Enhanced Efficiency Fertilizer Effects in Michigan Sugarbeet Production

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ABSTRACT

Spring weather variability and early planting dates increase the opportunity for leaching, denitrification, and volatilization leading to nitrogen (N) losses in non-irrigated sugarbeet production systems. Enhanced efficiency fertilizers (EEF) may provide greater flexibility for spring N management programs by lengthening the potential application period while reducing nutrient loss and increasing availability. Field trials were conducted from 2013-2015 near Richville, MI to study the effects of EEF in comparison to standard N programs utilized commercially in sugarbeet production. The use of EEF products and blended polymer-coated urea (PCU) applied with urea did not improve root yield or quality but also did not inhibit N uptake or plant development. At the N rates used in this study, EEF products applied pre-emergence reduced stand loss compared to urea alone. In-furrow applications of ammonium polyphosphate increased spring growth and canopy development but did not impact root yield or quality and increased stand loss even when applied at recommended rates compared to no in-furrow application. Due to rainfall variability, fertilizer technologies designed to reduce N losses under either wet or dry conditions may not consistently offer positive returns but rather targeted usage for impaired watersheds or known field regions of greater N loss potential may be appropriate.

Additional Key Words: nitrogen, enhanced efficiency fertilizer, polymer-coated urea, in-furrow, agronomic efficiency

Abbreviations: EEF = enhanced efficiency fertilizers, PCU = polymer-coated urea, AE = agronomic efficiency

Michigan sugarbeet production is focused on 61,155 hectares of non-irrigated land within the Great Lakes watershed basin (NASS, 2015a). Due to several technological advancements, mean sugarbeet yields have increased from 38.5 Mg ha^{-1} (1990-95) to 62.0 Mg ha^{-1} (2010-15) (Poindexter, 2014; NASS, 2015b). In 2010, Michigan Sugar Company began an initiative to increase beet quality with a company goal of 19% sugar (Flegenheimer, 2010). To accomplish increases in beet quality and maintain or improve root yield, management practices including refined N management strategies were one consideration. Due to intensified Great Lakes water quality concerns and increased variability in spring and summer weather, growers continue to pursue N fertilizer strategies that may improve beet quality and simultaneously promote environmental sustainability.

In dryland production systems such as Michigan, little residual N overwinters in the soil for spring plant uptake. Much of the sugarbeet crop has N applied pre- or at-plant with some growers splitting applications to include side-dress at or near the 2-4 leaf stage. Sufficient but not excessive amounts of N are critical to optimize sugarbeet root yield, quality, and economics. Sub-optimal N rates reduce root yield and sucrose per acre while over-application decreases sucrose concentration, increases impurities, and increases environmental concerns (Draycott, 1993; Hergert, 2010). To reduce the number of passes through a field during the season, producers have shown interest in one-pass spring N applications and stale seedbed (i.e., spring planting with no other soil disturbance) approaches to N management

Enhanced efficiency fertilizers (EEF) are intended to reduce nutrient loss and increase plant nutrient availability thus improving both environmental and economic efficiencies (www.tfi.org, accessed 23 May, 2017). Two categories of N-focused EEFs include 1) slow and controlled release N, and 2) N extenders and additives. Polymer-coated urea (PCU) is one example of a controlled-release N product intended to extend the activity of urea over a longer time period to more closely synchronize with crop N uptake. Environmentally Smart Nitrogen (ESN, Agrium Inc., Calgary, Alberta, Canada) is the most widely used PCU with the rate of N release controlled by temperature, moisture, and polymer thickness (Wilson et al, 2009; Schwab and Murdock, 2010). Advantages of PCU to sugarbeet growth and quality may include longer N availability with fewer applications and decreased volatilization and leaching losses (Dave et al., 1999). Negative attributes of PCU in sugarbeet production may also include longer N availability as N available later in the season can reduce beet quality, increased cost compared to soluble N sources, little N immediately available following application, and weather impacts on release characteristics as lack of soil moisture would inhibit release while moist soil conditions may hasten release (Fujinuma et al., 2009; Guertal, 2009). The second category of EEFs includes urease and nitrification inhibitors both of which are intended to delay specific modes of N transformation. Urease inhibitors (UI) delay ammonia volatilization from surface-applied urea and may improve the functionality of urea-based fertilizers (Upadhyay, 2012). However, UIs begin to lose effectiveness 10-14 days after application and will still require sufficient precipitation (>1.3 cm) to incorporate N into the soil (Watson, 2005; Olson-Rutz et al., 2009). Nitrification inhibitors (NI) inhibit the conversion of ammonium to nitrate by disrupting the activity of nitrifying bacteria in the soil or by inhibiting enzymes within nitrification bacteria (Draycott and Christenson, 2003). Allowing N to remain in ammonium form reduces the risk of leaching and groundwater contamination while maintaining greater levels of available N in the upper soil profile (Frame and Reiter, 2013). Depending on soil pH, moisture, and temperature, NIs can delay the conversion of ammonium to nitrate from 4-10 weeks (Nelson and Huber, 2001). Potential benefits of EEFs are appealing to growers, but little research has been conducted on sugarbeet production and concerns persist over longer N availability negatively impacting sugarbeet quality, storage, and processing.

Sugarbeets are more sensitive to fertilizer placement than other rotational field crops. Current optimal N guidelines in Michigan for growing sugarbeet following corn (*Zea mays* L.) or wheat (*Triticum aestivum* L.) suggest a total of 179 kg N ha^{-1} with 45 kg N ha^{-1} of this total applied in a 5 cm x 5 cm band at planting (Steinke and Chomas, 2014). Nitrogen application may be accomplished through a combination of pre-plant, at-plant, in-furrow, or sidedress applications. Decreased plant populations have been observed with pre-plant N applications > 112-135 kg N ha^{-1} (personal observation). To promote early plant growth and provide nutrients to developing roots, Michigan growers occasionally place fertilizer with sugarbeet seed at planting (e.g., in-furrow or pop-up). Salt rates (i.e., $N+K_2O$) for these applications in sugarbeet are limited to < 5.6 kg ha^{-1} otherwise delayed seedling emergence and uneven stands may occur as has been observed in other field crops (Niehues et al., 2004). Urease inhibitors have been used in small grains production to protect against seed injury and may allow greater rates of N to be safely applied with seed at planting (Grant, 2004). Enhanced efficiency fertilizers may give growers the opportunity to safely increase N application rates with less risk of stand loss and fewer applications but data on sugarbeet are limited.

The objectives of this study were to 1) evaluate multiple controlled-release and soluble N blending ratios on sugarbeet yield and quality, total N concentration and greenness, and agronomic efficiency of applied N fertilizer, and 2) determine if EEFs affect root yield and quality, plant population and canopy coverage, and total plant N accumulation as compared to the current recommended Michigan grower N practices.

MATERIALS AND METHODS

Field trials were conducted from 2013-2015 at the Saginaw Valley Research and Extension Center near Richville, MI on a Tappan-Londo loam (fine-loamy, mixed, active, calcareous, mesic Typic Epiaquoll). The site is located in northeastern MI on non-irrigated, tile-drained conditions representative of production areas throughout the region with a 30-yr mean annual temperature and precipitation of 8.7ºC and 84.6 cm, respectively. Fields were moldboard plowed following corn (Zea mays L.) harvest in the autumn. Soil samples were collected before planting to a depth of 20 cm, dried at 60ºC, and ground to pass through a 2 mm sieve. Soil characteristics over each study year included 7.8 to 8.0 pH, 32 to 41 mg kg^{-1} P (Bray-P1), 159 to 203 mg kg^{-1} K, and 27 g kg^{-1} soil organic matter. Residual spring soil N was measured to a depth of 60 cm in 30-cm increments and averaged 21 to 25 kg N ha^{-1}. Two herbicide and four fungicide applications were used to minimize weed and disease incidence each year. Environmental data were recorded throughout the growing season and obtained from Enviro-weather (http://www.agweather.geo.msu.edu/mawn/, Michigan State University, East Lansing, MI).

Experimental Procedures for PCU Blending Study (2013-14)

Individual plots measured 4.5 m x 10.7 m long (six 76-cm rows) and were arranged as a randomized complete block with four replications. Six treatments consisted of an untreated check and five N blending ratios (%PCU: %urea) of 100:0, 75:25, 50:50, 25:75, and 0:100. The source of PCU was ESN® (44N-0P-0K, Agrium Inc., Calgary, Alberta, Canada). Treatments received 45 kg N as urea ammonium nitrate (UAN, 28N-0P-0K), 23 kg P_2O_5, 56 kg K_2O, and 2.2 kg Mn ha^{-1} applied in a subsurface band 5 cm to the side and 5 cm below the furrow with total N applications of 179 kg N ha^{-1}. The untreated check only received the 23 kg P_2O_5, 56 kg K_2O, and 2.2 kg Mn ha^{-1} at planting. All treatments containing PCU were applied pre-plant incorporated the day of planting. To reduce seedling injury from excessive saltation in the root zone, the 100% soluble N treatment was applied side-dress to 2-4 leaf sugarbeet as this is also the practice that controlled-release N sources were intended to replace.

Plots were planted on 2 May 2013 and 6 May 2014 using 'Crystal RR059' (ACH Seeds Inc., Eden Prairie, MN) at a rate of one seed every 10.8 cm. The uppermost fully developed and extended leaf and petiole from 25 plants $plot^{-1}$ were collected at the 6-8 and 12-14 leaf growth stages. Tissue samples were dried at 60°C, mechanically ground to pass through a 1-mm mesh screen, and analyzed for total N using a micro-Kjeldahl digestion method and colorimetric analysis with a Lachat rapid flow injector autoanalyzer (Nelson and Sommers, 1973; Bremner, 1996). Changes in plant N status as measured by plant greenness during the season were determined relative to a sufficiently fertilized (i.e., 269 kg N ha^{-1}) in-field reference plot utilizing chlorophyll readings collected with a Minolta SPAD 502 chlorophyll meter at the 6-8 and 12-14 leaf growth stages (Spectrum Technologies, Inc., Aurora, IL). Due to factors other than N (e.g., variety, growth stage) affecting leaf greenness, a relative greenness index was established using the SPAD measurements (Piekielek et al., 1995). The greenness index was calculated from the mean SPAD reading from each treatment divided by the mean SPAD reading from the non-N limiting in-field reference strips. Agronomic efficiency (AE) of N fertilizer was calculated to measure the effect of blending ratio on yield at the same N rate. The AE was calculated by subtracting root yield of the untreated control from the root yield of a treatment and dividing by the N rate of the treatment (Wortmann et al., 2011). Sugarbeets from the center two rows of each plot were harvested on 18 October 2013 and 16 October 2014 with a mechanical harvester and weighed. Root subsamples (10 roots plot^{-1}) were collected from each plot and analyzed for sugar and purity components including recoverable sucrose (kg Mg^{-1} and kg ha^{-1}), sucrose concentration, and extraction percentage at the Michigan Sugar Company laboratory (Bay City, MI).

Experimental Procedures for EEF Study (2014-2015)

Individual plots measured 4.5 m by 10.7 m long (six 76-cm rows). Six treatments and an untreated check were arranged in a randomized complete block design with four replications. All treatments, other than the check, received 45 kg N ha^{-1} as UAN applied in a subsurface band 5 cm to the side and 5 cm below the furrow with total N applications of 179 kg N ha^{-1}. Treatments consisted of urea (46N-0P-0K) applied pre-emergence, urea applied pre-emergence with a urease inhibitor (Agrotain®, Koch Agronomic Services, Wichita, KS), urea applied pre-emergence with a urease and nitrification inhibitor (SUPERU®, Koch Agronomic Services, Wichita, KS), a 75:25 blending ratio of PCU:urea applied pre-emergence (ESN®, Agrium Inc., Calgary, Alberta, Canada), ammonium polyphosphate (10N-34P-0K) applied in-furrow at 4 kg N ha^{-1} with remaining N side-dressed at 2-4 leaf sugarbeet, and UAN side-dressed at 2-4 leaf sugarbeet.

Plots were planted on 6 May 2014 and 17 April 2015 using 'Crystal RR059' (ACH Seeds Inc., Eden Prairie, MN) at a rate of one seed every 10.8 cm. Plant emergence was counted at 10-20 and 20-30 days after planting in addition to pre-harvest from 16.3 m^{-2} of the inner two rows. To determine percent ground coverage, digital images from each plot were taken weekly between the 2-4 leaf stage until canopy closure (SigmaScan Pro version 5.0, Systat Software, Inc., San Jose, CA) (Steinke et al., 2011). At harvest beet tops were collected from 3 m of row, dried at 60°C, and a subsample analyzed for total N. Four beet roots were randomly collected at harvest, washed, weighed, and sliced to collect pulp for total N analysis (Nelson and Sommers, 1973; Bremner, 1996). Sugarbeets from the center two rows of each plot were harvested on 16 October 2014 and 8 October 2015 with a mechanical harvester and weighed. Root subsamples (10 roots plot^{-1}) were collected from each plot and analyzed for sugar and purity components including recoverable sucrose (kg Mg^{-1} and kg ha^{-1}), sucrose concentration, and extraction percentage at the Michigan Sugar Company laboratory (Bay City, MI).

Statistical Analysis

Data were analyzed for treatment significance using the GLIMMIX procedure in SAS (SAS Institute, 2012). Year and treatment were designated as fixed effects and replication as a random effect. Data were analyzed separately after being determined to be significantly different by year ($P \leq 0.05$). To verify a response to N application, Dunnett's test was used to compare the untreated check relative to all treatments receiving N application (Dunnett, 1955). Normality of residuals was checked using the UNIVARIATE procedure in SAS ($P \leq 0.05$). Root yield data in 2015 were normalized using a Log 10 transformation with de-transformed means presented. Treatment means were compared using Fisher's protected LSD when ANOVA resulted in a significant F value ($P \leq 0.10$). Correlations of sucrose concentrations and recoverable sucrose ha^{-1} with root yield were analyzed using PROC CORR in SAS.

RESULTS AND DISCUSSION

Growing Conditions

Total precipitation in the 2013 and 2015 growing seasons (April – September) was 20-23% less than the 30-yr mean but near the average in 2014 (Table 1). Precipitation totals in April 2013 and 2014 were 11.3 and 2.6 cm above average, respectively, delaying planting until May while below average April 2015 precipitation allowed for an April

Table 1. Growing season (April – September) and 30-yr mean precipitation and temperature data for Richville, MI, 2013-2015.

	Precipitation†				**Air temperatures**			
Month	**2013**	**2014**	**2015**	**30-yr avg.‡**	**2013**	**2014**	**2015**	**30-yr avg.**
	-----------------cm-----------------				-----------------°C-----------------			
Apr.	18.8	10.1	5.0	7.5	6.0	7.4	7.4	7.5
May	8.7	7.8	7.3	8.7	16.0	14.3	15.5	13.3
Jun.	4.4	7.0	6.8	10.0	19.1	20.2	18.5	18.9
Jul.	5.2	10.6	5.6	9.3	21.3	19.0	20.9	21.1
Aug.	4.7	9.9	10.0	8.6	19.5	19.7	20.0	19.8
Sept.	1.5	7.7	6.7	9.8	15.5	15.5	18.5	16.0
Total	43.3	53.1	41.4	53.9				

†Precipitation and air temperatures were collected from Michigan Automated Weather Network (http://www.agweather.geo.msu.edu/mawn/).

‡30-yr means for precipitation and air temperatures came from NOAA (http://www.ncdc.noaa.gov/cdo-web/datatools/normals).

planting date. Decreased moisture early in the 2015 growing season appeared to delay sugarbeet emergence but stand counts were similar across each study year. July 2013 and 2015 rainfall totals were 40-42% below the 30-yr mean and may have limited sugarbeet growth as compared to 2014. Monthly precipitation totals were near or below average for 5, 3, and 5 of the 6 month growing season in 2013, 2014, and 2015, respectively. Air temperatures were 0.1 – 1.5ºC below normal to begin each growing season, but average temperatures during each growing seasons were within 0.7ºC of the 30-yr mean.

Effect of PCU Blending Ratio on Root Yield and Quality

Root yields averaged between 53.1 to 70.7 Mg ha^{-1} and 59.2 to 88.4 Mg ha^{-1} in 2013 and 2014, respectively. Fertilized treatments yielded greater than the non-treated check regardless of blending ratio. However, blending ratios of PCU:urea did not significantly affect root yield in either study year (Table 2). Similar root yields were obtained applying 100% PCU or 100% urea as the N source with yield reductions as the blending ratios approached a 50:50 mix. Due to increased, consistent precipitation throughout the 2014 growing season, overall root yields were greater across treatments. Despite the ability of PCU to limit the amount of soluble N available to the plant after N application, dry soil conditions and the lack of excessive individual rainfall events or low-lying areas to collect water likely limited leaching and denitrification N losses resulting in similar root yields across the continuum of blending ratios. Similar findings have been reported in corn where a 20% decrease in rainfall was attributed to a lack of yield differences between PCU and soluble N applications (Nash et al., 2012). A 20% reduction from 30-yr mean precipitation in 2013 and a lack of excessive individual rainfall events in 2014 resulted in a low risk of N losses over both years limiting the benefits of a PCU application in this study.

Root quality as indicated by recoverable sucrose per hectare was not affected by blending ratio in either study year while recoverable sucrose per Mg was significantly impacted by blending ratio in 2013 (Table 2). The decrease in extractable sucrose per Mg was not severe in 2013 and all treatments resulted in reduced sucrose compared to no N application. The 25:75 PCU:urea blend decreased sucrose concentration compared to both the 100% PCU and 100% urea treatments. However, grower concern that PCU application may inadvertently reduce root quality in dry years due to increased N availability later in the season appeared to be unsubstantiated in this study as both PCU and urea decreased beet quality similarly when compared to no N application. Results may differ in growing seasons receiving > 23% reduction from 30-yr mean precipitation levels as observed in the current study. The use of PCU or blending ratios of PCU and urea decreased sucrose concentration and extraction percentage similarly to urea individually. The 25:75 PCU:urea blend resulted in the lowest sucrose and extraction percentages over both study years. Regardless of

Table 2. Soluble and slow-release nitrogen blending ratio effects on sugarbeet recoverable sucrose (kg Mg^{-1} and kg ha^{-1}), root yield, sucrose concentration, and extraction percentage, Richville, MI, 2013-2014.

%PCU : %urea	Recoverable sucrose		Root yield	Sucrose	Extraction
2013					
	kg Mg^{-1}	kg ha^{-1}	Mg ha^{-1}	percent	percent
100:0	145 b[†]	10227 a	70.7 a	19.3 b	95.3 ab
75:25	141 bc	8844 a	63.0 a	19.2 b	94.4 cd
50:50	138 cd	8283 a	59.9 ab	18.9 bc	94.2 cd
25:75	134 d	8854 a	66.0 a	18.5 c	93.9 d
0:100	144 bc	9577 a	66.6 a	19.4 b	94.8 bc
0N	152 a	8085 a	53.1 b	20.0 a	95.9 a
2014					
	kg Mg^{-1}	kg ha^{-1}	Mg ha^{-1}	percent	percent
100:0	141 a	12440 a	88.4 a	18.5 a	96.3 cd
75:25	140 a	12250 a	87.4 a	18.4 a	96.4 bc
50:50	142 a	12149 a	85.7 a	18.5 a	96.6 b
25:75	140 a	11941 a	85.5 a	18.4 a	96.1 d
0:100	141 a	12836 a	91.2 a	18.5 a	96.3 cd
0N	146 a	8598 b	59.2 b	18.9 a	96.9 a

[†]Means in the same column followed by the same letters for each year are not significantly different at $P \leq 0.10$.

the ratio, PCU did not improve root quality under the conditions of this study and decreased sugarbeet quality similarly to urea.

Effect of PCU Blending Ratio on Tissue N, Relative Greenness, and Agronomic Efficiency of N Fertilizer

Six to eight leaf sugarbeet total N concentrations were significantly greater than untreated plots across both study years but few significant differences were observed across blending ratios (Table 3). The 50:50 blending ratio resulted in lower 6-8 leaf total N concentrations in 2013 but all treatments receiving N were > 4.1 percent. The lack of early season plant tissue N differences was not surprising as the 45 kg N ha^{-1} applied in a 5 x 5 cm band at planting was likely accessed by the plant soon after root emergence and facilitated sufficient early canopy growth as has been suggested for proper fertilizer N management in rainfed sugarbeet production systems (Hergert, 2010). The 12-

Table 3. PCU blending ratio effects on sugarbeet tissue total N concentration, relative greenness index, and agronomic efficiency (AE) of nitrogen fertilizer application, Richville, MI, 2013-2014.

%PCU : %urea	Total N†	Relative greenness index‡	Total N	Relative greenness index	Agronomic efficiency§
	---- 6-8 leaf sugarbeet -----		----12-14 leaf sugarbeet----		
			2013		
	percent		percent		kg root kg N^{-1}
100:0	4.6 a¶	0.99 a	4.4 a	1.00 a	98.3 a
75:25	4.8 a	0.98 a	4.1 ab	0.99 a	54.0 a
50:50	4.3 b	0.97 a	4.4 a	1.00 a	37.7 a
25:75	4.6 a	0.97 a	4.3 ab	0.98 a	71.9 a
0:100	4.6 a	1.00 a	3.9 b	1.00 a	75.0 a
0N	4.1 b	0.90 b	2.9 c	0.90 a	----
			2014		
	percent		percent		kg root kg N^{-1}
100:0	4.5 a	0.98 ab	2.7 a	0.99 a	163.2 a
75:25	4.5 a	0.95 b	3.3 a	1.00 a	157.1 a
50:50	4.4 a	1.00 ab	3.1 a	1.00 a	148.0 a
25:75	4.6 a	0.99 ab	2.9 a	1.00 a	146.9 a
0:100	4.7 a	1.00 a	3.2 a	1.00 a	178.7 a
0N	3.6 b	0.89 c	2.5 a	0.93 b	----

†Uppermost fully developed and extended leaf and petiole sampled from 25 plants per plot.

‡Relative greenness index calculated as chlorophyll meter reading from treatment of interest divided by chlorophyll meter reading from non-N limiting (i.e., 269 kg ha^{-1} N) treatment.

§Agronomic efficiency (AE) is calculated by subtracting yield of the control (no nitrogen) from the yield of the treatment and dividing by the nitrogen rate of the treatment.

¶Means in the same column followed by the same letters for each year are not significantly different at $P \leq 0.10$.

14 leaf (i.e., 8-10 weeks after planting in Michigan) sugarbeet total N concentrations significantly differed in 2013 but not in 2014 (Table 3). The 100% soluble N treatment maintained the lowest N concentration with greater but not statistically different values when 25-100% of the blending ratio comprised PCU. The greater tissue N concentration with any amount of PCU at the 12-14 leaf growth stage may indicate that the controlled release characteristic extended the release time and

availability of urea. A 104% increase in July 2014 precipitation as compared to July 2013 may explain the nearly 40% reduction in 12-14 leaf tissue N concentrations.

Relative greenness values at the 6-8 leaf growth stage ranged from 0.90 – 1.00 and 0.89 – 1.00 in 2013 and 2014, respectively (Table 3). All blending ratio values were significantly greater than 0 N at this growth stage across both study years indicating that without N application residual N levels were insufficient for early season growth as critical greenness levels of 0.93 have been used to delineate N-sufficiency from N-deficiency in corn (Piekielek et al., 1995). Although statistical differences did occur amongst blending ratios at the 6-8 leaf stage in 2014, relative greenness values at the 6-8 and 12-14 leaf growth stages were consistently > 0.95 across blending ratios and study years indicating N deficiencies did not exist from the treatments in this study. Despite no improvements in plant greenness by including PCU in the N blending ratio, data indicate that including a percentage of N as controlled release did not inhibit color development in sugarbeet plants under the conditions of this study.

In both study years, AE was not impacted by blending ratio indicating that the PCU did not improve the efficiency of the beet to utilize N for root production (Table 3). Root yield increase per kg of N fertilizer applied ranged from 37.7 to 98.3 and 146.9 to 178.7 in 2013 and 2014, respectively. Nearly 20% less rainfall in 2013 likely limited N movement and uptake reducing the AE of applied N fertilizer. The 135% increase in mean AE values in 2014 reinforces the importance of soil water in relation to N management as has been previously suggested (Cariolle and Duval, 2006; Burkhart and Stoner, 2008).

EEF Effect on Root Yield and Quality

Sugarbeet root yields ranged from 77.3 to 84.2 Mg ha^{-1} and from 51.7 to 65.8 Mg ha^{-1} in 2014 and 2015, respectively. All treatments yielded greater than the non-treated check regardless of N strategy. No differences in root yield occurred in 2014 but urea applied pre-emergence did reduce yield in 2015 compared to other N strategies (Table 4). Urease inhibitors delay the conversion of amide-N to ammonium for up to 14 days under dry soil conditions by inhibiting the hydrolytic action of the urease enzyme (Trenkel, 2010). Total accumulated rainfall in the 14 days following pre-emergence N applications in 2014 and 2015 was 7.4 and 1.1 cm, respectively. Dry soil conditions following 2015 pre-emergence N applications likely increased opportunities for surface N volatilization as the remaining EEF treatments applied pre-emergence resulted in a significant 18-24% yield increase. In-furrow application followed by sidedressed N did not increase yield compared to sidedressed N individually or the EEF treatments. Sidedressed N applications have increased yield in irrigated production or when excessive rainfall occurs between pre-plant and side-dress application timing, but the lack of excessive rainfall in this study limited early season leaching potential and thus benefits of side-

Table 4. Effects of sugarbeet nitrogen strategies on recoverable sucrose (kg Mg^{-1} and kg ha^{-1}), root yield, sucrose concentration, and extraction percentage, Richville, MI, 2014-2015.

N Strategy†	Recoverable sucrose		Root yield	Sucrose	Extraction
			2014		
	kg Mg^{-1}	kg ha^{-1}	Mg ha^{-1}	%	%
Pre-emergence	143 a‡	11243 a	78.8 a	18.7 a	96.6 a
UI§ pre-emergence	144 a	11897 a	82.7 a	18.8 a	96.6 a
UI & NI¶ pre-emergence	140 a	10918 a	77.9 a	18.4 a	96.4 a
PCU: urea pre-emergence (75:25)	143 a	10992 a	77.3 a	18.8 a	96.2 a
In-furrow followed by SD††	141 a	11624 a	82.7 a	18.5 a	96.4 a
SD	144 a	12142 a	84.2 a	18.9 a	96.5 a
Significance P>F	0.57	0.39	0.73	0.76	0.57
			2015		
	kg Mg^{-1}	kg ha^{-1}	Mg ha^{-1}	%	%
Pre-emergence	130 a	6740 b	51.7 b‡‡	17.4 a	95.6 a
UI pre-emergence	139 a	8443 a	61.0 a	18.3 a	96.2 a
UI & NI pre-emergence	140 a	8970 a	64.1 a	18.4 a	96.3 a
PCU: urea pre-emergence (75:25)	140 a	8999 a	64.3 a	18.4 a	96.3 a
In-furrow followed by SD	136 a	8213 a	60.0 a	18.1 a	95.9 a
SD	143 a	9373 a	65.8 a	18.7 a	96.3 a
Significance P>F	0.18	0.06	0.08	0.17	0.23

†All treatments received 45 kg N ha^{-1} applied as a 5 x 5 cm subsurface band at planting.

‡Values followed by the same lower case letter are not significantly different at $P \leq 0.10$.

§Urease inhibitor (UI)

¶Nitrification inhibitor (NI)

††Side-dressed (SD) at the 2-4 leaf stage on 29 May 2014 and 20 May 2015.

‡‡Means normalized using Log 10 transformation; de-transformed means presented.

dressed N. Data suggest growers may consider an EEF for pre-emergence N when dry soil conditions persist at planting time, but the quantity of precipitation received after planting will determine sugarbeet yield response.

Root quality as indicated by recoverable sucrose per Mg was not affected in either study year but recoverable sucrose per hectare was reduced by pre-emergence urea in 2015 (Table 4). The recoverable su-

Table 5. Impact of N strategies on sugarbeet plant population (plants 16.3 m^{-2}) at 15 – 30 days after planting, Richville, MI, 2014-2015.

	Plants 16.3 m^{-2}			
	2014		2015	
N Strategy[†]	**15 DAP**	**25 DAP**	**20 DAP**	**30 DAP**
Pre-emergence	127 c[‡]	133 c	83 b	86 c
UI[§] pre-emergence	152 b	145 bc	139 a	138 ab
UI & NI[¶] pre-emergence	168 a	160 a	149 a	144 ab
PCU: urea pre-emergence (75:25)	165 ab	159 ab	153 a	158 a
In-furrow followed by SD[††]	159 ab	157 ab	125 a	123 b
SD	167 a	160 a	154 a	151 ab
Significance P>F	<0.01	0.06	0.01	0.01

[†]All treatments received 45 kg N ha^{-1} applied as a 5 x 5 cm subsurface band at planting.
[‡]Values followed by the same lower case letter are not significantly different at $P \leq 0.10$.
§Urease inhibitor (UI)
¶Nitrification inhibitor (NI)
[††]Side-dressed (SD) at the 2-4 leaf stage on 29 May 2014 and 20 May 2015.

crose per hectare ranged from 6,740 to 9,373 kg ha^{-1} in 2015 with 23% less sucrose production using pre-emergence urea compared to the mean of all other N strategies. Significant, positive Pearson correlation coefficients (r) of 0.94 and 0.97 (2014 and 2015, respectively) between sucrose per hectare and root yield correspond to previous research showing that as root yield increased recoverable sucrose per hectare also increased (Campbell and Kern, 1983). Sucrose concentration and extraction percentages were not affected by EEF in this study and EEF impacted recoverable sucrose similar to in-furrow followed by side-dressed N and side-dressed N individually. Due to a lack of rainfall after planting, EEF did improve sucrose production in 2015 as compared to urea applied pre-emergence.

EEF Effect on Plant Population and Row Closure

Pre-emergence applied urea reduced plant population in 2014 and 2015 compared to other N strategies (Table 5). Populations were counted prior to side-dress N application timing allowing the individual side-dress treatment to remain unaffected by pre-plant N application. Stand reductions of 17 and 43% were noticed 25-30 days after planting (DAP) using pre-emergence urea as compared to side-dressed N in 2014 and 2015, respectively. The UI/NI combination and PCU/urea treatments appeared to moderate plant stand reductions

Table 6. Sugarbeet percent canopy coverage as affected by N management strategy at 23, 37, and 51 days after planting, Richville, MI, 2014.

N Strategy†	23 DAP	37 DAP	51 DAP
	----------	%	----------
Pre-emergence	1.5 bc‡	20.5 b	73.1 abc
UI§ pre-emergence	1.6 bc	21.4 b	72.3 bc
UI & NI¶ pre-emergence	1.4 c	19.4 b	67.1 c
PCU: urea pre-emergence (75:25)	1.8 b	20.3 b	76.4 ab
In-furrow followed by SD††	3.8 a	26.0 a	79.9 a
SD	1.6 bc	19.3 b	66.4 c
Significance P>F	<0.01	0.04	0.03

†All treatments received 45 kg N ha^{-1} applied as a 5 x 5 cm subsurface band at planting.

‡Values followed by the same lower case letter are not significantly different at $P \leq 0.10$.

§Urease inhibitor (UI)

¶Nitrification inhibitor (NI)

††Side-dressed (SD) at the 2-4 leaf stage on 29 May 2014 and 20 May 2015.

compared to untreated urea and had similar plant populations as side-dressed N in both study years (Table 5). The UI treatment individually reduced 15 DAP stand counts compared to remaining EEF treatments in 2014 but populations were similar in 2015. Limited rainfall (1.1 cm) within the first 14 days following 2015 pre-emergence N applications likely limited N dissolution and distribution throughout the upper soil profile leading to reduced plant populations. Due to the proximity of the in-furrow fertilizer to the sugarbeet seed and minimal rainfall, plant population was reduced 19% in 2015 compared to the individual side-dress N treatment. Despite applying less than recommended threshold amounts of N and K_2O in-furrow (i.e., < 5.6 kg ha^{-1}), lack of sufficient moisture following in-furrow nutrient applications can increase the osmotic pressure of the soil solution surrounding the seed, reduce water imbibition, and decrease plant population (Last et al., 1983). Under limited rainfall previous research has shown spring pre-plant N applications reduced plant populations but few establishment effects were observed when 2.8-4.0 cm rainfall occurred soon after planting (Last et al., 1983; Blumenthal, 2001). The time interval in Michigan between pre-plant and at-plant N applications can range from one day to several weeks. Data indicate that EEF may protect against seed injury and allow greater rates of N to be safely applied in a one-pass fertilizer program mitigating the risk of stand loss and eliminating post-plant N applications.

Canopy coverage was significant on 3 of 7 dates in 2014 but no differences were observed in 2015 (Table 6). Ammonium polyphosphate

Table 7. Total N accumulation of sugarbeet tops, roots, and tops plus roots (T&R) as influenced by N strategy, Richville, MI, 2014-2015.

N Strategy†	2014 Tops	2014 Roots	2014 T&R	2015 Tops	2015 Roots	2015 T&R
	kg N ha^{-1}					
Pre-emergence	101 c‡	94 a	195 a	62 a	71 a	145 a
UI§ pre-emergence	137 a	104 a	241 a	68 a	92 a	159 a
UI & NI¶ pre-emergence	123 ab	99 a	222 a	57 a	92 a	149 a
PCU: urea pre-emergence (75:25)	118 abc	98 a	216 a	68 a	99 a	167 a
In-furrow followed by SD††	99 c	104 a	203 a	58 a	92 a	150 a
SD	104 bc	103 a	207 a	60 a	94 a	154 a
Significance P>F	0.04	0.93	0.33	0.63	0.34	0.63

†All treatments received 45 kg N ha^{-1} applied as a 5 x 5 cm subsurface band at planting.

‡Values followed by the same lower case letter are not significantly different at $P \leq 0.10$.

§Urease inhibitor (UI)

¶Nitrification inhibitor (NI)

††Side-dressed (SD) at the 2-4 leaf stage on 29 May 2014 and 20 May 2015.

applied in-furrow increased canopy cover the quickest for a period lasting 23-37 DAP. At 23 DAP, the in-furrow fertilizer increased canopy coverage >100% relative to all other N strategies. As the growing season progressed, differences in canopy coverage diminished between N strategies but the in-furrow treatment maintained the greatest canopy coverage at 51 DAP. Despite residual soil nutrient levels exceeding critical values, moist, cool soil conditions in 2014 may have allowed the in-furrow application to stimulate early-season leaf and shoot growth thus enhancing canopy coverage. Although early canopy development and row closure can enhance light interception, photosynthesis, and maximize sucrose production and yield (Carter, 1987), the increased canopy coverage from the in-furrow strategy did not impact sugarbeet yield or quality with few differences observed among the remaining treatments.

EEF Effect on Top and Root N Accumulation

Enhanced efficiency fertilizer increased 2014 sugarbeet top N accumulation, but no significant impacts occurred on 2014 root N accumulation and 2015 top or root N accumulation (Table 7). Differences in 2014 top N accumulation corresponded to biomass differences as treatments with less biomass ha^{-1} at harvest resulted in decreased top

N accumulation (data not shown). A 46% decrease in 2015 biomass ha^{-1} corresponded with a similar decrease in top N accumulation as leaf area index has a direct relationship with N uptake (Scott and Jaggard, 1993). A 22% decrease in 2015 precipitation reduced top and root growth resulting in an overall 28% decrease in total top and root N accumulation than observed in 2014. Residual soil nitrate levels (0-30 cm) after harvest were not affected in either study year and ranged from 4.9 to 7.1 kg N ha^{-1} and from 4.6 to 6.7 kg N ha^{-1} in 2014 and 2015, respectively (data not shown). Despite increased top N accumulation using EEF in 1 of 2 years, there was no advantage to attaining greater vegetative N uptake regarding yield or sucrose production in this study.

CONCLUSIONS

Without N loss conditions, growers are unlikely to see a yield or quality benefit from EEF. The lack of excessive individual rainfall events or low-lying areas to collect water in these studies likely limited leaching and denitrification N losses and thus limited the usefulness of these products. While blending PCU with urea did not improve root yield or quality and decreased quality similar to urea alone, this practice also did not inhibit N uptake or plant development. Similarly, EEF products did not improve nor inhibit sugarbeet root yield and quality. With pre-emergence N, the use of EEF products may allow growers the opportunity to apply greater rates of N in a one-pass system while mitigating the risk of reduced plant populations by slowing the release of N into the soil. However, sugarbeet germination times will vary considerably under cool spring soil conditions and could extend beyond the stabilized N time period. Ammonium polyphosphate applied in-furrow stimulated early spring growth and canopy development but failed to elicit a root yield or sucrose response and increased stand loss when compared to side-dress N application alone. Due to rainfall variability, fertilizer technologies designed to reduce N losses and improve plant production may not consistently offer positive returns but targeted usage across impaired watersheds or regions of greater N loss potential may be more appropriate.

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