EVALUATION OF THE GREENSEEKER ACTIVE SENSOR FOR SUGARBEET CROPPING SYSTEM NITROGEN MANAGEMENT

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Abstract

The application of adequate, non-excessive rates of N fertilizer to sugarbeets (*Beta vulgaris* L.) continues to increase in importance with rising fertilizer costs and industry transitions from yield-based payments to payments weighted toward crop quality. The objective of this study is to evaluate the use of an optical sensor for its potential in assessing in-season sugarbeet N status, in-season yield prediction, and total N in foliage on day of harvest. Six N fertilizer treatments, from 0 to 224 kg N ha^{-1}, were applied at four sites in Michigan in 2006 and 2007. Urea N fertilizer was banded at planting at 45 kg N ha^{-1}; 28% urea ammonium nitrate solution sidedress applications at the 4-leaf stage comprised the remainder of each N rate. Normalized difference vegetative indices (NDVI) were measured in mid-June, mid-July, mid-August and at harvest with a Greenseeker red-band active sensor. Total leaf biomass and root yield were determined at harvest, and root subsamples were collected for determination of sucrose content, clear juice purity, and amino N concentration. Growing season NDVI readings differentiated control treatments from fertilized plots, but were not useful for identifying a yield response threshold until late in the season. Prediction of recoverable white sucrose per area in July was strongly related to NDVI readings (R^2=0.89). End-of-season NDVI was strongly related to sugarbeet vegetation total N (R^2 = 0.88). Active sensing during the growing season shows promise as a means to estimate root yield and recoverable sugar in sugarbeet fields. Sensing on day of harvest may improve rotational N management by providing an indication of N return to the cropping system.

Introduction

Sugarbeet processing efficiency depends on both root quantity and sugar quality – factors that are largely influenced by N fertilization. While inadequate N supply limits total yield, excess N uptake affects the processing quality through decreased sucrose levels and increased impurities (Giles et al., 1975, Cattanach, 1993 , Shock et al., 2000). Considerable efforts have been made to develop indicators of sugarbeet N need.

Recently, measurement of the absorption/reflectance characteristics of foliage at specific wavelengths has been adopted for N status assessment in various crops. Optical sensing instrumentation can be used to calculate vegetative indices, which are indicators of a plant's photosynthetic potential and above ground, living biomass. Research efforts have focused on the use of active sensors as a tool to estimate N use efficiency, N requirement, and yield potential for crops including corn and wheat. (Martin et al., 2007; Girma et al., 2006; Teal et al., 2006)

An in-season assessment of sugarbeet yields would be a valuable tool to assist in 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 unit sugarbeet. Development of NDVI for prediction of sugarbeet yield and quality during the growing season would be of value to producers and industry. Remote sensing for in-season yield prediction has been successfully implemented in crops such as wheat (Teal et al., 2006) and soybean (Ma et al., 2001). Hoffmann and Blomberg (2003) had moderate success using aerial NDVI measurements to predict sugarbeet root yield, finding a significant relationship (R^2=0.47) between September NDVI and yield. Humburg et al. (2002) reported a relationship (R^2=0.80) between aerial NDVI and recoverable sucrose concentration in sugarbeet roots. Additionally, Humburg et al. (2006) found relationships ranging from R^2=0.25 to R^2=0.54 between NDVI obtained from Landsat7 data in mid-September and sugarbeet sucrose.

Increasing N fertilizer costs have recently prompted renewed interest in system-wide N accountability. Fifty to sixty percent of total sugarbeet N is located in top foliage (Giles et al., 1973). Organic N contained in sugarbeet foliage has been shown to mineralize considerably the spring following harvest. Franzen et al. (2000) found that 70-90% of sugarbeet residues are decomposed by mid-June of the following year. Moragham and Smith (1996) estimated 22 kg N ha^{-1} could be credited towards a subsequent wheat crop from yellow or light green sugarbeet tops at harvest and as much as 80 kg N ha^{-1} for dark green foliage. They found 1 kg of N in dark green tops in the fall was equivalent to about 0.5 kg N fertilizer for a following wheat crop, while 1 kg N in yellow canopies resulted in 0.25 kg N fertilizer N.

Based on the results of previous studies the use of active sensors during the sugarbeet growing season shows promise as a means to predict root yield and quality, and to improve rotational N management by providing an indication of N return to the cropping system. The objectives of this study are to determine the effect of N rate and residual N on sugarbeet yield and quality (i.e., sucrose content and clear juice purity) and to evaluate the applicability of a Greenseeker (NTech Industries Inc., Ukiah, CA) optical sensor for estimating sugar beet N requirement, root yield, and plant residual N (leaf N).

Materials and Methods

Field experiments were established at four sites in the principle sugarbeet producing region of Michigan in 2006 and 2007. Treatments included six N rates ranging from 0 to 224 kg N ha^{-1} in 45 kg N ha^{-1} increments. Nitrogen starter fertilizer at 45 kg N ha^{-1} as urea (46-0-0) was banded 5 cm x 5 cm at planting for all N rates except the 0 kg N ha^{-1} control treatment. Sidedress N as 28% UAN, comprising the remaining N rate, was injected between rows in early June. One site in 2006 and 2 sites in 2007 did not receive starter fertilizer. At those sites, all N fertilizer was applied at sidedress. Plots measured 4.6 by 12.2 meters and were arranged in a randomized complete block design with four replications. Plots were managed by the cooperating producer as part of the entire field, with the exception of N application and harvest. One site each year was on a university experiment farm and was managed similarly as the other sites following general production practices of the region. In 2006, one site was dropped from the study due to poor stand establishment.

Canopy NDVI was measured in mid-June, mid-July, mid-August and at harvest using a hand-held Greenseeker optical sensor. The Greenseeker sensor calculates NDVI based on absorption/reflectance characteristics of plant tissue in the red (650 ± 10 nm) and near-infrared (NIR, 770 ± 15 nm) bandwidths, and using the formula: NDVI = (NIR – Red) / (NIR + Red).

Above-ground biomass samples were obtained immediately following Greenseeker scanning on day of harvest by manually removing all foliage from 4.5 m of each of the center two rows of each plot. Total biomass was measured as fresh weight and dry matter following drying at 60° C. Representative subsamples were ground to pass through as 2 mm screen.

Root yield was determined by harvesting two row lengths of approximately 21 meters each. Subsamples of 10-15 roots were analyzed for sucrose, clear juice purity and amino N concentrations. Recoverable white sucrose as Mg ha^{-1} (RWSA), an economic parameter used for grower payments, was calculated from the following formula:

RWSA = yield * (((%sucrose * 18.4)-22)*(1-(60/%clear juice purity-3.5)))/0.4

SAS statistical procedures (SAS Institute, Cary, NC) were used for the preliminary analysis of all data. Analysis of variance was performed to determine differences in NDVI among fertilizer treatments and to determine the effects of N rate of sugar beet yield and quality. Root yield response to N was fit to linear-plateau, quadratic, or quadratic plateau models – the model with that best visually fit (when R^2 values were comparable) was used to determine the yield response at each site. When no model fit the data, mean separation was used to determine optimum N rate. Similar modeling efforts were attempted to determine relationships between NDVI readings and crop growth variables.

Summary

Sugarbeet root yield in 2006 was maximized at 69 Mg ha^{-1} with 97 kg N ha^{-1} at Saginaw and 62 Mg ha^{-1} with 132 kg N ha^{-1} at Tuscola (Table 1). Yield response at Huron did not fit any model tested, so the optimum N rate was determined as the lowest N rate in the highest t-grouping for yield as determined by analysis of variance. Thus, at the Huron site, the application of 45 kg N ha^{-1} resulted in similar yields as 90 and 225 kg N ha^{-1}, resulting in a mean root yield of 48 Mg ha^{-1}. Since an evaluation of NDVI relationship to multiple variables across combined sites was to be tested, yields were also averaged for all sites combined. Combining sites showed that a maximum root yield of 56 Mg ha^{-1} was achieved with 96 kg N ha^{-1}.

Canopy NDVI was monitored throughout the season for assessment of crop N status. In 2006, NDVI measurements were similar for all treatments except the control in June, July and August. Mean NDVI values in September were greater for the 180 and 225 kg N ha^{-1} treatments compared with the 0 and 45 kg N ha^{-1} treatments (Table 2). Similar trends were observed in 2007 (Table 3). The differences in NDVI measured with the Greenseeker in the latter part of the growing season confirmed visual observations recorded at the field sites. As the season progressed, differences in relative greenness of the sugarbeet canopy among N rate treatments became more pronounced.

NDVI tended to increase throughout the growing season as the sugarbeet canopy developed. The relatively low NDVI values and the lack of differentiation in NDVI among N treatments early in the season (June) is indicative that the use of active sensors for N management at that time may not be practical, particularly if small differences in canopy characteristics cannot be detected. Soil background reflectance has been found to significantly impact wavelength reflectance (Daughtry et al., 2000). 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 sensors field of vision (Freeman et al., 2007). High soil background reflectance may be a significant challenge in sensing sugarbeet biomass at early growth stages and in appropriate time for corrective N management. Improved relationships between NDVI and leaf N concentration from June to July in 2007 (data not shown) may be a result of increased canopy to soil ratios in the sensor field of vision.

When averaged across all sites, NDVI measurements in July were strongly related with RWSA (R^2=0.87, Fig. 1). RWSA includes components of both beet yield and root sucrose concentration. Industry payments are based upon these factors, making RWS an important gauge of total production. NDVI readings also showed a very strong relationship with root yield in July (R^2=0.87) and August (R^2=0.84) (data not shown). Optical sensors have been observed to have strong relationships with sugarbeet yield (R^2=0.64) as early as 14.8 weeks after planting (around late July) (Wiesler et al., 2002). These relationships were similar at 18.4 and 20.7 weeks after planting (late August through mid-September).

While yield relationships with mid-season NDVI remained similar at both July and August timings, RWS relationships with NDVI improved closer to harvest. This finding indicates that NDVI readings are able to predict root yield with relatively good accuracy in mid-season, but prediction of final sugarbeet quality is not as accurate early in the season. Teal et al. (2006) suggested that difficulties correlating early season NDVI measurements with yield may be due to final determination of yield occurring only later in the growing season.

Harvest NDVI was strongly related to sugarbeet top total N across all sites and N rates in 2006 (R^2=0.86, Fig. 2). Our results are similar to those seen by Franzen et al. (2003) who reported significant relationships between Greenseeker NDVI and total N content at harvest (eR^2=0.55). The relationship they found between NDVI and total N improved when canopy height was multiplied by NDVI (R^2=0.81).

Our results from 2006 indicate that delineation of N zones for subsequent crop N utilization using NDVI may be possible for Michigan sugarbeet cropping systems. This approach is similar to work by Franzen et at. (2005) using, among other tools, satellite imagery and aerial photography to construct N management zones.

Based upon results from 2006, the Greenseeker optical sensor holds potential for in-season sugarbeet yield and quality prediction and end-of-season top N return assessment. Yield data from 2007 was not yet available for this printing.

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Table 1. Sugarbeet root yield for 3 sites in Michigan in 2006.

N rate	Saginaw	Tuscola	Huron	Sites Combined
kg N ha^{-1}	---------------------------- Mg ha^{-1} ----------------------------			
0	50.0	28.0	30.0c	36.0
45	62.8	44.3	43.9ab	50.3
90	70.7	59.1	40.0bc	56.6
135	64.2	63.5	56.2a	61.3
180	69.6	55.3	34.6bc	53.1
225	70.5	45.4	45.1ab	53.7
Model	QP	Q	No fit	QP
Equation	$y = -0.002x^2 + 0.39x + 50$	$y = -0.002x^2 + 0.52x + 27$	--	y = -0.0022 + 0.42x + 36
YONR (kg N ha^{-1})	97	132	45	96
Y Max. (Mg ha^{-1})	69	62	48†	56
R^2	0.92	0.99	---	0.91

YONR: N rate needed to maximize root yield
Y_{YONR} : Root yield at the yield optimizing N rate
QP: Quadratic plateau; Q: quadratic
† Average of the 45, 135, and 225 kg N ha^{-1} treatments

Table 2. Mean Greenseeker NDVI measurements for 3 sites in 2006 in relation to N fertilizer rate and sampling time. Means labeled with same letter on a given date are not different as determined by LSD at α=0.05.

N rate	June	July	August	Harvest
kg N ha^{-1}	- - - - - - - - - - - - - - - NDVI - - - - - - - - - - - - - - -			
0	0.2049b	0.5545b	0.5099b	0.6787c
45	0.2567ab	0.7221a	0.6092a	0.6921c
90	0.2741a	0.7432a	0.6781a	0.7270bc
135	0.2628a	0.7242a	0.6828a	0.7348bc
180	0.2584a	0.7581a	0.6836a	0.7705ab
225	0.2572ab	0.7255a	0.6900a	0.7935a

Table 3. Mean Greenseeker NDVI measurements for 4 sites in 2007 in relation to N fertilizer rate and sampling time. Means labeled with same letter on a given date are not different as determined by LSD at α=0.05.

N rate	June	July	August	September
kg N ha^{-1}	- - - - - - - - - - - - - - -	- - NDVI - -	- - - - - - - - - - - - - - -	
0	0.4219b	0.6572b	0.6985c	0.6735d
45	0.4939a	0.6855b	0.7134c	0.6897d
90	0.4993a	0.7123a	0.7423b	0.7347c
135	0.4990a	0.7188a	0.7518ab	0.7596b
180	0.4896a	0.7226a	0.7691a	0.7782a
225	0.5000a	0.7188a	0.7652a	0.7954a

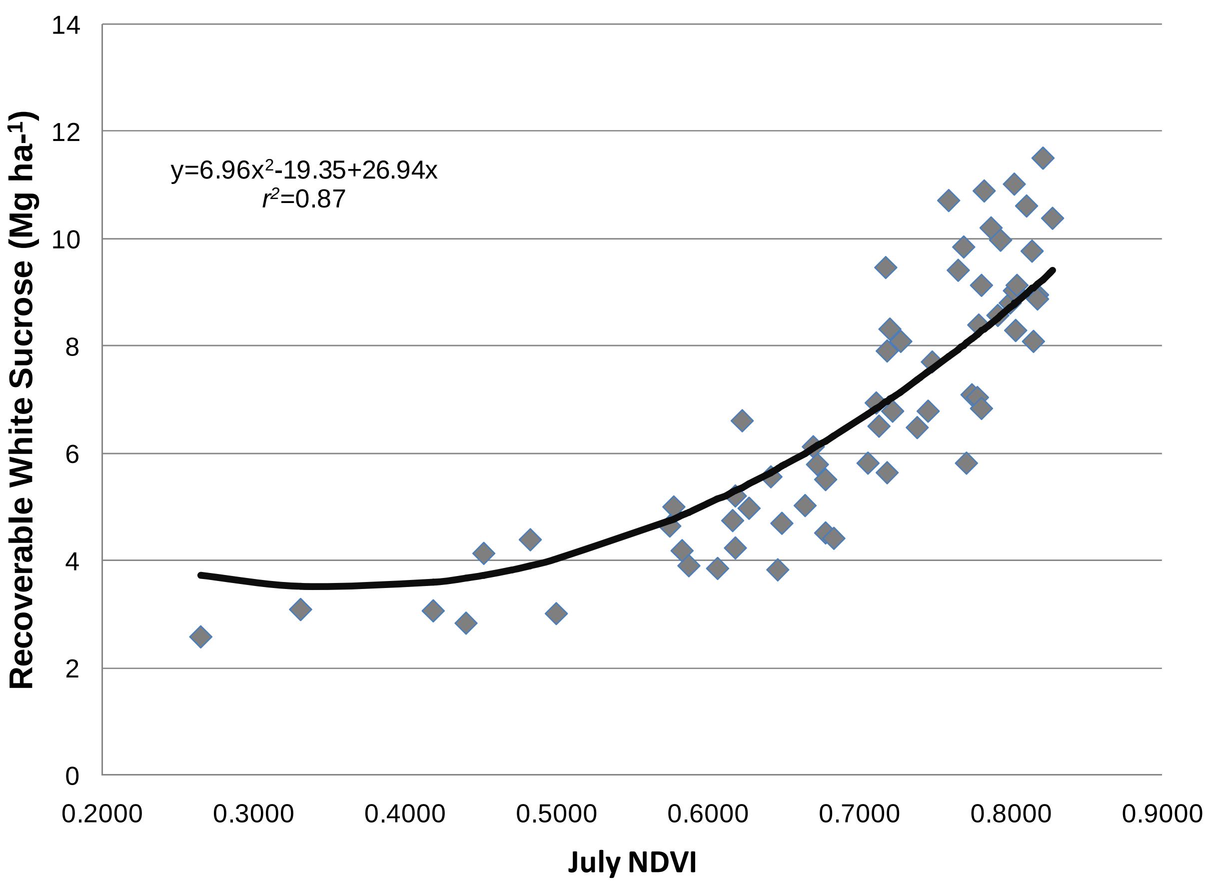

Figure 1. Recoverable white sucrose from sugarbeet roots relative to July NDVI measurements, averaged across 3 sites and multiple N treatments in Michigan in 2006.

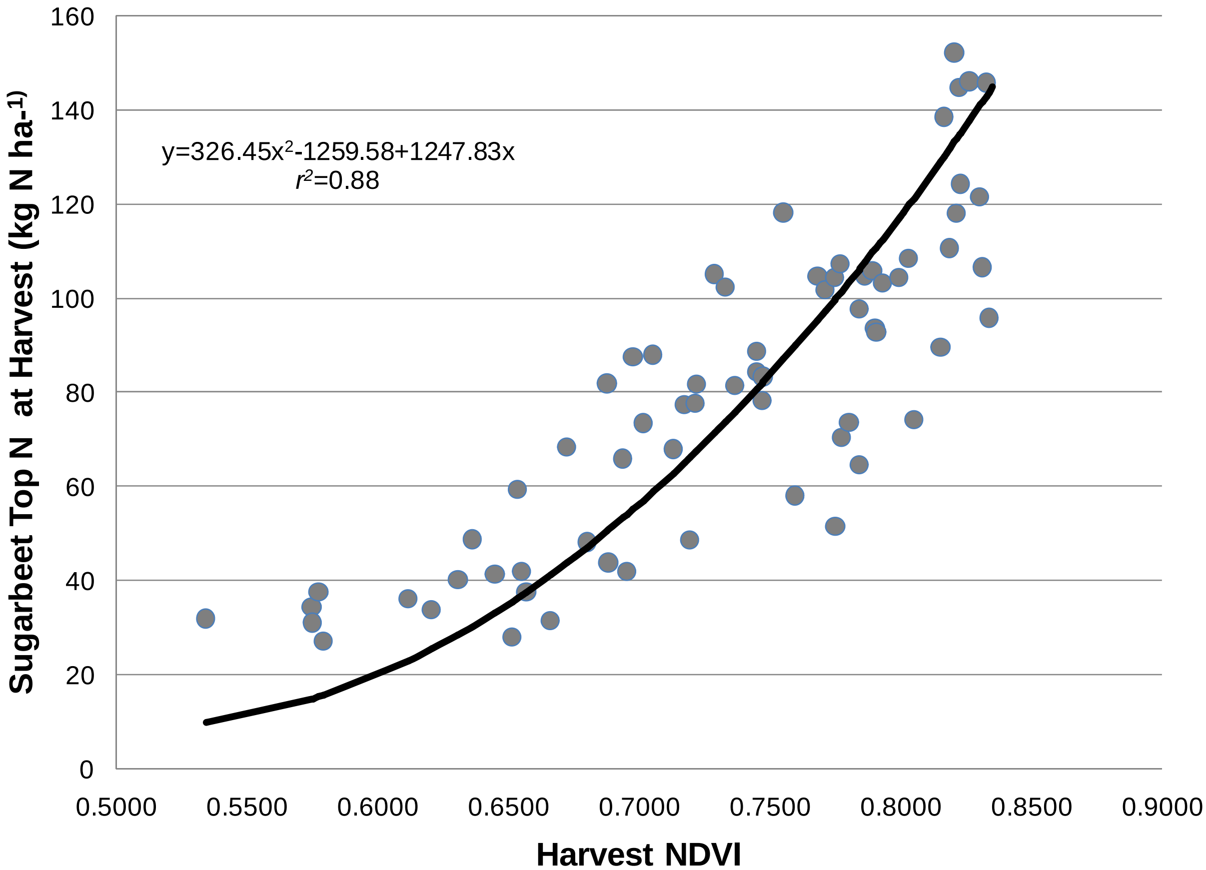

Figure 2. Total N measured in sugarbeet top foliage at harvest and harvest NDVI, averaged across 3 sites and multiple N treatments in Michigan in 2006.

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