HS31A32, HS39A42, S25-L9, S28-D3, S30-V6, S35-A5, S37-Z8, R2T2501, R2C2674, R2C3113, R2C3323, R2C3783, R2C3800). These were planted on 15 May 2015 to achieve a final population of approximately 160,000 plants/ acre in two- row plots 17.5 feet in length with 30 inch row spacing. The influence of foliar protection was evaluated by applying both an insecticide (Fastac ™ EC; alpha-cypermethrin) and fungicide (Priaxor ™; fluxapyroxad + pyraclostrobin) at the R3 stage (20 July 2015) at a rate of 4 oz per acre each using a backpack sprayer, and comparing to unsprayed plots.

***Nutrient application scheduling***

Irrigation was applied at soil water capacity of 40% to 60% according to soil probes. When natural precipitation was adequate for crop growth and development, water was applied only as a medium for the fertigation component of this study. Soluble nutrient sources were used with a low ability to form precipitates in solution (e.g., urea ammonium-nitrate, ammonium polyphosphate, ammonium thiosulfate, etc.). During periods of fertigation, a non-continuous (bulk) application of nutrients was applied during specific developmental stages (Tables 2 and 3). An equal parts application technique was used in which: 1) the system is brought to full pressure with water (for 1 hour), 2) nutrients are injected and applied (for 1 hour), then 3) the system is allowed to rinse with only irrigation water (for 1 hour). Using the values and the timing at which nutrients were acquired in a non-irrigated environment from Bender et al. (2013), a seasonal fertigation design was used to supply corn with an additional 113 lbs N, 120 lbs $P_2O_5$, 150 lbs $K_2O$, 12 lbs S and 16 oz Zn/ acre during seven fertigation periods between V5 to R5 in addition to a standard application of 180 lbs N /acre as urea at planting (Table 2). The control irrigation treatment also received 180 lbs N/ acre at planting.

**Table 2.** Nutrient application schedule for corn fertigation at Champaign, IL in 2015.

| Growth Stage | Application Amount/ Cumulative Total† | | | | |
|---|---|---|---|---|---|
| | N | $P_2O_5$ | $K_2O$ | S | Zn |
| | ---------------------------------- lbs/ acre | ---------------------------------- | | | oz/acre |
| V5 - V6 | 7/ 7 | 8/ 8 | 17/ 17 | 2/ 2 | 2/ 2 |
| V7 – V8 | 4/ 11 | 2/ 10 | 8/ 25 | 1/ 3 | 0/ 2 |
| V11 – V12 | 12/ 23 | 0/ 10 | 75/ 100 | 5/ 8 | 6/ 8 |
| V13 – V14 | 6/ 29 | 30/ 40 | 0/ 100 | 0/ 8 | 0/ 8 |
| VT – R1 | 24/ 53 | 20/ 60 | 25/ 125 | 2/ 10 | 2/ 10 |
| R2 – R3 | 20/ 73 | 20/ 80 | 15/ 140 | 1/ 11 | 2/ 12 |
| R4 – R5 | 40/ 113 | 40/ 120 | 10/ 150 | 1/ 12 | 4/ 16 |

† In addition to 180 lbs N/ acre at planting.

The schedule for soybean nutrient fertigation was based largely upon soybean nutrient uptake curves (Bender et al., 2015) and recommendations for soybean fertigation by Bar (2004). A total of 75 lb N, 55 lb $P_2O_5$, 150 lb $K_2O$, 25 lb S, and 18 oz Zn per acre was applied through fertigation. Nitrogen fertigation included an early starter application with an additional 50 lb N supplied to assist grain development during seed-filling. Supply of other macronutrients, including P and K, was by incremental applications throughout vegetative and reproductive growth (Table 3).

**Table 3.** Nutrient application schedule for soybean fertigation at Champaign, IL in 2015.

| Growth Stage | Application Amount/ Cumulative Total | | | | |
|---|---|---|---|---|---|
| | N | $P_2O_5$ | $K_2O$ | S | Zn |
| | ---------------------------------- lbs/ acre | | | ---------------------------------- | oz/acre |
| V3 | 25/ 25 | 5/ 5 | 35/ 35 | 3/ 3 | 3/ 3 |
| V7 | 0/ 25 | 10/ 15 | 35/ 70 | 4/ 7 | 3/ 6 |
| R2 | 0/ 25 | 10/ 25 | 35/ 105 | 4/ 11 | 3/ 9 |
| R4 | 0/ 25 | 10/ 35 | 35/ 140 | 4/ 15 | 3/ 12 |
| R5 | 25/ 50 | 10/ 45 | 10/ 150 | 5/ 20 | 3/ 15 |
| R6 | 25/ 75 | 10/ 55 | 0/ 150 | 5/ 25 | 3/ 18 |

***Measured Parameters***

Soil samples were obtained from plot areas prior to planting to confirm that fertility levels are uniform across the site. Daily air and soil temperatures, precipitation, irrigation, and soil moisture were monitored throughout the growing season. At physiological maturity, whole corn plant biomass and nutrient accumulation was measured from six- plant subsamples to estimate the recovery efficiency of applied nutrients. Plant nutrient contents were analyzed by A & L Great Lakes Laboratories, Inc. (Fort Wayne, IN) and by Ward Laboratories, Inc. (Kearney, NE). Yield for corn was obtained using a plot combine on the center two rows of each plot, and adjusted to 15% grain moisture concentration, and for soybean, yield was obtained from both rows of the plot and adjusted to 13% grain moisture concentration. Experimental units were arranged in a split- plot RCB design, for corn with six blocks, and for soybean with four blocks. For both crops, the main plot was irrigation system with two levels: irrigated, and fertigated. In corn, the split- plot was population, while for soybean it was foliar protection, with hybrid/variety randomly assigned within each treatment block. Hybrid/ variety, irrigation system, and population/foliar protection were considered fixed effects, while block and interactions with blocks were considered random effects. Measured parameters were analyzed using the PROC MIXED procedure of SAS (Version 8, SAS Institute, Cary, NC) and means were separated using Fisher's protected LSD test at the 0.10 level of significance.

## RESULTS

***Weather***

Environmental conditions during 2015 generally were warm and wet in the spring to early summer, and drier and cooler the remainder of the season, with little other weather-induced stress (Table 4). As a result, record yields were recorded for corn and soybean at the local, state, regional, and/or national level. Consequently, irrigation water was only required during the reproductive stages of both corn and soybean (Table 5). Irrigated fields in 2015 produced similar yields to dryland fields (data not shown).

**Table 4.** Temperature and precipitation during the production season at Champaign, IL in 2015 compared to the 30-year average.

| | **Precipitation (in)** | | **Temperature (°F)** | |
|---|---|---|---|---|
| **Month** | **2015** | **30-Year Average** | **2015** | **30-Year Average** |
| April | 3.1 | 3.6 | 54 | 52 |
| May | 5.6 | 4.9 | 67 | 63 |
| June | 8.4 | 4.3 | 72 | 72 |
| July | 2.8 | 4.7 | 73 | 75 |
| August | 2.7 | 3.9 | 71 | 73 |
| September | 5.9 | 3.1 | 71 | 66 |

**Table 5.** Amount of water supplied using a subsurface drip irrigation system at various corn and soybean growth stages at Champaign, IL in 2015. Irrigation was applied at soil water capacity of 40% to 60% according to soil probes to both irrigated and fertigated treatments.

| | | **Growth Stage** | |
|---|---|---|---|
| **Date** | **Irrigation (cm)** | **Corn** | **Soybean** |
| July 21 | 0.7 | R2 | R3 |
| August 4 | 1.0 | R3 | R4 |
| August 18 | 1.1 | R5 | R5 |
| August 26 | 1.0 | R5 | R6 |

***Corn Fertigation Trial***

When averaged over the five corn hybrids, the irrigated treatment produced yields of 194 bu/ acre (Table 6). This is slightly less than the county- wide average for 2015 of 216 bu/ acre, possibly due to this SDI- fertigation system being installed the previous year and disturbing the soil, or due to hybrid selection. Fertigation significantly increased corn yields by approximately 52 bu/ acre (27%), regardless of population (Table 6). While there was a trend for greater corn yields with increasing population in the irrigated treatment, fertigation maximized yields even at the lowest planting population (Table 6).

**Table 6.** Corn yield response to population, fertigation, and the difference of fertigation over irrigation at Champaign, IL in 2015. Values are averaged over five hybrids and six replications. All treatments were balanced for water supply, and received a base application of 180 lbs N/ acre at planting.

| Population | Irrigated | Fertigated | Difference (Δ) |
|---|---|---|---|
| Plants/ acre | ----------------------- bushels/ acre ----------------------- | | |
| 32,000 | 190 | 243 | +53* |
| 38,000 | 191 | 247 | +56* |
| 44,000 | 197 | 248 | +51* |
| 50,000 | 196 | 245 | +49* |
| Average | 194 | 246 | +52* |

* Fertigated significantly different from Irrigated at the 0.05 probability level.

Fertigation increased individual corn hybrid's yields by 34 to 69 bu/ acre, equivalent to yield boosts of 17% to almost 40%, when averaged over all planting populations (Table 7). This finding may indicate that some hybrids are more suited to fertigation and can take advantage of the increased nutrient supply to produce greater yields.

**Table 7.** Corn yield response to hybrid, fertigation, and the difference of fertigation over irrigation at Champaign, IL in 2015. Values are averaged over four populations and six replications. All treatments were balanced for water supply, and received a base application of 180 lbs N/ acre at planting.

| Hybrid | Irrigated | Fertigated | Difference (Δ) |
|---|---|---|---|
| | ----------------------- bushels/ acre ----------------------- | | |
| 214-45STXRIB | 204 | 238 | +34* |
| 7087VT2P | 179 | 248 | +69* |
| DKC61-54 | 181 | 225 | +44* |
| DKC64-87 | 201 | 257 | +56* |
| N74R-3000GT | 204 | 260 | +56* |
| Average | 194 | 246 | +52* |

* Fertigated significantly different from Irrigated at the 0.05 probability level.

The increased yield in fertigated corn corresponded to an increase in the accumulation of the fertigated nutrients (Table 8). We calculated nutrient recovery as the increase in plant content of the fertigated plants minus the nutrient amount in irrigated plants divided by the amount of the nutrient supplied by fertigation. Nutrients are taken up preferentially, with 65% of the fertigated N accumulated, but only 25% of the fertigated $P_2O_5$ being accumulated. Complete (100%) fertigated nutrient recovery was not expected, as soil microorganisms also may accumulate these nutrients. However, further studies to determine the optimal timing or rate of these nutrients may be necessary to achieve the most efficient fertigation system.

**Table 8.** Corn whole plant nutrient uptake response to fertigation, the difference of fertigation over irrigation, and nutrient recovery efficiency at physiological maturity for plants grown at Champaign, IL in 2015. Values are averaged over five hybrids, four populations and six replications. All treatments were balanced for water supply, and received a base application of 180 lbs N/ acre at planting. Fertigated plants received an additional 113-120-150-12S-1Zn (lbs/ acre) compared to irrigated plants.

| Nutrient element | Irrigated | Fertigated | Difference (Δ) | Recovery |
|---|---|---|---|---|
| | ----------------------- Nutrient (lbs/ acre) ----------------------- | | | % |
| N | 137 | 210 | +73* | 65 |
| $P_2O_5$ | 59 | 89 | +30* | 25 |
| $K_2O$ | 130 | 177 | +47* | 31 |
| S | 12.8 | 17.4 | +4.6* | 38 |

* Fertigated significantly different from Irrigated at the 0.05 probability level.

***Soybean Fertigation Trial***

Fertigation significantly increased soybean yields by 8 bu/ acre when averaged over all 17 varieties evaluated (Table 9). Adding foliar protection to either irrigated or fertigated soybean boosted yields an additional 2 to 4 bushels/ acre (Table 9). The greatest yields were produced when soybean received both fertigation and foliar protection (Table 9). Similar to corn, there was a wide range in yield response to fertigation among soybean varieties.

**Table 9.** Soybean yield response to fertigation and foliar protection at Champaign, IL in 2015. Values are the average of 17 commercial soybean varieties with relative maturities ranging from 2.5 to 3.9 and four replications. Fertigated plants received 75-55-150-25S-1Zn (lbs/ acre) compared to irrigated plants. Foliar protection included an insecticide and fungicide applied at the R3 growth stage.

| System | Foliar Protection | Average | Range |
|---|---|---|---|
| | | bushels/ acre | |
| Irrigated | None | 70.5 | 57 – 80 |
| Irrigated | Foliar Protection | 74.7 | 59 – 83 |
| Fertigation | None | 78.6 | 68 – 85 |
| Fertigation | Foliar Protection | 80.6 | 70 – 89 |

* Least significant difference ($P \leq 0.10$) for foliar protection within a culture system is 0.75.

The range in yield response to the fertigation and foliar protection treatments can be observed when focusing in on a subset of the soybean varieties with a range of relative maturities within one company (Table 10). There was a general trend for the longer season soybean varieties to have greater yields. In the shorter season varieties (S25-L9 and S28-D3), there was a greater yield increase due to fertigation than foliar protection, approximately 13 versus 4 bu/ acre increase, respectively (Table 10). In contrast, the fuller season varieties (S35-A5 and S37-Z8) had average yield increases of approximately 5 bu/acre with either fertigation or foliar additions, and these increases tended to be additive (Table 10). The variation in yield responses of different soybean varieties to fertigation or foliar protection highlights the importance of soybean variety selection.

**Table 10.** The interaction of fertigation, foliar protection, and relative maturity on soybean yield grown at Champaign, IL with four replications. Fertigated plants received 75-55-150-25S-1Zn (lbs/ acre) compared to irrigated plants. Foliar protection included an insecticide and fungicide applied at the R3 growth stage.

| | | Variety (Relative Maturity) | | | | |
|---|---|---|---|---|---|---|
| System | Foliar Protection | S25-L9 (2.5) | S28-D3 (2.8) | S30-V6 (3.0) | S35-A5 (3.5) | S37-Z8 (3.7) |
| | | ----------------------- bushels/ acre ----------------------- | | | | |
| Irrigated | None | 59.3 | 57.8 | 67.0 | 75.6 | 72.6 |
| Irrigated | Foliar Protection | 59.1 | 67.8 | 70.9 | 82.4 | 78.9 |
| Fertigation | None | 70.1 | 74.8 | 68.7 | 83.1 | 76.4 |
| Fertigation | Foliar Protection | 72.7 | 78.4 | 69.5 | 89.0 | 80.1 |

* Least significant difference ($P \leq 0.10$) for variety, irrigation by variety, and foliar protection are 2.9, 7.2, and 0.75, respectively.

**CONCLUSIONS**

Using a subsurface drip irrigation system to precisely deliver fertilizer to the root zone successfully increased yields in both corn and soybean in central IL in 2015, in a season without the need for irrigation. Applying fertigation throughout the growing season increased yields, on average, by 52 bu/ acre for corn, and 8 bu/ acre for soybean, with maximum yield increases up to 30% to 40%, depending on variety or hybrid. Typically, a greater planting population is necessary for increasing yields, however, fertigation enabled corn to maximize yield even at a population of 32,000 plants/ acre. Soybean yield was increased both by fertigation and foliar protection, however, the magnitude of response was dependent upon genotype. These hybrid and variety differences in response to fertigation suggest a need for characterization of optimal genetics for enhanced nutrient use and additional yield improvement

**ACKNOWLEDGEMENTS**

The authors would like to acknowledge the generous support of numerous partners that helped make this research possible, including the Fluid Fertilizer Foundation, A & L Great Lakes Laboratories, BASF, John Deere, Mosaic, Monsanto, Netafim, Syngenta, Ward Laboratories, Inc., and Winfield Solutions.

**REFERENCES**

Bar, I. 2004. Irrigation and Fertigation Recommendations for Soybeans. Netafim USA. Fresno, CA. http://www.netafimusa.com/files/literature/agriculture/other-literature/crop-applications/A103-Soybean-Crop-Crop-Recommendation.pdf. (accessed 29 Dec 2012).

Bender, R.R., J.W. Haegele, and F.E. Below. 2015. Nutrient uptake, partitioning, and remobilization in modern soybean varieties. Agron J. 107:563-573.

Bender, R.R., J.W. Haegele, M.L. Ruffo, and F.E. Below. 2013. Nutrient uptake, partitioning, and remobilization in modern, transgenic insect-protected maize hybrids. Agron J. 105:161-170.

Fixen, P.E., T.W. Bruulsema, T.L. Jensen, R.L. Mikkelsen, T.S. Murrell, S.B. Phillips et al. 2010. The fertility of North American soils, 2010. Better Crops 94(4):6–8.

Hartz, T.K. and G.J. Hochmuth. 1996. Fertility management of drip-irrigated vegetables. Hortic. Technol. 6(3):168-172.

Lamm, F.R. and T.P. Trooien. 2003. Subsurface drip irrigation for corn production: a review of 10 years of research in Kansas. Irrig. Sci. 22:195-200.

Netafim. 2010. Manual for corn production using sub-surface drip irrigation. Netafim USA. Fresno, CA. http://www.netafimusa.com/files/literature/agriculture/other-literature/crop-applications/Corn-Manual.pdf. (accessed 15 Sept. 2015).

Ruffo, M.L., L.F. Gentry, A.S. Henninger, J.R. Seebauer, and F.E. Below. 2015. Evaluating management factor contributions to reduce corn yield gaps. Agron. J. 107:495-505.

USDA-NASS. 2015a. Quick Stats: Corn, Grain, Irrigated, Chemigation – Treated, Measured in Acres. USDA Natl. Agric. Statistics Serv. http://quickstats.nass.usda.gov (accessed 15 Sept 2015).

USDA-NASS. 2015b. Quick Stats: Soybeans, Irrigated, Chemigation – Treated, Measured in Acres. USDA Natl. Agric. Statistics Serv. http://quickstats.nass.usda.gov (accessed 15 Sept 2015).