EFFICIENT MANAGEMENT OF WATER AND NUTRIENT RESOURCES: ASSESSING THE POTENTIAL FOR DRIP IRRIGATION AND FERTIGATION (year 3 of 3)

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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. In 2016, nutrient availability timing was investigated, comparing rainfed plots receiving all nutrients at pre-plant, versus fertigated plots with half of the nutrients supplied at preplant, and the other half distributed throughout the growing season to obtain conditions for more efficient fertilizer use. When averaged across five corn hybrids and four planting populations, when half of the nitrogen (N), phosphorus (P), and potassium (K) was supplied by fertigation after the V5 growth stage in 2016, yields were similar to those obtained by preplant application in 2015, with the advantage of less potential nutrient runoff and loss. However, the split application of nutrients in 2016 decreased yields by about 53 bu /acre compared to the all-preplant control, with hybrid selection influencing yield changes by 32 bu/ acre. Increasing the plant population from 32,000 to 50,000 plants/ acre did not alter yields under either fertility system. The 2016 findings highlight that adequate nutrient availability is needed upfront in corn, and that delaying half of the fertilization until after the V5 stage by fertigation may lead to less nutrient loss, but may hinder maximum corn growth and yield.

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 2016 National Corn Growers Contest winners all exceeding 300 bushels per acre, and almost 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. 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 root mass 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, sulfur (S), and zinc (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 soil concentrations of P, K, S, and Zn reported recently by IPNI (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 element. 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, many 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.

MATERIALS AND METHODS

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 Association 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 (Croplan 8621 VT2P, Croplan 7087 VT2P, DeKalb C61-54, DeKalb C64-87, and NK 74R-3000GT) were planted on 21 May 2016. 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.

Nutrient applications

Half of the plots received a preplant broadcast application of 180 lbs N/ acre as urea, plus 100 lbs P_2O_5/ acre as Microessentials SZ (MESZ, The Mosaic Company), plus 100 lbs K_2O / acre as Aspire (The Mosaic Company) on 15 May 2016. The remaining plots received half of the above rates as preplant, then equilibrated with the remaining 90 lbs N, 50 lbs P_2O_5, 50 lbs K_2O / acre during seven fertigation periods between V5 to R5 (Table 2). The values and the timing at which nutrients were acquired in a non-irrigated environment from Bender et al. (2013), was the basis for the fertigation design (Table 2). 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 (Table 2). 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).

Table 2. Nutrient application schedule for corn fertigation at Champaign, IL in 2016.

	Application Amount/ Cumulative Total†		
Growth Stage	N	P_2O_5	K_2O
	------------------------ lbs/ acre -----------------------		
V5 - V6	45/ 45	0/ 0	0/ 0
V7 – V8	9/ 54	0/ 0	10/ 10
V11 – V12	9/ 63	10/ 10	15/ 25
V13 – V14	9/ 72	10/ 20	10/ 35
VT – R1	5/ 77	0/ 20	10/ 45
R2 – R3	5/ 82	10/ 30	5/ 50
R4 – R5	8/ 90	20/ 50	0/ 50

† In addition to 90 lbs N, 50 lbs P_2O_5, 50 lbs K_2O per acre at planting.

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. Yield for corn was obtained on 16 October 2016 using a plot combine on the center two rows of each plot, and adjusted to 15% grain moisture concentration. Experimental units were arranged in a split- plot RCB design with six blocks. The main plot was fertilization design with two levels: 100% preplant fertilizer and rainfed only, versus 50% preplant fertilizer: 50% fertigated. The split- plot was population, with hybrid/variety randomly assigned within each treatment block. Hybrid, fertilization/irrigation system, and population 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 AND DISCUSSION

2014 and 2015

In 2014, due to a wet spring, the SDI system was completed behind schedule, and the corn crop wasn't planted until 15 June 2014. Four hybrids were evaluated at populations ranging from 24,000 to 48,000 plants/ acre. A control treatment of 180 lbs N/ acre applied at V4 was compared to a fertigation system of an additional 80 lbs N, 0 lbs P2O5, 70 lbs K_2O, and 14 lbs S per acre applied between the V6 and R2 plant growth stages. With up to 44% of the fertigated nutrients recovered in the aboveground biomass, yields were increased about 10% over the irrigated control.

In 2015, more timely planting of five corn hybrids occurred on 28 April, with populations ranging from 32,000 to 50,000 plants per acre evaluated. An irrigated control received 180 lbs N/ acre at planting, although, due to abundant rainfall, only minimal irrigation was necessary during the season. The SDI system supplied an additional 113 lbs N, 120 lbs P_2O_5, 150 lbs K_2O, 12 lbs S and 16 oz Zn per acre during seven fertigation periods between V5 to R5 in addition to a standard application of 180 lbs N /acre as urea at planting. When averaged over the hybrids, fertigation increased yields by 52 bu/ acre, to 246 bu/ acre, over the irrigated control. 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. All hybrids had increased yields in response to fertigation, varying from 49 to 56 bushels/ acre.

2016

The initial studies in 2014 and 2015 provided a greater level of nutrients via fertigation, which resulted in greater yields. Therefore, in 2016, to investigate the potential for nutrient efficiency of fertigation, the objective was to provide the same total level of nutrients, 180 lbs N 100 lbs P_2O_5, 100 lbs K_2O/ acre, to both fertigated and unfertigated corn, using fertigation to spread out the timing of nutrient availability commensurate with plant nutrient uptake. Compared to an all- upfront- preplant fertilized non- irrigated control, fertigated plots received half of the nutrient supply preplant, the other half between V5 and R5 (Table 2).

The 2016 production year experienced near-ideal growing conditions in Champaign, IL with average temperatures and timely, adequate rainfall throughout the growing season (Table 3). As a result, corn in this region experienced little weather- induced heat or moisture stress, and near-record yields were chronicled for corn at the local, state, regional, and/or national level. The fertigation system used the equivalent of 17” of water, similar to the May- August natural precipitation at Champaign, IL (Table 3).

Table 3. Temperature and precipitation during the production season at Champaign, IL in 2016 compared to the 30-year average. Data obtained from the Illinois State Water Survey.

Month	Precipitation (in)		Temperature (°F)	
	2016	**30-Year Average**	**2016**	**30-Year Average**
April	3.8	3.6	53	52
May	4.7	4.9	62	63
June	5.7	4.3	74	72
July	4.4	4.7	75	75
August	4.1	3.9	75	73
September	5.5	3.1	70	66

When averaged over the five corn hybrids, the 100% preplant rainfed control produced yields of 247 bu/ acre (Table 4). In contrast, in 2016, the 50% preplant: 50% delayed fertigation resulted in a 52 bu/ acre decrease in yield. Planting population did not change the overall results of either fertility program (Table 4). Notably, the 100% rainfed yields were similar to the fertigated yields of 2015, using less fertilizer.

Table 4. Corn yield response to population, fertigation, and the difference of fertigation over 100% preplant fertilization at Champaign, IL in 2016. Values are averaged over five hybrids and six replications. All treatments received a total application of 180-100-100 lbs/acre of N- P_2O_5- and K_2O.

Population	100% preplant Rainfed	50% preplant: 50% Fertigated	Difference
Plants/ acre	----------------------- bushels/ acre -----------------------		
32,000	246	195	-51*
38,000	249	195	-54*
44,000	244	195	-49*
50,000	250	195	-55*
Average	247	195	-52*

* Fertigated significantly different from 100% preplant at the 0.10 probability level.

Individual corn hybrid's yields varied by 25 to 26 bu/ acre in both fertility scenarios, but there were varietal differences (Table 5). The greatest yields in the 100% preplant control plots were produced by 7087VT2P and N74R-3000GT, while the greatest yields in the delayed fertigation were produced by DKC64-87 and 8621VT2PRIB (Table 5). These yield decreases were due to 10% decreases in both kernel number and kernel weight (data not shown). Decreases in kernel number may be due to plant stresses before pollination. Potentially, the delay in nitrogen availability from fertilization in combination with the depth of the SDI system below the root zone, led to an early nutrient deficiency that was unrecoverable. However, these findings also indicate that some hybrids are more suited to fertigation and can better take advantage of the timed nutrient supply to produce greater yields with more efficient nutrient use.

Table 5. Corn yield response to hybrid, fertigation, and the difference of 50% fertigation over 100% preplant fertilization at Champaign, IL in 2016. Values are averaged over four populations and six replications. All treatments received a total application of 180-100-100 lbs/acre of N-P_2O_5- and K_2O.

Hybrid	100% preplant Rainfed	50% preplant: 50% Fertigated	Difference
	------------------------ bushels/ acre	------------------------	
7087VT2P	258	197	-61*
8621VT2PRIB	244	200	-44*
DKC61-54	232	191	-41*
DKC64-87	248	205	-43*
N74R-3000GT	253	180	-73*
Average	247	195	-52*

* Fertigated significantly different from 100% preplant at the 0.10 probability level.

CONCLUSIONS

Using a subsurface drip irrigation system to precisely deliver supplemental fertilizer to the root zone successfully increased yields in both corn and soybean in central IL in both 2015 and 2016, by 52 bu/ acre for corn depending on the hybrid. Supplying only half of the fertilizer preplant in 2016 led to yield losses, even when supplying the remainder throughout the growing season via fertigation. Typically, a greater planting population is necessary for increasing yields, however, the weather in all three years (2014-2016) enabled corn to maximize yield even at a population of 32,000 plants/ acre. Fertigation by SDI resulted in hybrid and variety yield differences, which suggests a need for characterization of optimal genetics and optimal nutrient supply scheduling for enhanced nutrient use and additional yield improvement.

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