ACTIVE SENSOR ORIENTATION OVER CORN ROWS AND EFFECT ON ASSESSMENT OF BIOMASS

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Abstract

Our long-term research goal is to develop practical N application systems that use on-the-go remote sensing as a means to assess crop N status and only apply N where needed at times when the crop can most efficiently utilize N. Our preliminary testing of two active sensor systems has shown considerable promise for rapid and accurate assessment of canopy N status and crop biomass. In this work, the effect of sensor positioning and orientation over the canopy and their effects on assessment of biomass were tested using two different active canopy sensors. The red version of the GreenSeeker provided a better estimation of biomass than the green version at V10. Sensitivity of the vegetation indices evaluated for biomass estimation did not improve by orienting the sensor at a 45° angle. Reflectance values for individual bands decreased according to the inverse square law. Sensitivity prompted us to work between 60 and 110 cm over the canopy with the Crop Circle sensor and between 80 and 110 cm for the GreenSeeker® sensor. Vegetation index values for both sensors decreased as they moved from over the row to between the rows at V7. Displacing the sensors by 10 cm to the side of the row underestimated NDVI for the GreenSeeker sensor with corn at V10. Special effort should be made to keep the sensor directly over the row while driving in the field.

Introduction

In Nebraska, over application of nitrogen (N) fertilizer on corn has resulted to elevated levels of nitrate in ground and surface waters. Traditionally, farmers prefer to apply N early in the season before the crop can effectively use this N, thus leading to conditions conducive for losses. Our long-term research goal is to develop practical N application systems that use on-the-go remote sensing as a means to assess crop N status and only apply N where needed at times when the crop can most efficiently utilize it. Our preliminary testing of two active sensor systems has shown considerable promise for rapid and accurate assessment of canopy N status and crop biomass. In this work, we evaluate the effect of sensor positioning over the canopy on assessment of biomass.

The inverse square law states that the intensity of radiation emitted from a point source varies as the inverse square of the distance between source and receiver. When working with satellites and airborne imagery, the impact of a little variation in distance between source and receiver is not important. However, when working with tractor or pivot mounted sensors that operate on irregular field surfaces and/or across different soil management zones where crop height can be variable, distance between the sensor and top to the canopy can realistically vary by 10 cm or more. Somehow we need to determine whether a low sensor value is due to low crop vigor or increased sensor height above the soil. Furthermore, and especially in row crops such as corn, early in the season with low vegetation fraction, failure to position the sensor directly over the plants results in an underestimation of biomass. Thus, the objectives of this work were to determine the best position and orientation of active sensors over the canopy for the V7 to V12 growth stages and to characterize sensor output stability as a function of distance between the sensor and top of the canopy.

Approach

Two newly developed active canopy sensors were tested under field conditions. The Crop Circle sensor (ACS-210) simultaneously emits in two bands (visible and NIR) and has a field of view of 32 degrees by 6 degrees (at 60 cm from the target, the field of view is ~50 by 10 cm). The red version of the sensor emits in red (650nm +/-5.5nm) and NIR (880nm ~+/-10nm) wavebands; while the amber version emits in amber (590nm +/-5.5nm) and NIR (880nm ~+/-10nm) wavebands. The sensor was calibrated using a 20% universal reflectance panel with the sensor placed in the nadir position above the panel. Sensor amplifiers for each waveband were adjusted so that a value of 1.0 was obtained from the 20% reflectance panel at 90 cm from the target. As a result, outputs of the sensor are pseudo-reflectance values for each band that allows calculation of various vegetation indices (NDVI; Deering et al, 1975, and WDRVI; Gitelson, 2004).

The GreenSeeker sensor simultaneously measures incident and reflected light from the plant at 660 ± 15nm (red version) and 770 ± 15 nm (NIR). The green version of the sensor measures at 530 ± 15 nm and 770 ± 15 nm (NIR). The field of view is ~60 by 1 cm, with the long dimension typically positioned perpendicular to the direction of travel. The field of view is approximately constant for heights between 60 and 120 cm above the canopy because of light collimation within the sensor. Outputs from the sensor are NDVI (green or red version) and simple ratio (visible/NIR).

Experiment 1: The effect of distance between the sensor and target on sensor output was tested for GreenSeeker and Crop Circle sensors. Sensors were mounted on a motorized track (screw-type garage door opener) to systematically move the sensors at a constant speed over the target. The rail was suspended perpendicular to the soil surface. Readings were taken over bare soil, turf, and corn at V4 and V10 growth stages (Ritchie et al, 1997). This selection of targets provided us with a range of reflectance and vegetation cover. Sensor outputs were plotted against distance to an imaginary horizontal plane located at the on top of the canopy for corn and grass and at ground level in the case of bare soil.

Experiment 2: The objective of this experiment was to evaluate the effect of sensor orientation (nadir position and 45 degree to the normal) on corn biomass. The Crop Circle sensor was tested at the Kansas State University experimental station near Topeka in June 2004 with the sensor mounted on a front-end loader tractor that made adjustments for distance above the canopy convenient. Eight field strips 180-m long with different N rates applied during the fall and at planting were sensed at V10. Average plant height (measured as a distance from the soil to an horizontal imaginary plane on top off the canopy) was used to estimate plant biomass. Green and red versions of GreenSeeker sensors were tested in Argentina at EEA-INTA Paraná during February 2004. Sensors were mounted on a four-wheeled mobile device (moved manually) that facilitated quick changes in sensor orientation. Twenty-four plots from an on going study with different N rates and planting densities were used to test the sensors at the V9-10 growth stage.

Two linear meters of row were harvested, dried and weighted to determine dry matter. In both locations, for the nadir position, sensors were placed at a constant height of 90 cm over a horizontal imaginary plane at the top of the canopy. For the off nadir position, the sensors were oriented at a 45 degree angle of inclination with respect to the ground and kept at a constant distance of 90 cm to the center of the plant whorl.

Experiment 3: The objective of this experiment was to understand how corn biomass estimation is affected by sensor position over corn rows. Sensors were mounted on a modified garage door opener to systematically move the sensor across three adjacent rows. The device was placed across the rows so that the field of view was perpendicular to the row. Corn was sensed at V7 and V12.

Results

Experiment 1: Pseudo NIR reflectance at 1.0 m was from 2.2 (bare soil) to 7 (grass) times higher than pseudo reflectance for the amber waveband. Values from individual bands decreased as the distance between the sensor and target increased (followed the inverse square law)(Figure 1a and 1b). Our suggestion for the ACS-210 sensor is to work in the range between 60 and 110 cm above the canopy. Positioning the sensor closer than 60 cm significantly increases the dependence on distance. Sensor output declined by ~70% at 110 cm and was only ~15% at 150 cm compared to 60 cm.

As mentioned above, the ACS-210 was calibrated with a 20% universal reflectance panel at a distance of 90 cm from the sensor (sensor output = 1.0 with 20% panel). An NIR pseudo reflectance value of 8 for grass at 40 cm (Figure 1a) would correspond to a reflectance of 160%, which is clearly unreasonable but illustrates the sensitivity of active sensors to distance from the target. The reality of the situation is that both NIR and red reflectance increase as distance between the sensor and canopy decreases. Vegetation indices like NDVI and reflectance ratios were developed for passive aircraft sensor systems to compensate for atmospheric interferences. Under these conditions, distance between the sensor and target is infinitely large. However, when the sensor is moved to within a meter of the target and the energy source is weak (i.e., modulated visible and NIR radiation), distance becomes important and atmospheric interference becomes negligible. The situation with active sensors is that it doesn't take very much vegetation to absorb all of the red light emitted. As such, fluctuations in visible light reflectance are much more likely to be caused by changes in the distance between the sensor and target than by changes in chlorophyll status. Failure of modulated visible light to conform to reflectance concepts established for natural light (i.e., red reflectance decreases as NIR reflectance increases) raises questions about using established reflectance indices to interpret active sensor data. Figure 2a and 2b illustrates how increased distance between the sensor and target decreases the simple ratio (NIR/amber) and NDVI values. A reasonable distance window for both sensors is probably between 80-110 cm.

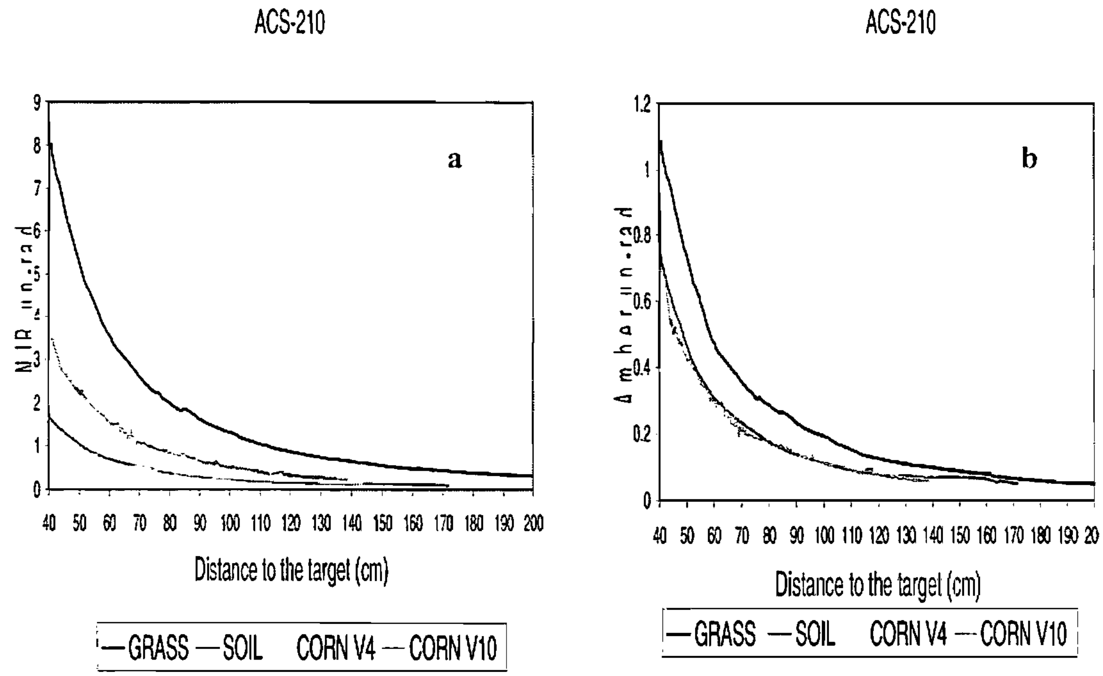

Figure 1a and 1b: NIR and amber upwelling radiance as a function of distance between sensor and four different targets. Blue corresponds to grass, orange to corn at V10, yellow to corn at V4 and purple to bare soil.

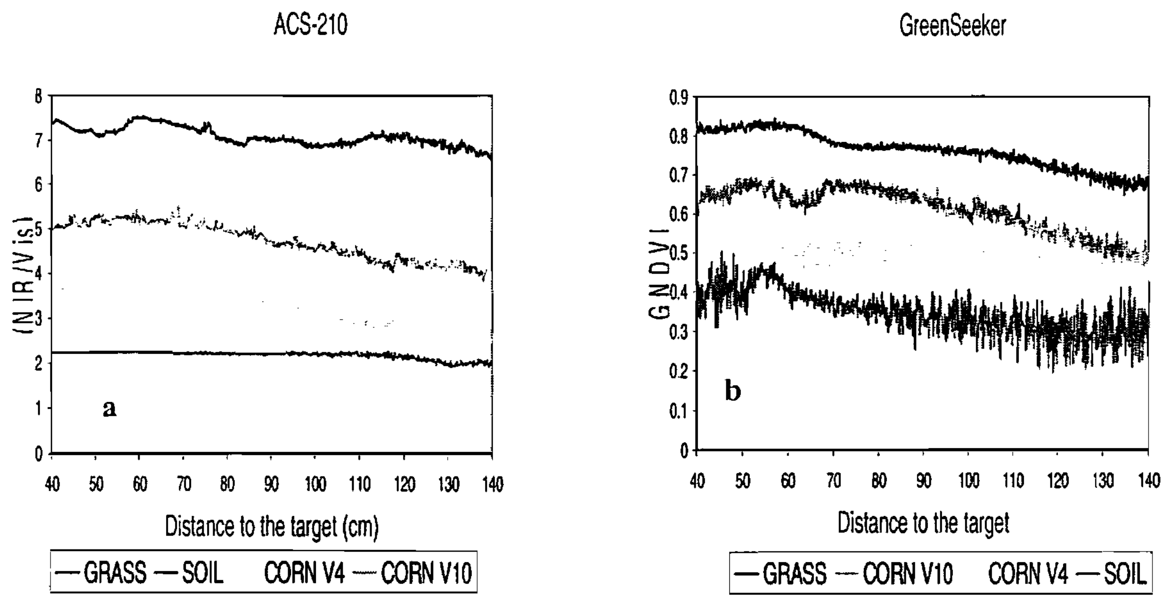

Figure 2a and 2b: Simple NIR/Amber ratio for Crop Circle sensor and green NDVI for GreenSeeker sensor as influenced by distance from sensor.

Experiment 2: It was not possible to directly compare Crop Circle and GreenSeeker sensors at both locations because the Crop Circle sensor was not available in Argentina and the GreenSeeker sensor was not functioning properly in Kansas. Better estimates of biomass where achieved using the red than the green GreenSeeker sensor at V10 (Figure 3). However, red NDVI showed little response to dry matter values >200 g/m^2. This is because the vegetation was more than adequate to absorb all of the modulated red light (Gitelson, 2004). It is not known if the NIR detector became saturated at high biomass values or the NDVI formula limited expression of the biomass (GreenSeeker software would have to be modified to provide reflectance data for individual wavebands). Both the simple ratio (NIR/Vis) and NDVI for the ACS-210 sensor were responsive to plant height at V10 (Figure 3). However, both indices saturated at relatively high biomass/height values at this growth stage. There was no apparent benefit to off-nadir viewing of the canopy at V10. The situation would likely be different after tassel formation in that either the sensor height above the soil would have to be increased or the reflectance of the tassel would have a large effect on the readings. The goal of placing the sensor in an off-nadir position was to include more green vegetation in the field of view. However, targeting the desired portion of the canopy became an apparent problem with the green version

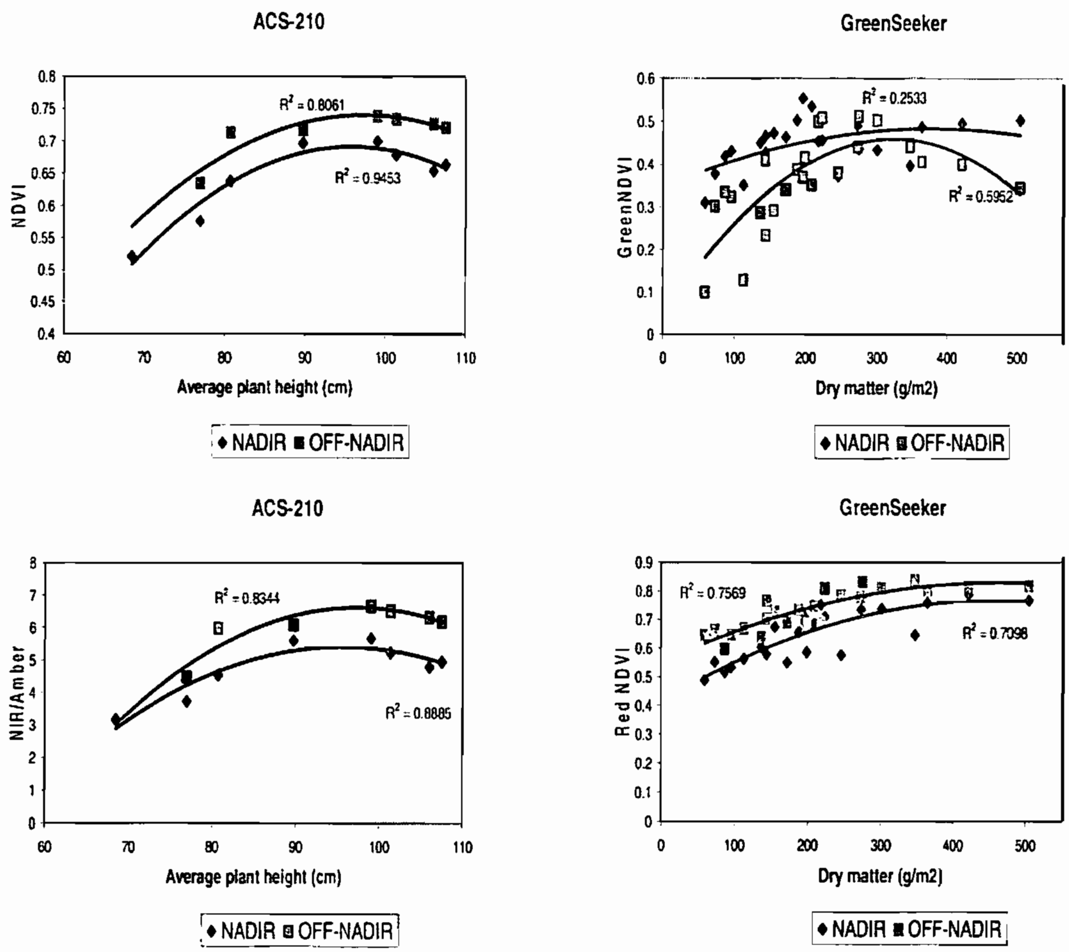

Figure 3: Sensor orientation effect on assessment of biomass.

of the GreenSeeker even though it was mounted identical to the red GreenSeeker. These differences could be due to the non-uniform distribution of light across the field of view and differences in the energy level between the red and green version of the sensors.

Experiment 3: The amount of biomass in the sensor's field of view is naturally influenced by sensor location over to the row. Direction of leaf orientation (plant rotation) relative to row direction can have a strong influence on sensor response (Figure 4). The lack of symmetry in response as the sensor moved across the rows was expected because the sensor was positioned to pass directly over the plant in the left row, but for the center and right rows the field of view included more inter-plant space (area between plants in the same row) and perhaps some vegetation from adjacent plants. Individual waveband data clearly illustrate that vegetation index values for active sensors are almost entirely driven by NIR reflectance, which is highly influenced by distance between the sensor and canopy and the amount of biomass in the field of view. In a practical sense, it follows that corn is a difficult crop to monitor because leaves exist at multiple levels (thereby affecting distance to the sensor) and leaf orientation (plant rotation relative to row direction) is variable relative to the sensor's field of view.

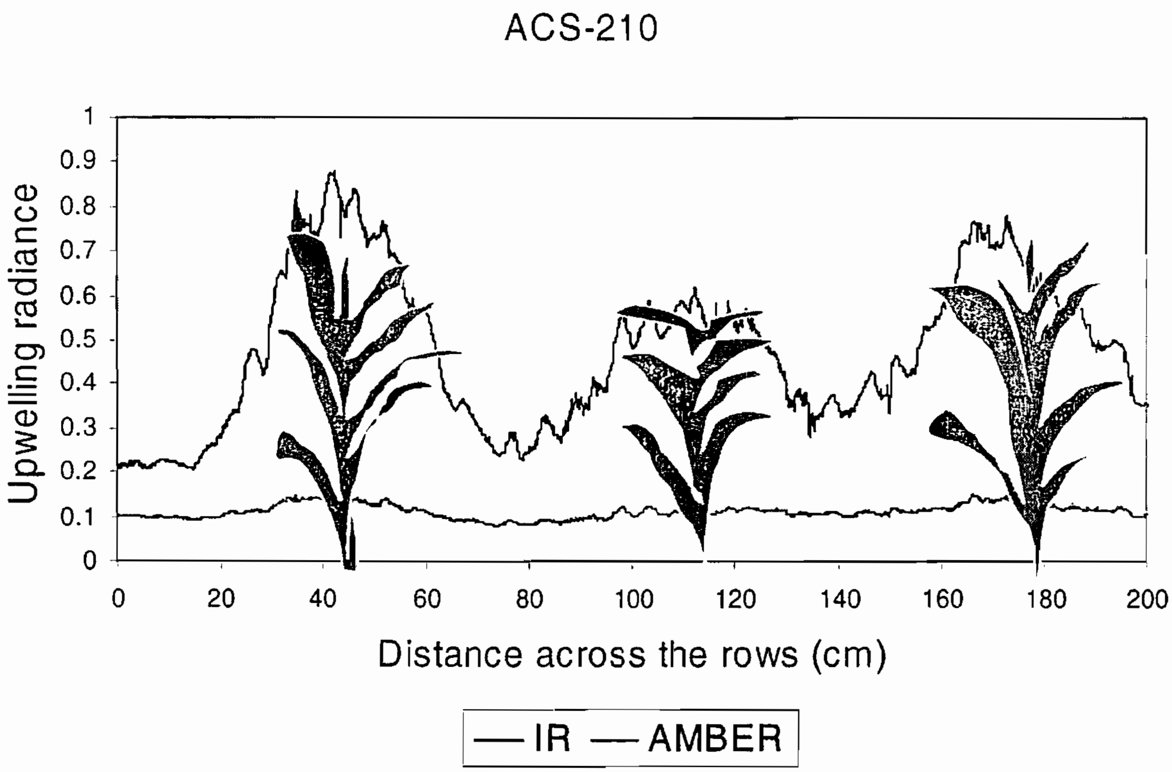

Figure 4: Individual band reflectance values as a function of distance for the Crop Circle sensor traversing over three rows of corn (sensor field of view perpendicular to row direction).

To illustrate the integrated effect of not positioning the sensor directly over the row, we placed the sensors at 90 cm over the canopy and moved them laterally 10-15 cm from the center of the row. Readings were collected while moving through the field with the sensors mounted on a tractor with a front-end loader (Kansas) or on a mobile device (Argentina). In the case of the GreenSeeker, a sensor offset of 10-15 cm clearly underestimated the NDVI values for corn at V10 (Figure 5). These data illustrate the importance of keeping the GreenSeeker positioned directly over the plant row (i.e., GNDVI consistently lower for the offset position). This point is attributed to the fact that light intensity is not uniformly distributed across the field of view with the GreenSeeker (e.g., ~75% of the radiation is concentrated in the center 25-30 cm of the 60 cm width of the field of view). In the case of the Crop Circle sensor, half of the data points showed that the offset sensor position had no effect on sensor output. The remaining half suggest a possible offset effect, but these differences in reflectance could also be caused by incorrectly adjusting the sensor height. The extent to which sensor output was influenced by distance between the sensor and average height of the canopy surface is not known, but at both locations attempts were made to standard the distance. Argentina data were from small plot studies with manual height adjustment for each plot, so distance should have been quite consistent. Kansas data were collected from field strips, so maintaining the desired distance between the sensor and canopy (on-the-go) was a challenge.

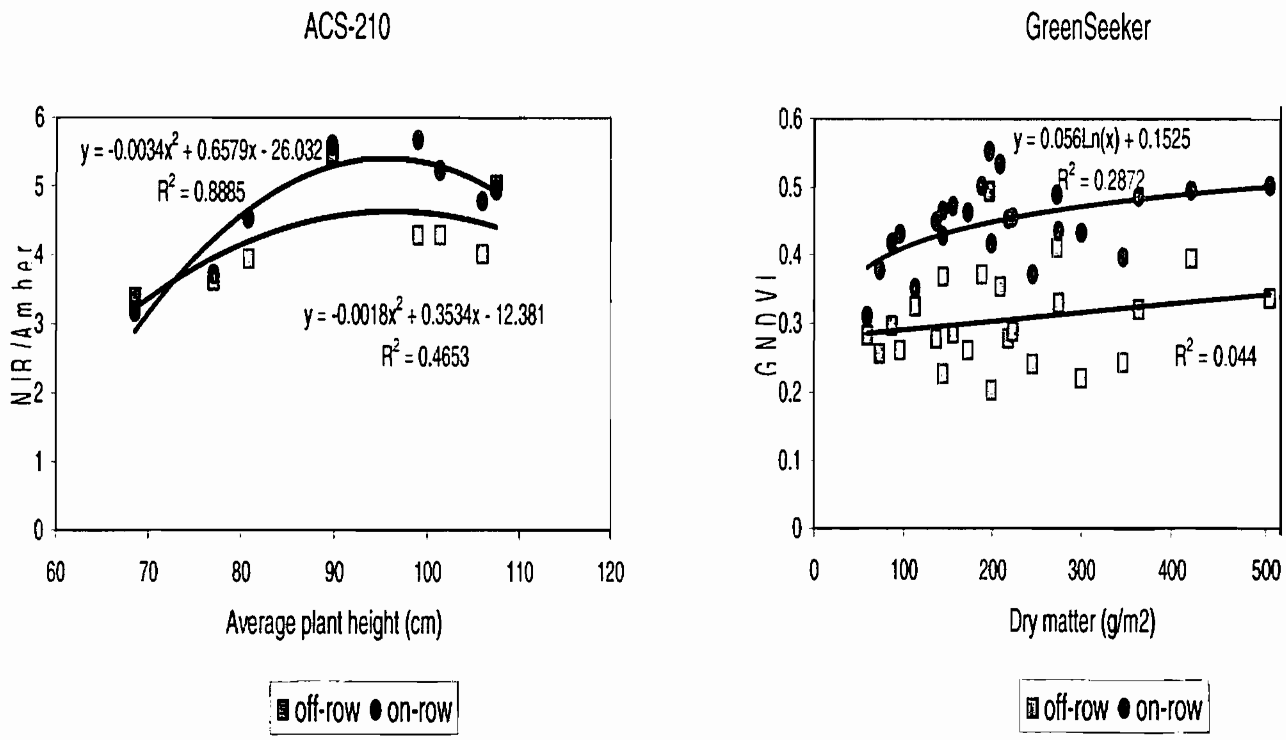

Figure 5: Comparison between sensor outputs when placed in the nadir position over the row vs. 10-15 cm to the side of the row.

Summary

For a good assessment of biomass, sensors should be oriented in the nadir position with their field of view centered over the row. Output of both Crop Circle and GreenSeeker sensors is sensitive to distance between the sensor and the target, so care must be taken to maintain a consistent distance or to understand the influence of variable distance on sensor readings.

References

Deering, D.W., J.W. Rouse, Jr., R.H. Hass, and J.A. Schell. 1975. Measuring "forage production" of grazing units from Landsat MSS data, pp 1169-1178. In Proc. Tenth Int. Symp. On Remote Sensing of Environment. Univ. Michigan, Ann Arbor.

Gitelson, A. 2004. Wide Dynamic Range Vegetation Index for Remote Quantification of Biophysical Characteristics of Vegetation. Journal of Plant Physiology.161. 165-173

Ritchie, S.W., J.J. Hanway, and G.O. Benson. 1997. How a corn plant develops. Iowa State Univ. of Sci. and Tech. Coop. Ext. Service. Ames, IA. Spec. Pub. 48.

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