Predicting sugarbeet yield, quality, and N status in season using an active sensor

Sugarbeet processing efficiency depends on both root quantity and sugar quality—factors that are largely influenced by N fertilization. While inadequate N supply limits the total yield, excess N uptake affects the processing quality through decreased sucrose levels and increased impurities. Monitoring plant N status during the growing season provides one tool to improve N management in sugarbeet production systems.

While a number of indicators of N status have been developed and implemented in many sugarbeet-producing regions, no methods have gained widespread adoption in Michigan, which ranks third among all U.S. sugarbeet-producing states and accounts for about 15% of the total U.S. sugarbeet production. Testing is frequently used in Minnesota and North Dakota to adjust sugarbeet N fertilization rates and to identify fields with high residual NO₃ levels that would be unsuitable for sugarbeet production the following year. Because Michigan gets more winter precipitation and has more tile drainage, the tests are less viable in Michigan. Although preplant soil NO₃ testing has been shown to be an effective estimator of the optimal N rate for sugarbeet production, poor test reliability has been demonstrated under conditions of water stress or leaching. Petiole NO₃ levels may be an effective indicator of crop N status, but in-season NO₃ concentrations are not well related to sugarbeet yield or quality.

Recently, numerous investigations have explored the use of remotely sensed crop spectral data to understand growth characteristics and improve N management for several crops. Many of these studies have specifically reported on the use of active-light crop canopy reflectance sensors as a promising tool to improve N use efficiency by estimating N dynamics (e.g., N requirement) and yield potential for crops including corn and wheat. Active sensors emit light and detect reflectance from the crop canopy, typically in both the visible and near-infrared wavelengths so that vegetative indices can be computed. The normalized difference vegetative index (NDVI) is a proven measure of the total aboveground green biomass. The NDVI is a function of the difference in the reflectance characteristics of plant tissue in the red (660 ± 10 nm) and near-infrared (767 ± 15 nm) bandwidths.

The use of canopy reflectance and NDVI as an in-season assessment of sugarbeet yields and sugar production has the potential to be a valuable tool to assist in N management as well as harvest scheduling and prioritization. Yearly sugarbeet production is limited by suitable storage days and processing plant capacity. In this limited window, profitability is directly related to recoverable sucrose per root mass. The development of NDVI for the prediction of yield and quality during the growing season would be of value to producers and the industry.

Beyond in-season prediction of sugarbeet harvest components, NDVI has been used as a predictor of residual N deposited by the return of foliage (tops) to the field. The N content of sugarbeet tops left in the field is typically much greater than that removed by root harvest because sugarbeet roots contain only about 30% of the total N absorbed by the plant. The organic N in sugarbeet tops can mineral-
ize considerably by the spring following harvest and be a readily available N source for subsequent crops. Further understanding of the potential contribution of soil N from sugarbeet tops is important in managing system-wide N accountability.

To date, most published reports of sugarbeet NDVI data have been remotely sensed using passive sensing methods such as aerial and satellite imagery. These methods have been successfully used for the delineation of N “precision management zones.” Approximately 43% of the sugarbeet acreage under contract for the American Crystal Sugar Company in North Dakota and Minnesota used this type of zone management in 2009. The application of active sensors for the same or a similar purpose thus shows promise for sugarbeet N management.

A recent article in *Agronomy Journal* reports on a study investigating the applicability of active-sensor NDVI for the assessment of in-season sugarbeet N demand, in-season yield and quality prediction, and end-of-season sugarbeet top N content. The development of procedures to achieve these goals represents potential fertilizer input savings for producers, more accurate yield forecasting, and improved system-wide N accountability.

### Materials and methods

Field experiments were established in the principle sugarbeet-producing region of Michigan at three sites in 2006 and at four sites in 2007. Treatments included six N rates ranging from 0 to 200 lb N/ac. Nitrogen starter fertilizer was banded 2 inches to the side and 2 inches below the seed at planting for all N rates except the control treatment. Liquid urea–ammonium nitrate (28%) was then sidedress-injected between the rows in early June to complete the desired N rate for each treatment. One site in 2006 and two sites in 2007 did not receive starter fertilizer. At those sites, all N fertilizer was sidedressed.

Soil samples were collected at each site in each year, before fertilization, for initial site characterization of soil chemical properties (Table 1). Canopy NDVI was measured at several growing degree day (GDD) ranges throughout the season and again on the day of harvest using a Greenseeker (Trimble Navigation Ltd., Sunnyvale, CA) handheld, red-band optical sensor.

Aboveground biomass samples were obtained immediately after Greenseeker scanning on the day of harvest by manually removing all foliage from a portion of each of the center two rows of each plot. Biomass was measured as fresh weight and reported as dry matter following drying for at least 72 hours. Representative subsamples were ground, and total N analysis was conducted by the Dumas method using thermal conductance.

### Results and discussion

#### Root yield

Sugar beet yield was significantly affected by N rate within years and when averaged across all site-years. The year × N rate interaction was not significant, indicating that yield responded similarly to N rate each year of the study. Across sites and years, N-fertilized plots on average yielded 30% greater than plots with 0 N (Table 2). Yield was generally similar within the fertilized plots, with the exception that the most highly treated plots yielded greater than the lower treatments.

Comparison of the means of root yield response to fertilizer N rate showed that N rate was significant within individual site-years with the exception of Ithaca in 2007 (Table 2). Organic soils, such as those present at Ithaca, have been reported to mineralize N at higher levels and depress sugarbeet N yield response. Soil organic matter content at Ithaca was the highest of all of the study sites (Table 1). Generally, plots receiving even the least amount of N yielded greater than the control plots, and only a few differences in yield were noted among any of the fertilized plots. Thus, to determine the yield-maximizing N rate (YMNR), treatment means were used to develop yield response curves for each responsive site-year and across all site-years combined (Table 3).

Sugarbeet yields in 2006 were maximized with 85 to 119 lb N/ac for yields ranging from 20 to 31 tons/ac (Table 3), while the increased yields in 2007 resulted in YMNR values of 87 to 96 lb N/ac maximizing yields at 33 to 41 tons/ac. Because an evaluation of the NDVI relation-
Canopy NDVI was monitored throughout the season for assessment of the crop N status. Because not all plots were planted on the same date and sugarbeet growth varied by planting date and site-specific growing environments, the data collected were organized by GDDs, which were divided into four ranges in 2006 (450–650, 650–850, and 1,900–2,300) and five in 2007 (the same as 2006 with the additional sampling range of 2,300–2,600 GDD). These ranges approximated monthly sampling from emergence through harvest at individual site-years.

The NDVI tended to increase throughout the growing season as the sugarbeet canopy developed, particularly from readings before 1,200 GDD compared with those after. In 2006, in-season NDVI measurements were similar for all treatments except the control for NDVI collected between 650 and 1,400 GDD. Similar trends were observed in 2007, although differentiation between the control and other N treatments was evident at the first sampling period. Differences in NDVI measurements among treatments throughout the growing seasons confirmed visual observations of foliage color and biomass recorded at the field sites.

Although potential yield–N rate thresholds became seemingly detectable after 1,900 GDD in both years, the relatively low NDVI values and the lack of NDVI differentiation among fertilized N treatments early in the season (450–650 GDD in 2006) indicates that the use of active sensors for sugarbeet N fertilization decisions before 850 GDD may not be practical, particularly if small differences in canopy characteristics cannot be detected. Previous work has shown that leaf area index accounted for 99.8% of the variability in NDVI measurements in corn, highlighting the importance of sufficient leaf area for NDVI measurements. Early-season NDVI readings in particular are affected by soil background interference compared with later season readings, when crop canopies occupy a greater portion of the sensor’s field of vision. The low ratio of visible plant material to background soil may be a significant challenge in sensing sugarbeet canopies at early growth stages and in a timely enough fashion for corrective N management.

### In-season yield and quality prediction

When data were averaged across all site years, exponential response functions were found to best explain the relationship between NDVI and recoverable white sucrose per acre (RWSA). Although the model fit was significant for all sampling periods including the day of harvest, the strength of the relationship (as indicated by $R^2$) tended to be weakest for early-season sampling (450–650 GDD) and then increased during midseason sampling (1,200–2,300 GDD) before declining again after GDD 2300. This observed trend followed closely the visually observed trends of
sugarbeet canopy response to N rates during the growing seasons. The findings of this research thus indicate that NDVI can be used to predict the RWSA (and thus, yield, because yield is a factor in RWSA calculation) with relatively good accuracy in midseason, but the prediction of final sugarbeet yield is not as accurate early in the season.

Others have reported that sugarbeet canopy greenness measurements from multispectral optical sensors have strong relationships with sugarbeet yield ($R^2 = 0.64$) as early as 14.8 weeks after planting (around late July) but that earlier season measurements were not as predictive. Difficulties correlating early-season NDVI measurements with yield may be due to the final determination of yield occurring only later in the growing season.

Others have observed that sugarbeet leaf size did not differ between 0 and moderate rates of N addition until

<table>
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<th>Year</th>
<th>Location</th>
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<th>Model†</th>
<th>YMNR‡</th>
<th>Yield</th>
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† Selected model: Q, quadratic; QP, quadratic plateau; LP, linear plateau.
‡ YMNR, yield maximizing N rate: the N rate at which maximum yield occurred.
§ Root yield at Ithaca in 2007 was nonresponsive to N fertilizer.
Foliage nitrogen at harvest

Sensor NDVI readings on the day of harvest were strongly related to sugarbeet top total N across all sites and N rates (Fig. 1). These relationships indicate that optical sensors may be useful in determining N credits or delineating N zones for improving N management of a subsequent crop. The delineation of N management zones within a field based on sugarbeet top NDVI measurements has been successfully implemented for spring wheat crops following sugarbeets in the Upper Midwest Red River Valley, where as much as 27% of beet top N was recovered by a subsequent wheat crop.

The ability of sugarbeet top N to serve as an N credit for subsequent crops has been effective when based on visual observation or satellite imagery of canopy color. Current North Dakota recommendations for a previous crop credit following sugarbeet have been published, but other work suggests that more refinement of these recommendations to create more precise N credits may be possible.

The strong correlation of harvest NDVI with sugarbeet top N found in this study has not been consistently observed in other regions where sugarbeet N credits are applied to subsequent crops. Poorer relationships may result due to possible NDVI saturation when a full canopy exists. However, others have found that inclusion of canopy height as a factor can improve the correlation. The poorer correlation observed by others may also be attributed to broader measurement resolution. In this study, 81,000 readings were collected per 2.47 ac. This increased resolution that is possible with ground-based active sensors may decrease the need for canopy height measurements.

Conclusions

This study investigated the use of an optical sensor for assessment of in-season sugarbeet foliage N status, root yield and root quality prediction, and total N in foliage on the day of harvest during a two-year period. Normalized difference vegetative indices were measured based on GDD intervals each season and on the day of harvest with a red-band active sensor. The NDVI readings were useful for differentiating the root yield of control treatments from fertilized plots but were not able to identify a potential yield response threshold until late in the season. Midseason GDD and harvest NDVI values were strongly related to RWSA, and harvest NDVI was strongly related to sugarbeet foliage total N. Active sensing during the sugarbeet growing season shows promise as a means to estimate root yield and recoverable sugar in sugarbeet fields.

The results also indicate that the use of an active sensor to determine the NDVI on the day of sugarbeet harvest can be used as a tool for delineation of N management zones for the subsequent crop year by estimating the amount of residual N returned to the system as foliage. Further evaluation of this technology, particularly the determination of optimum data resolution, cultivar effects, and environmental influences on NDVI–canopy relationships, will be useful in establishing yield and quality thresholds and yield potential prediction equations using optical NDVI sensors for sugarbeet cropping systems.