Field comparison of ultrasonic and canopy reflectance sensors used to estimate biomass and N-uptake in sugarcane

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Abstract

The use of crop canopy reflectance sensors is being studied intensively in sugarcane crops; however, real-time measurements of plant height provide another possibility for estimating the spatial variability of biomass and nitrogen uptake by the crop during the in-season fertilization period. An ultrasonic proximity sensor system was deployed to measure crop canopy height. The data were combined with commercially available canopy optical reflectance measurements to characterize spatial variability of crop growth in two commercial areas (a sandy soil field and a clay soil field) during two different growing stages. After mapping, ten points in each field were defined to determine plant biomass and N-uptake through manual sampling and traditional measurements. Through the data analysis, a pixel by pixel comparison was performed to relate the interpolated maps obtained using different sensor systems. The ten points in each field were used to relate the actual biomass and N-uptake with the sensor data. It was shown that all correlations were significant and there was a slight indication that canopy reflectance sensing produced a better assessment of crop growth at the earlier growth stage whereas the ultrasonic sensor resulted in more accurate predictions at the later growing stage.

Keywords: Ultrasonic sensor, canopy height, plant reflectance, biomass, N-uptake.

Introduction

Sugarcane (*Saccharum spp*.) is the most important crop for the production of sugar and ethanol in tropical and subtropical regions. As with most grass species, nitrogen (N) is one of the major inputs for this crop; nevertheless, there is no reliable and inexpensive soil analyses procedure to determine N availability *in situ* during the growing season on tropical soils. To manage nitrogen fertilization according to local needs, canopy reflectance sensors are already being intensively studied and results show that they can provide the status of biomass and N nutrition of sugarcane in real time (Amaral et al., 2012, Portz et al., 2012a). However, these sensors exhibit signal saturation when the sugarcane crop is above the 0.6 m stem height. As shown previously (Portz et al., 2012b), increasing biomass does not reflect an adequate increase of the vegetation index (VI) later in the season when there is still room to conduct nitrogen fertilization in-season.
As an alternative, measuring crop canopy using ultrasonic proximity sensors is not new. During the 1980´s, Shibayama et al. (1985) used such a sensor for crop canopy characterization, and Sui et al. (1989) developed a measurement system using ultrasonic ranging modules to provide cumulative plant volume, plant width and height for a variety of bush-type plants, such as cotton and soybean. Later, ultrasonic proximity

sensors were used simultaneously with crop canopy reflectance sensors. Scotford and Miller (2003) concluded that ultrasonic sensors proved useful for monitoring winter wheat growth beyond GS 30, whereas NDVI measurements were useful for monitoring winter wheat up to GS 31 (before the point of stem elongation). This evidence suggests that by combining these two measurements, the crop can be monitored throughout the entire growing season.

Sui and Thomasson (2006) combined plant reflectance sensors and ultrasound sensors to determine the status of nitrogen in cotton. The results showed that the spectral information and plant height measured by the system showed significant correlation with the nitrogen contained in the leaves of the cotton plants.

Shrestha et al. (2002) investigated ultrasonic sensor estimates of corn plant height in a lab environment. They showed that the estimated height correlated with the manually measured height. While working with an optical reflectance sensor on corn, Freeman et al. (2007) also took measurements of plant height during the investigation and concluded that plant height alone was a good predictor of plant biomass at all stages of growth sampled. Similarly, recent work by Shiratsuchi et al. (2009) showed that correlations between height, biomass and nitrogen were observed in corn, suggesting the integration of plant reflectance sensor and ultrasound measurements of plant height, to estimate nitrogen extracted by the crop during the entire growing season.

During previous work, Portz et al. (2012c) observed that sugarcane stem height measured manually correlated with the crop biomass and N-uptake. This means that crop canopy height can provide complementary information or it can be considered an alternative to optical reflectance sensing when estimating the biomass and N-uptake in the crop. The objective of this project was to compare canopy reflectance and ultrasonic crop height sensing when predicting sugarcane biomass and N-uptake in real time.

Materials and methods

The study involved two commercial fields located in the state of São Paulo, Brazil, on sandy (12 ha) and clay (16 ha) soils. The fields were harvested during mid-season (first ratoon), and were mapped twice, when the crop was at 0.3 m to 0.5 m (11/10/2012), and at 0.5 m to 0.7 m (14/11/2012) average stem height. The fields were scanned simultaneously with a commercial crop canopy reflectance sensor (N-Sensor^{TM} ALS, Yara International ASA, Research Centre Hanninghof, Duelmen, Germany), and two ultrasonic sensors (both Polaroid 6500, Minnetonka, Minnesota, USA). The N-Sensor ALS is comprised of a transmitter with a xenon flashlight, providing high intensity illumination between 650 and 1100 nm and a 10 Hz receiver with 2 photodiodes and interference filters of 730 and 760 nm in front of them measuring the proprietarily defined vegetation index (Jasper et al., 2009). Two ultrasonic sensors were operated at a frequency of 49.4 kHz and connected to a data logger (CR 1000 Campbell Scientific, Logan, Utah, USA). All of the measurements were geo-referenced using a Global Positioning System (GPS) receiver and a 1 Hz log file was created by synchronizing and aggregating all of the data. The sensors were mounted on top of a high clearance vehicle (Figure 1) that passed the field every 10 rows (15 m) at a travel speed between 12 and 15 km h^{-1}. This produced about 200 independent data points per hectare. Since the crop canopy reflectance sensor had an oblique view, six crop rows were sensed at a time. Each ultrasonic system evaluated only one row, while being installed vertically.

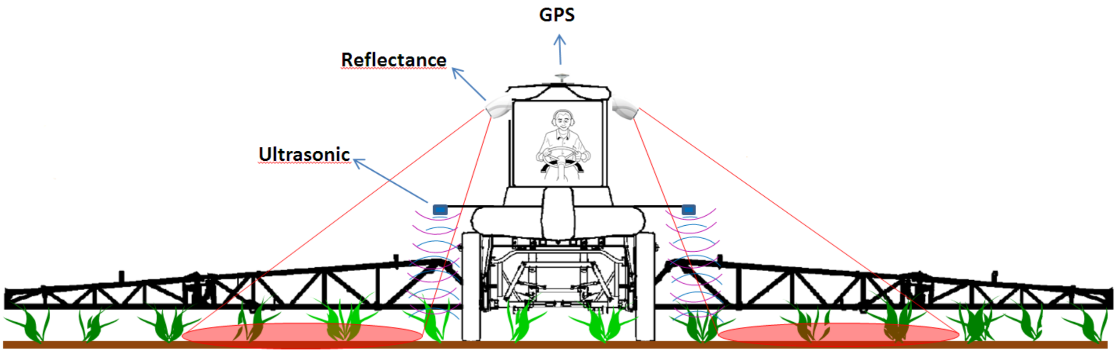

Figure 1. Canopy sensors disposition on a high clearance vehicle.

The average of the recorded data from the left and right sensors were filtered, cutting off points outside the field boundaries and the negative values; they were interpolated (inverse distance weighting) using a 5 x 5 m raster. A five-color legend was applied for visual analysis. Ten validation locations were selected in each field to represent the entire range of sensor-based measurements for both systems. Each validation location was in the middle of a 5-m cell. In every case, destructive plant samples of the above ground biomass were taken by manually cutting a 1.5 m sub-plot consisting of three rows (4.5 m). The samples were weighed in the field, and processed in the laboratory to measure total N content (Kjeldahl method) and, ultimately, the crop N-uptake. Figure 2 illustrates the entire process.

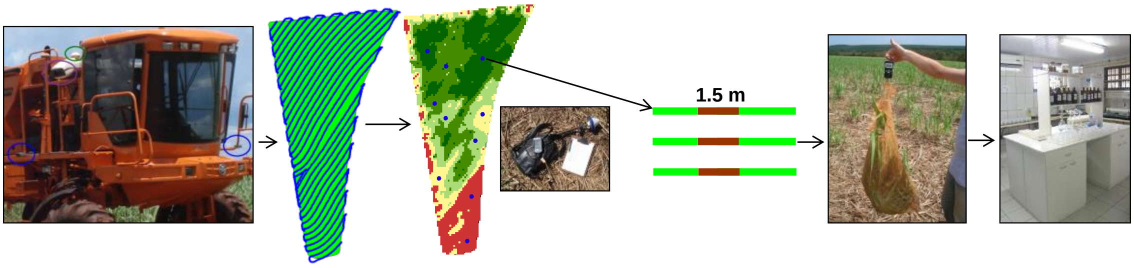

Figure 2 Sampling process

The sensor-based data were compared using a regression analysis applied to all of the interpolated pixels. Another set of linear regression analyses was conducted to relate the measured biomass, the N-uptake and the sensor measurements.

Results and discussion

Figure 3 presents the interpolated data for the canopy reflectance and the canopy height for the two measurements made on the sandy soil field. All of the maps illustrated the same spatial pattern with slightly less small-scale variability in crop canopy reflectance maps due to the smoothing caused by the oblique position of the sensor. The same conclusions can be made while observing the maps produced based on the data collected from the clay soil field (Figure 4).

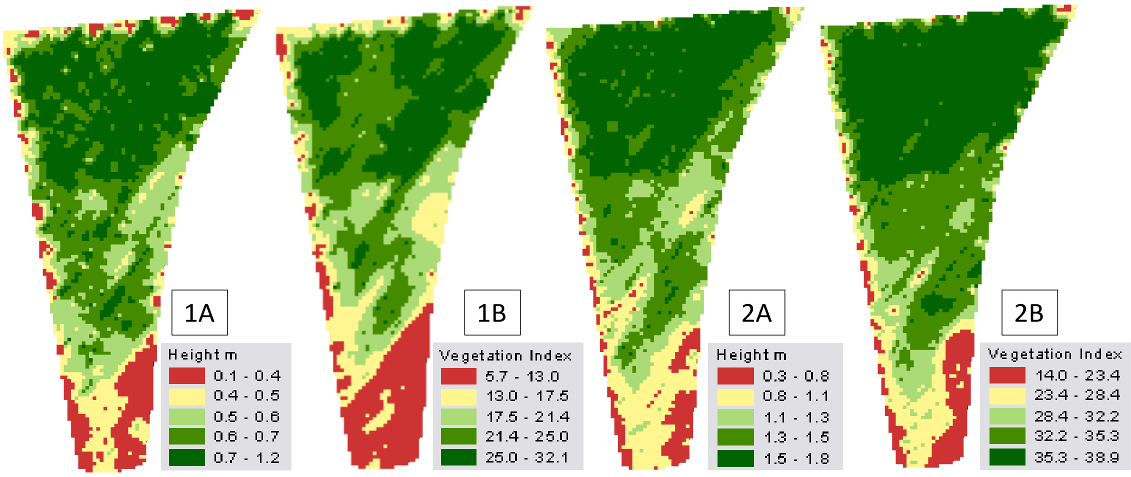

Figure 3 Interpolated maps of crop height during the first (1A) and second (2A) mapping and crop canopy reflectance during the first (1B) and second (2B) scanning of the sandy soil field

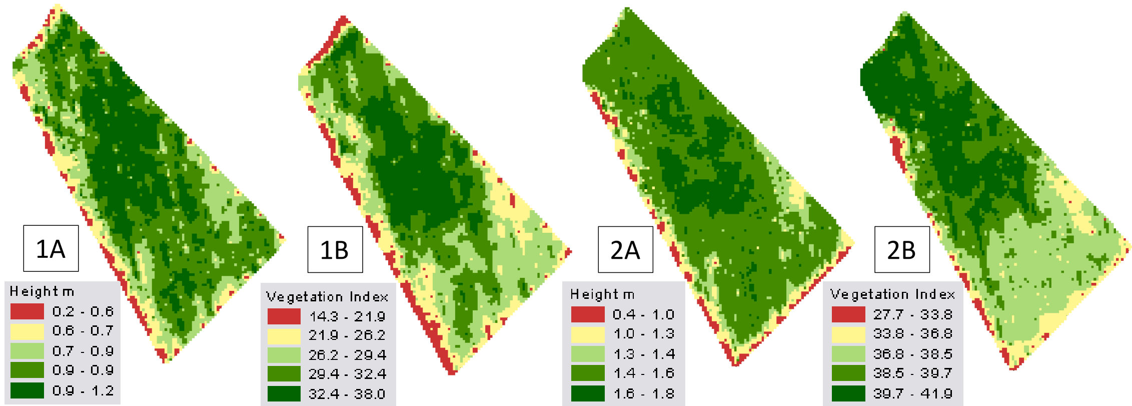

Figure 4 Interpolated maps of crop height during the first (1A) and second (2A) mapping and crop canopy reflectance during the first (1B) and second (2B) scanning of the clay soil field

A pixel-by-pixel comparison of corresponding maps produced using two different sensor systems (Figure 5) showed a strong, but field and growth stage specific, correlation. This is consistent with previously published observations (Portz et al., 2012a). Naturally, it is possible to see that during the first scanning of the sandy soil field (04 VI - 32 VI), the crop was shorter (0.2 m - 0.9 m) when compared to taller crops (0.4 m - 1.8 m) during the second scanning (16 VI – 38 VI). The crop canopy reflectance measurements did not exhibit this change due to possible sensor saturation when the canopy became closed. Furthermore, it could be seen that the range of measurements conducted by the ultrasonic sensor increased during the second scan indicating a strong sensor response to crop biomass. On the other hand, especially in the case of clay soil, the range of vegetation index values has declined at the later growth stage indicating that the sensor was less capable of distinguishing crop performance in different parts of the field when compared to the earlier growing stage. This could be explained by the fact that optical measurements primarily observe crop leaves and height estimates assess the stalks. Thus, during the first scanning over a younger sugarcane crop, the leaves were more relevant to crop biomass and N uptake than the stalks. During the second scanning, the stalk was a bigger contributor to crop biomass leaving crop height measurements more responsive to spatially different crop performance.

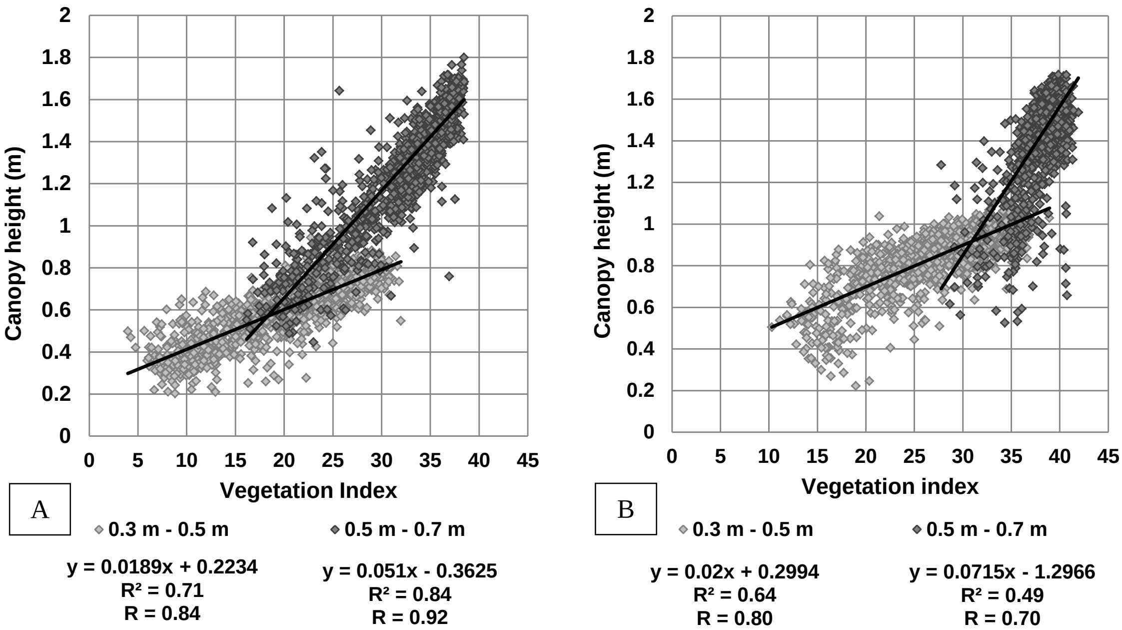

Figure 5 Pixel by pixel correlation of first and second scanning moments on sandy (A) and clay (B) soil fields

Through the analysis of data obtained from validation locations, it follows that sensor-based measurements correlated to both biomass and N-uptake in every field and during each scan (Figure 6).

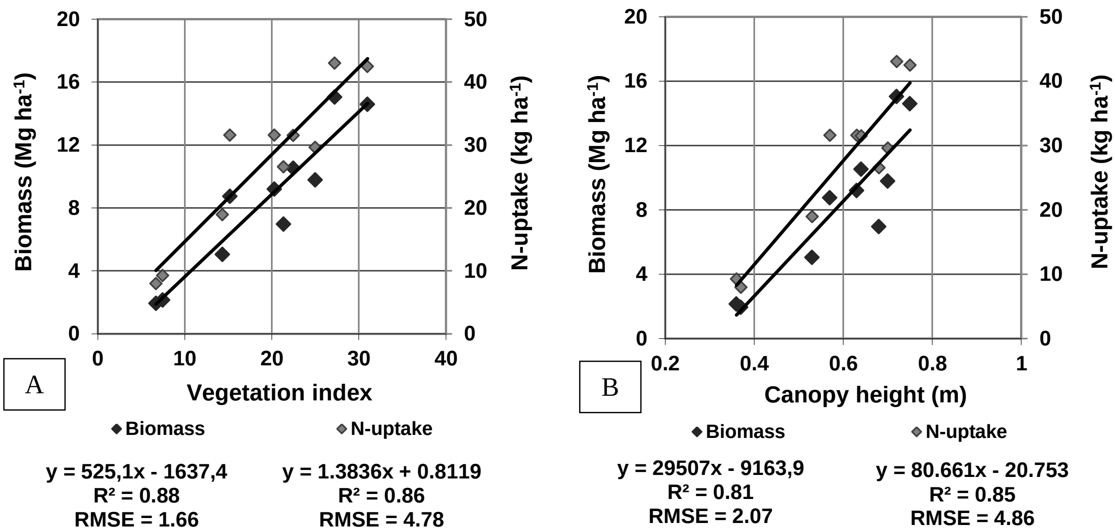

Figure 6 Canopy reflectance (A) and canopy height (B) related to biomass and N-uptake of the sample points from the first scanning over the sandy soil field.

Based on the analysis of regression models (Table 1), it once again appears that both sensor systems responded to changes in crop biomass and N uptake with coefficients of determination (R^2) at, or above, 0.70. Root mean squared error (RMSE) for biomass ranged between 1.66 and 6.25 Mg ha^{-1} and N-uptake varied between 4.8 and 10.4 kg ha^{-1}. Except for the height-based N-uptake estimates in the field with clay soil, RMSE values were higher during the second mapping event. In terms of the two sensor systems, in every case, the estimated RMSE were lower for crop canopy reflectance sensors during the first scanning and for the ultrasonic sensors during the second scanning. Many of these differences were not significant statistically and further research is needed to assess the quality of the predictions in different growing conditions and to verify if combining both sensors would reveal any benefits when compared to using one of them at a time.

Table 1 Analysis of relationships biomass and N-uptake as functions of vegetation index and crop height measurements

Sensor	Value	Soil	Mapping	Intercept[1]	Slope[1]	RMSE[2]	R^2
			Biomass (Mg ha^{-1})				
Canopy reflectance	Vegetation index	Sand	First	-1.6^{NS}	0.53***	1.66^{abc}	0.88
			Second	-29.9*	1.63**	6.25^{efg}	0.75
		Clay	First	-14.2*	0.97**	2.72^{abcde}	0.80
			Second	-211.6**	6.49**	5.84^{defg}	0.81
Ultrasonic sensing	Height (m)	Sand	First	-9.2*	29.51***	2.07^{abcd}	0.81
			Second	-18.5*	32.39***	5.27^{defg}	0.82
		Clay	First	-38.8*	58.03**	3.42^{bcdef}	0.69
			Second	-65.4**	71.21***	4.69^{cdefg}	0.88
			N-uptake (kg ha^{-1})				
Canopy reflectance	Vegetation index	Sand	First	0.8^{NS}	1.4***	4.78^{abc}	0.86
			Second	-44.8*	2.9***	10.43^{cde}	0.78
		Clay	First	-24.8^{NS}	2.3**	6.71^{abcde}	0.79
			Second	-259.6*	8.7**	9.61^{cde}	0.74
Ultrasonic sensing	Height (m)	Sand	First	-20.8*	80.7***	4.86^{abcd}	0.85
			Second	-24.3*	57.9***	8.64^{bcde}	0.85
		Clay	First	-85.9*	141.6**	8.05^{abcde}	0.70
			Second	-65.9*	97.5**	7.72^{abcde}	0.83

[1] Parameters of a simple linear regression significant at $\alpha = 0.05$ (*), $\alpha = 0.01$ (**), $\alpha = 0.001$ (***), as well as not significant at $\alpha = 0.05$ (NS)

[2] RMSE estimates with common letters (a-g) are not significantly ($\alpha = 0.05$) different from each other

Conclusions

The sensor data presented consistent correlations when generating similar maps for canopy reflectance and canopy height on the two studied areas. Sampled biomass and N-uptake also correlated with both canopy reflectance and crop height sensor-based measurements. With very little statistical significance, crop canopy reflectance measurements seemed more responsive to crop biomass and N uptake at a younger growth stage. Ultrasonic sensor crop height measurements seemed to be more relevant to more developed crops. This result indicates that it might be beneficial to integrate both sensors to make measurements during the entire growing season. More research is needed to evaluate the statistical significance of these findings and explore the benefits of such an integrated system applied to a sugarcane growing environment.

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