# INTEGRATION OF ULTRASONIC AND ACTIVE CANOPY SENSORS TO ESTIMATE THE IN-SEASON NITROGEN CONTENT FOR CORN

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## Abstract

The objectives of this research were to: (i) determine the correlation between active canopy sensor (ACS) assessments of N status and ultrasonic sensor measurements of canopy height at several growth stages for corn receiving varying amounts of N, (ii) test the ability of both sensors to distinguish N-mediated differences in canopy development and (iii) test the integrated use of both sensors. This experiment was conducted with varying N rates in an existing long-term study and farmer's fields during 2008 and 2009. Plant height, canopy reflectance (NIR and green portions of the spectrum) and geographic position using a DGPS receiver were recorded during different phenological stages. Preliminary results showed that there are correlations between plant height (H) and chlorophyll index (CI), with correlation coefficients ranging from 0.68 to 0.98 and higher results corresponding to V10 through V13 growth stages. Both sensors were able to separate different N rates from V8 until V13 in 2008 but they didn't have the same ability for 2009. The integration of interaction CI x H did not increase the ability to identify different N rates.

## Introduction

Use of active canopy sensor (ACS) reflectance measurements of corn canopy N status to guide spatially variable in-season N applications has been proposed as a means for improving corn NUE and decreasing environmental contamination (Solari et al., 2008). Previous studies have shown that canopy chlorophyll content is correlated to biophysical parameters such as leaf area index and plant height (Freeman et al, 2007). Sui & Thomasson (2006) noted that crop spectral reflectance (via ACS) and plant height measurements (via ultrasonic sensor) were both correlated with crop N status. If plant height and vegetation indices, either individually or together, can be used to estimate N content during the corn growing season, the use of these sensors is one good option for in-season site-specific N application. The objectives of this research were to: (i) evaluate correlations between plant height (H) measurements using an ultrasonic sensor and reflectance using an ACS; (ii) test the ability of both sensors to distinguish N-mediated differences in canopy development and (iii) test the integration of both sensors in detecting different N rates.

## Material and Methods

The experiment was conducted in a long-term nitrogen study site located at the South Central Agriculture Laboratory (SCAL) of the University of Nebraska at Clay Center, and at four center pivot-irrigated sites on cooperating farmer's fields (HU, BR, RT) during 2008 and 2009. The platform used for sensor data collection at several growth stages of corn was a bicycle modified to support an optical sensor (Crop Circle, model ACS-210, measuring wavelengths of 590 and

880 nm), an ultrasonic sensor (Senix model TS30S1), a Trimble GeoXT GPS receiver and laptop computer. A distance of at least 2 ft was maintained between sensors and the top of the crop canopy throughout the season. In the long term N study at SCAL, plant height and canopy reflectance were recorded during several phenological stages (Table 1). The Chlorophyll Index (CI) (Gitelson, 2003) was calculated from spectral reflectance data. CI = (NIR/VIS) – 1, where NIR is near infrared at 880 nm and VIS is the visible band at 590 nm. Because of sidedress N application at the V10 growth stage in the farmers' fields in 2009, crop sensing was done at later stages (VT and R4) (Table 1).

Table 1. Corn phenological stages and N rates at experimental sites conducted during 2008 and 2009. SCAL at experimental station and HU, BR, RT at different farmer's fields.

| Year \ Sites | SCAL | HU | BR | RT |
|---|---|---|---|---|
| 2008 | V4, V5, V6, V8, V10 and V13<br>(N applied at planting, rates: 0, 67, 134, 268 lb/ac) | V7, V10 and V13<br>(N applied at planting, rates: 0, 31, 36, 63, 94, 125, 156, 188, 219 lb/ac) | ----- | ----- |
| 2009 | V6, V8, V10 and V13<br>(N applied at planting, rates: 0, 67, 134, 268 lb/ac)) | VT and R4<br>(N side-dressed during V 11, rates: 67, 89, 134, 179, 223 lb/ac) | VT and R4<br>(N side-dressed during V 11, rates: 67, 89, 134, 179, 223 lb/ac) | VT and R4<br>(N side-dressed during V 11, rates: 67, 89, 134, 179, 223 lb/ac) |

The data was filtered using Math Lab (The MathWorks, Inc., Natick, Massachusetts) and later processed and analyzed using ArcGIS (ESRI, Redlands, California). Pearson correlation coefficients and LSD tests were conducted using SAS (SAS Institute, Inc., Cary, North Carolina).

## Results and Discussion

Generally both years had good growing conditions. The 2008 growing season had more rain, which was well distributed, and there was little need for irrigation (Figure 1).

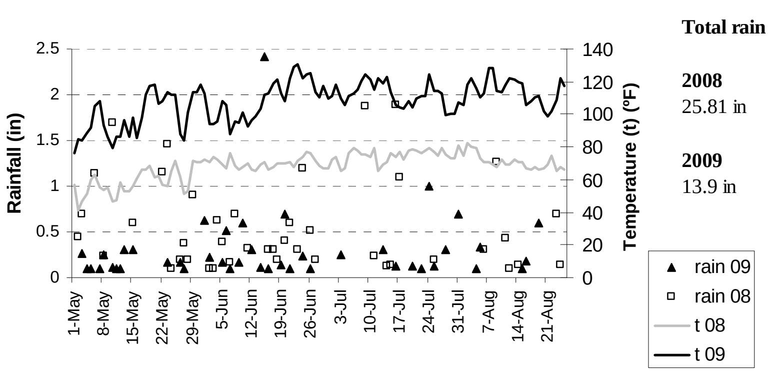


Figure 1. Daily rainfall (precipitation – inches) and temperature (ºF) for 2008 and 2009 growing seasons, South Central Agricultural Laboratory.

For the SCAL site in 2008, CI (averaged over N rates) increased steadily to the V8 growth stage, then tended to plateau (Figure 2). In 2009, CI increased until V10, then declined slightly. These results suggest that CI generally is maximized around V8. The trend in H was linear from V6 until V13.

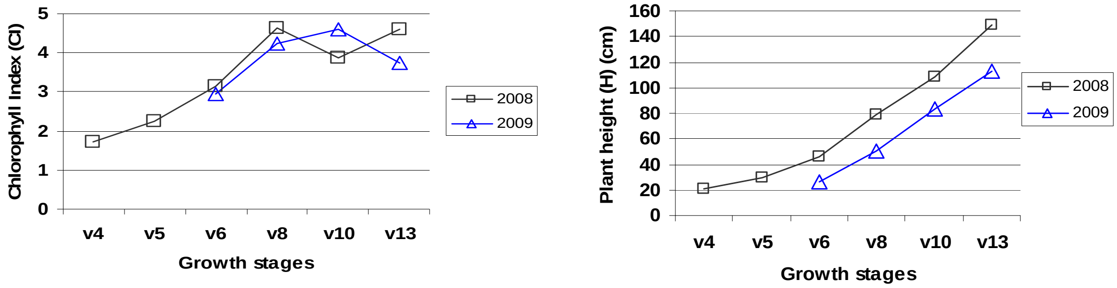


Figure 2. Average chlorophyll index and plant height in the small plots at SCAL

For the SCAL site there were significant correlations between CI and H in both years (Figure 3), CI and H were also significantly correlated with N rate between V10 and V13 growth stages both years. The correlations between HxN and CIxN were similar in 2008, but did not repeat for 2009 (Figure 3), suggesting that the soil N supply is greater early in the season in 2009 compared to 2008.

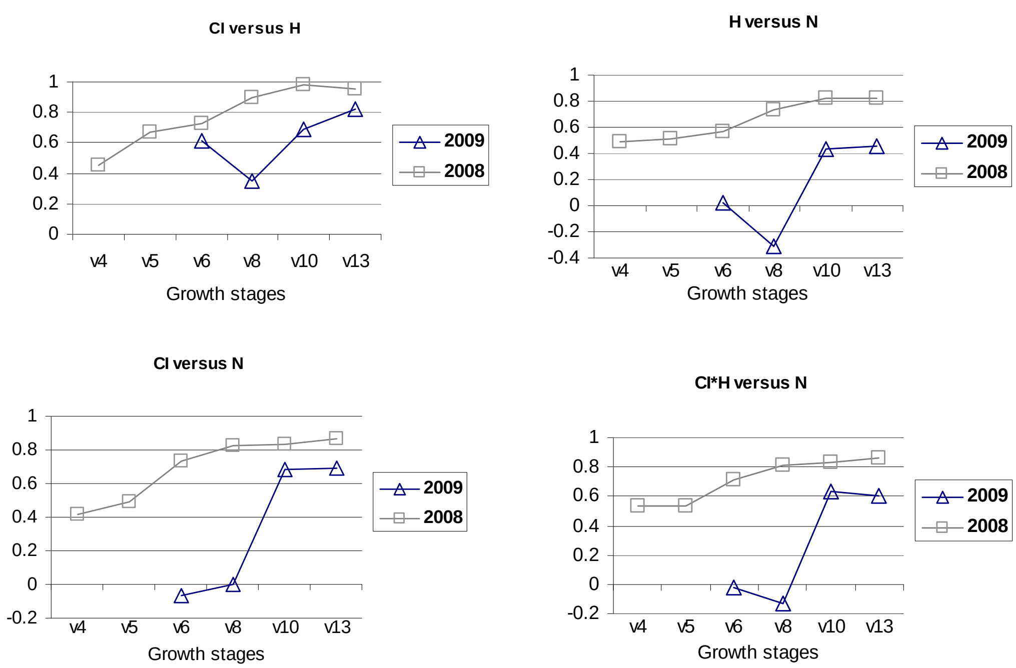


Figure 3. Pearson correlation coefficients (r) between Chlorophyll Index (CI) and plant height (H), CI and N rate, H and N rate, and the combination of CI x H and N rate, SCAL, 2008 and 2009.

For the producer fields (Table 2), CI x H correlations were relatively high for vegetative stages, but lower in reproductive stages. The relationship of CI and H with N rate varied with the year and site, For most site-years, CI and H were equally related to N rate, but for a couple of site-years (HU 2009, RT 2009), CI was better correlated to N rate than H.

The combination of CI and H did not substantially improve the ability to distinguish N rates over either CI or H individually.

Table 2. Pearson correlation coefficients (r) between sensors readings for different sites. NS – non significant at $p < 0.05$

| Site | Growth stages | CI x H | H x N | CI x N | (CI * H) x N |
|---|---|---|---|---|---|
| **SCAL 08** | V4 | 0.45 | 0.49 | 0.42 | 0.53 |
| | V5 | 0.67 | 0.51 | 0.49 | 0.53 |
| | V6 | 0.73 | 0.57 | 0.73 | 0.71 |
| | V8 | 0.89 | 0.74 | 0.82 | 0.82 |
| | V10 | 0.98 | 0.82 | 0.84 | 0.84 |
| | V13 | 0.96 | 0.82 | 0.87 | 0.86 |
| **SCAL 09** | V6 | 0.61 | 0.03 NS | -0.07 NS | -0.03 NS |
| | V8 | 0.35 | -0.31 NS | 0.00 NS | -0.13 NS |
| | V10 | 0.69 | 0.43 | 0.68 | 0.63 |
| | V13 | 0.82 | 0.46 | 0.69 | 0.60 |
| **HU 08** | V7 | 0.82 | 0.18 | 0.14 NS | 0.16 |
| | V10 | 0.91 | 0.34 | 0.32 | 0.44 |
| | V13 | 0.73 | 0.23 | 0.35 | 0.33 |
| **HU 09** | VT | 0.67 NS | 0.80 NS | 0.79 NS | 0.87 |
| | R4 | 0.19 NS | 0.33 NS | 0.96 | 0.97 |
| **BR 09** | VT | 0.69 NS | 0.37 NS | 0.91 | 0.84 NS |
| | R4 | 0.95 | 0.94 | 0.97 | 0.97 |
| **RT 09** | VT | 0.82 NS | -0.81 NS | -0.51 NS | -0.73 NS |
| | R4 | 0.43 NS | 0.16 NS | 0.94 | 0.87 |

In 2008 both sensors were able to distinguish N rates beginning at V8; the integration of both sensors didn’t improve this ability (Figure 3). The sensors were able to separate different N rates at V8, V10 and V13 growth stages in 2008. However, in 2009 sensors were only able to distinguish 0 lb/ac from the other rates at V10 and V13 growth stages (Figure 4 and 5).

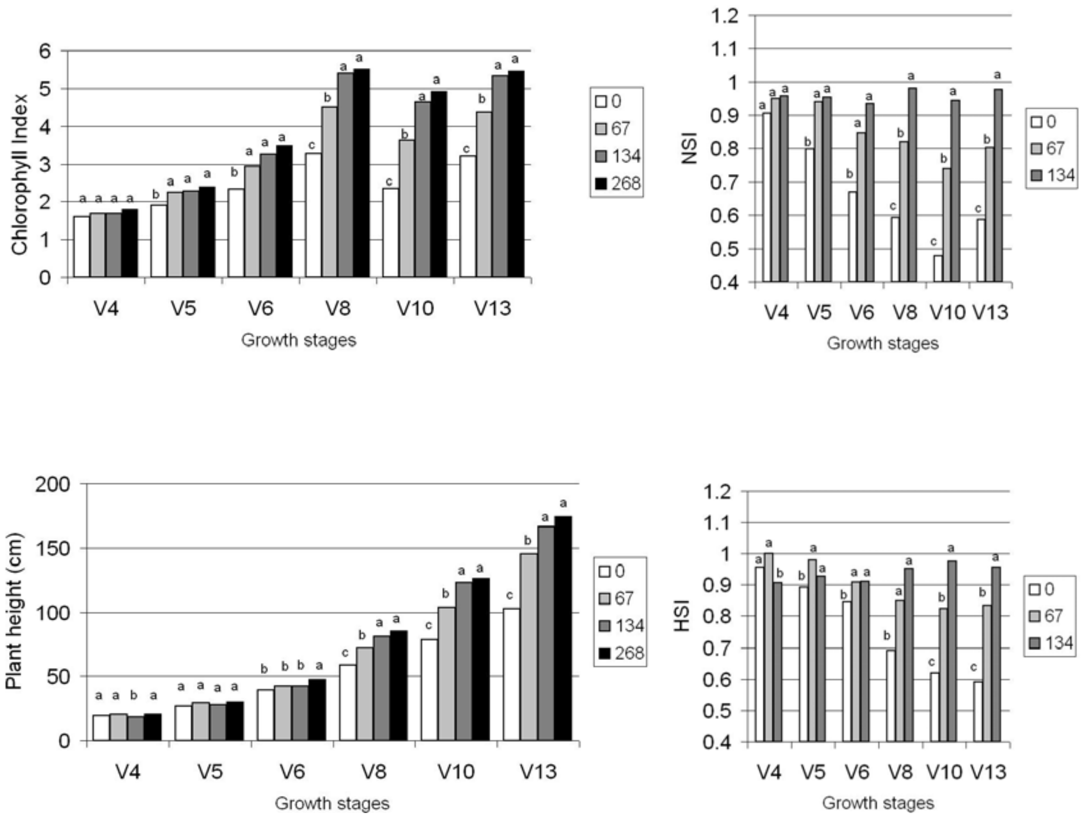


Figure 4. Chlorophyll Index, Plant Height, Nitrogen Sufficiency Index (NSI), and Height Sufficiency Index (HSI) by growth stage for different N rates, SCAL, 2008. NSI and HSI are normalized CI and H relative to the 268 lb/acre N rate.

For the SCAL site in 2008, CI increased with growth stage until V8 (Figure 4). The Nitrogen Sufficiency Index or relative index (NSI = CI for a specific N rate/reference CI, here = 268 lb N/acre) (Solari et al, 2008) showed the same trend as CI. Plant height (H) increased continuously. Normalized plant height (to the 268 lb N/acre rate), Height Sufficiency Index (HSI) showed the same trend as NSI. In 2008 both sensors were able to separate 0 from 67 lb/acre, 67 from 134 lb/acre and 134 from 268 lb/acre at V8, V10 and V13 growth stages using actual sensor readings. Normalized H (HIS) didn't show the same ability to separate N rates as the actual value of H measured by the ultrasonic sensor. The integration of CI*H did not improve the ability to differentiate N rates compared to CI alone (Table 2).

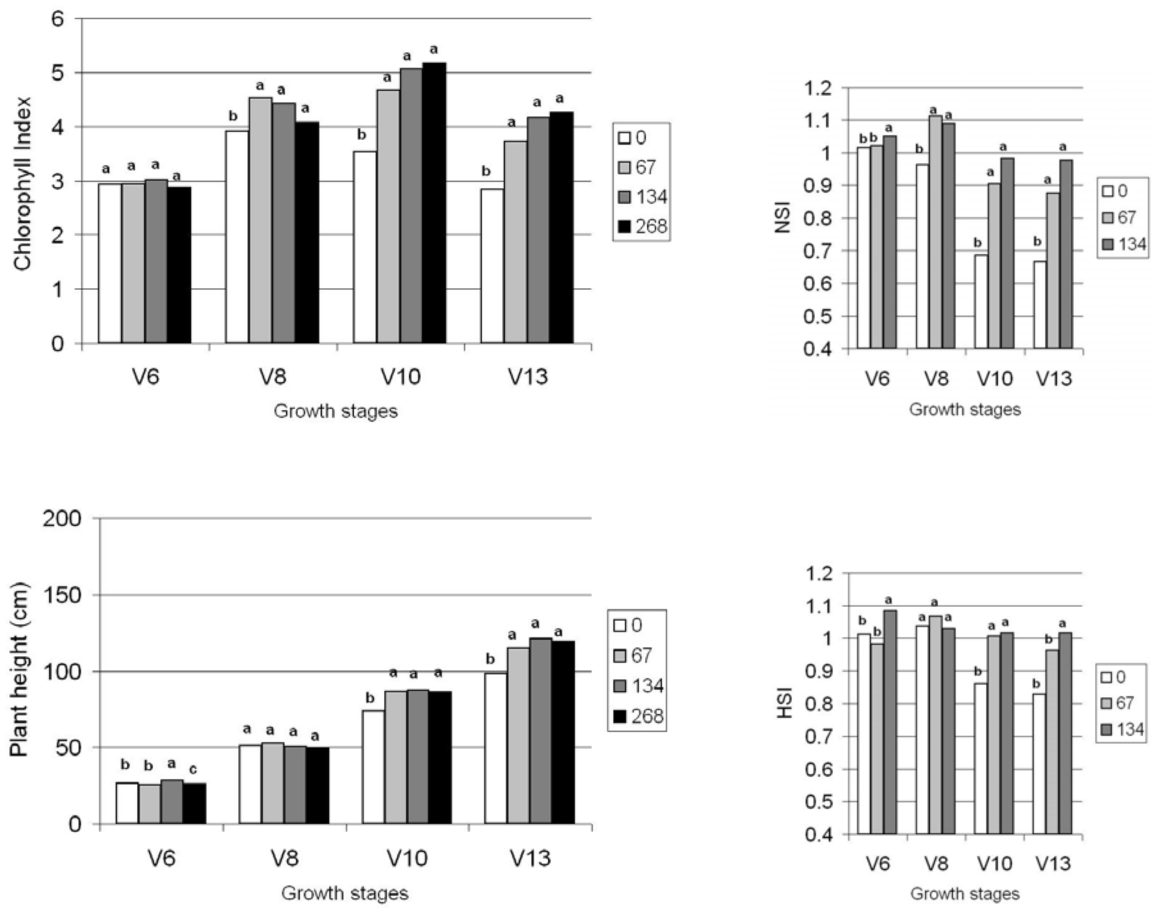


Figure 5. Chlorophyll Index, Plant Height, Nitrogen Sufficiency Index (NSI), and Height Sufficiency Index (HSI) by growth stage for different N rates, SCAL, 2009. NSI and HSI are normalized CI and H relative to the 268 lb/acre N rate.

At the SCAL site in 2009, CI increased until approximately V10 and then declined (Figure 5). Plant height again increased continuously. Sensors were not able to separate 67 from 134 lb/acre and 134 from 268 lb/acre in 2009, using either actual sensor or normalized values. NSI and CI were able to separate only 0 lb/acre from other N rates at V10 and V13 growth stages, using a LSD test with $p < 0.05$. HSI was also able to separate 0 lb/ac from other N rates only at V10. Again the integration of CI*H had the same ability to differentiate N rates as CI alone, showing no benefit to integrating CI and H in differentiating N rates at the vegetative stages studied. During both years, in general, CI and H have similar ability to separate N rates. H continuously increase unlike CI, which plateaus or even declines at the end of vegetative stage. The next step for this study is to include corn yield from both years to confirm if CI and H trends are related to yield.

## Summary

The goal of this research was to evaluate the integration of an ultrasonic height sensor with a crop canopy optical sensor, to indirectly measure chlorophyll content of the canopy allowing variable N rate application during the growing season. At V10 and V13 growth stages, plant height and CI were significant correlated and both have the same ability to differentiate N rates. The integration of CI and H did not increase correlation with N rate. More studies are needed to investigate if plant height could be used to predict yield potential or N requirement in the context of spatially variable environments.


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