Use of crop height and optical sensor readings to predict mid-season cotton biomass

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Abstract

The objective of this work was to evaluate the performance of optical and ultrasonic sensors, as well as the fusion of these data to predict cotton biomass. Two field experiments were conducted in commercial fields located on the state of Goiás, Mid-West Brazil, one planted on a conventional row system and other in narrow rows during the 2013/14 growing season. The results confirmed good correlations between crop height and cotton biomass for most evaluations. Using Normalized Difference Red Edge index and manually measured crop height in combination allowed better predictions of crop biomass than using any single variable. The fusion of optical and ultrasonic sensors also showed better performance, but the improvements were more pronounced only at the last sampling date. The better performance of manually measured crop height, when compared to ultrasonic readings, could be due to high plant-to-plant variability observed in the fields. The use of ultrasonic sensors is a good alternative to improve the prediction of mid-season cotton biomass, but some adjustments are needed to achieve results more similar to those obtained by manually measured crop height.

Keywords: spatial variability, ultrasonic sensors, sensor fusion.

Introduction

Cotton (*Gossypium ssp.*) is among the most important fiber crops, with approximately 35 Mha grown worldwide. Global demand has gradually increased since the 1950s, with an average annual growth of 2%. Brazil produces around 1.7 Mt of cotton lint per year and is among the top five global producers, alongside China, India, Pakistan and the USA. It is also the fourth largest exporter and achieves the highest yields in non-irrigated cotton (Neves & Pinto, 2013).

Cotton field management remains a challenge for growers, especially due to spatial variability of soil conditions, which demands the use of variable rate application of nitrogen and plant growth regulators. Canopy optical reflectance sensors have shown good performance to detect infield variability in early season (pin-head square to early bloom), but may have some limitations due to the known effect of signal saturation when used later in the season, due to very dense canopy and changes in the spectral signature of the plants (Gutierrez et al., 2012). Unlike optical readings, crop height is related to crop biomass throughout the season, even after peak bloom, and this fact could be used to improve the detection of infield variability (Portz et al. (2014). This could allow farmers to make better decisions and assist in variable rate application of plant growth regulators.

Plant height has been used to model cotton crop parameters in numerous studies. Kerby et al. (1990) considered plant height as an important deciding factor for plant growth regulators application. Munier et al. (1993) found relationships between plant height, plant vigor and early fruit retention, and also considered plant height as a good indicator for the use of growth regulators. Cotton plant height was also found to be significantly correlated with many vegetative indices (Leon et al., 2003).

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

Ultrasonic sensors measure the time that waves take to travel, reflect and come back to the sensor. That time is then used to calculate the distance traveled, which has innumerous applications. Andújar et al. (2011) used these sensors to detect weed infestations. The sensor readings permitted the detection and discrimination of different groups of weeds, contributing in the development of real-time spatially selective weed control techniques.

Escolà et al. (2011) used ultrasonic sensors to characterize apple tree canopies. The results showed that the increase of variability in field conditions, when compared to laboratory, reduces the accuracy of this kind of sensors when estimating distances to canopies.

Portz et al. (2013) studied the use of optical and ultrasonic canopy sensors in sugarcane and found the crop canopy reflectance measurements seemed more responsive to crop biomass and N uptake at a younger growth stage, while ultrasonic sensor crop height measurements seemed to be more relevant to more developed crops. They concluded it might be beneficial to integrate both sensors to make measurements during the entire sugarcane growing season.

Sui et al. (2013) used an experimental ultrasonic device coupled with a GPS to measure real time, in situ cotton plant height. They found plant height had a quadratic relationship with yield, and this relationship was stronger in the non-irrigated plots ($R^2=0.60$) than in irrigated plots ($R^2=0.16$).

Sharma and Frazen (2014) evaluated the use of corn height to improve the relationship between active optical sensor readings and yield estimates. They concluded that measurements of corn height improved the relationship between in-season estimates of yield and actual yield often enough to suggest that incorporating corn height into an algorithm for yield prediction would strengthen yield prediction, and thus improve N rate decisions.

Portz et al. (2014) used cotton plant height to predict aboveground fresh matter, dry matter and nitrogen uptake. They concluded that the relationship between the variables remained linear for all ages and heights ($0.90 < R^2 < 0.94$), showing the potential of using plant height to detect infield spatial variability from early stages of crop development to the reproductive stage. Based on this previous research, the objective of this work was to evaluate the performance of optical and ultrasonic sensors, as well as the fusion of these signals, to predict mid-season cotton biomass.

Materials and methods

Two commercial fields located in the state of Goiás, Middle West Brazil, were investigated during the 2013/14 growing season. Both were planted on a no tillage system following soybean as previous crop, over Oxisols with varying clay contents (400 – 600 g kg^{-1}). The first one centered at 52º37´19´´ S and 18º20´42´´ W, had an area of 95 ha and was planted in 3 Jan 2014 using a conventional row system (0.80 m), with 100,000 seeds ha^{-1}. The second field, centered at 52º37´19´´ S and 18º27´08´´ W, had an area of 90 ha and was planted in 18 Jan 2014 on narrow row system (0.45 m), with 190,000 seeds ha^{-1}.

The optical sensor readings were collected with a pair of commercial crop canopy reflectance sensors (Crop Circle ACS-430, Holland Scientific, Lincoln, NE, USA), integrated in a mapping system (GEOSCOUT GLS-420, Holland Scientific, Lincoln, NE, USA). The sensors measure canopy reflectance at three wavelengths, but only the red edge (730 nm) and near infrared (780 nm) were used to calculate the Normalized Difference Red Edge index (NDRE), which was used in all comparisons (Horler et al. 1983).

Plant height was obtained using a pair of ultrasonic sensors (Polaroid 6500, Minnetonka, Minnesota, USA), that measured the distance between the top of the canopy and the sensor based on the time of flight principle. The sensors operate at a frequency of 49.4 kHz and have a beam width about ±15º wide (Cao & Borenstein, 2002). Data was acquired using custom software and a data logger (CR 1000 Campbell Scientific, Logan, Utah, USA).

The fields were scanned simultaneously with both pairs of sensors and all measurements were geo-referenced using an autonomous Global Positioning System (GPS) receiver and collected data at a frequency of 1 Hz. Both sensors were mounted 1 m externally from each of the tire tracks and 1.20 m above the top of the canopy (Figure 1), pointing towards the same area, on a high clearance vehicle that traversed the field every 30 m at a ground speed of 23 km/h. This process produced about 100 data points ha^{-1}. At this mounting height, each Crop Circle sensor had a footprint 1 m wide, which means 6.7% of the field was effectively scanned.

Figure 1. Positioning of sensors above narrow row cotton canopy.

To represent the entire range of plant variability, 30 validation locations were selected in each field. For each validation sample point, plant height was manually measured and destructive plant samples of the aboveground biomass were collected by manually cutting and weighing a 1.0 m sub-plot consisting of three rows.
Data obtained at the sampling points was submitted to analysis of variance (ANOVA) using the aboveground biomass as the dependent variable with the different planted row rows spacing and sensor readings as independent variables. Linear regression analysis was then conducted, considering different sets of predictors and interactions among them. All statistical procedures were performed using the R software, version 3.1.0 (R Development Core Team, 2014).

Results and Discussion

Data collected by the sensors was used to generate maps of the spatial distribution of crop height and vegetation index. In the field cultivated with conventional row spacing (Figure 2), it was observed that the top right and center portions of the field had smaller plants and lower vegetation index values while the top left part had the taller plants but not higher vegetation index values.

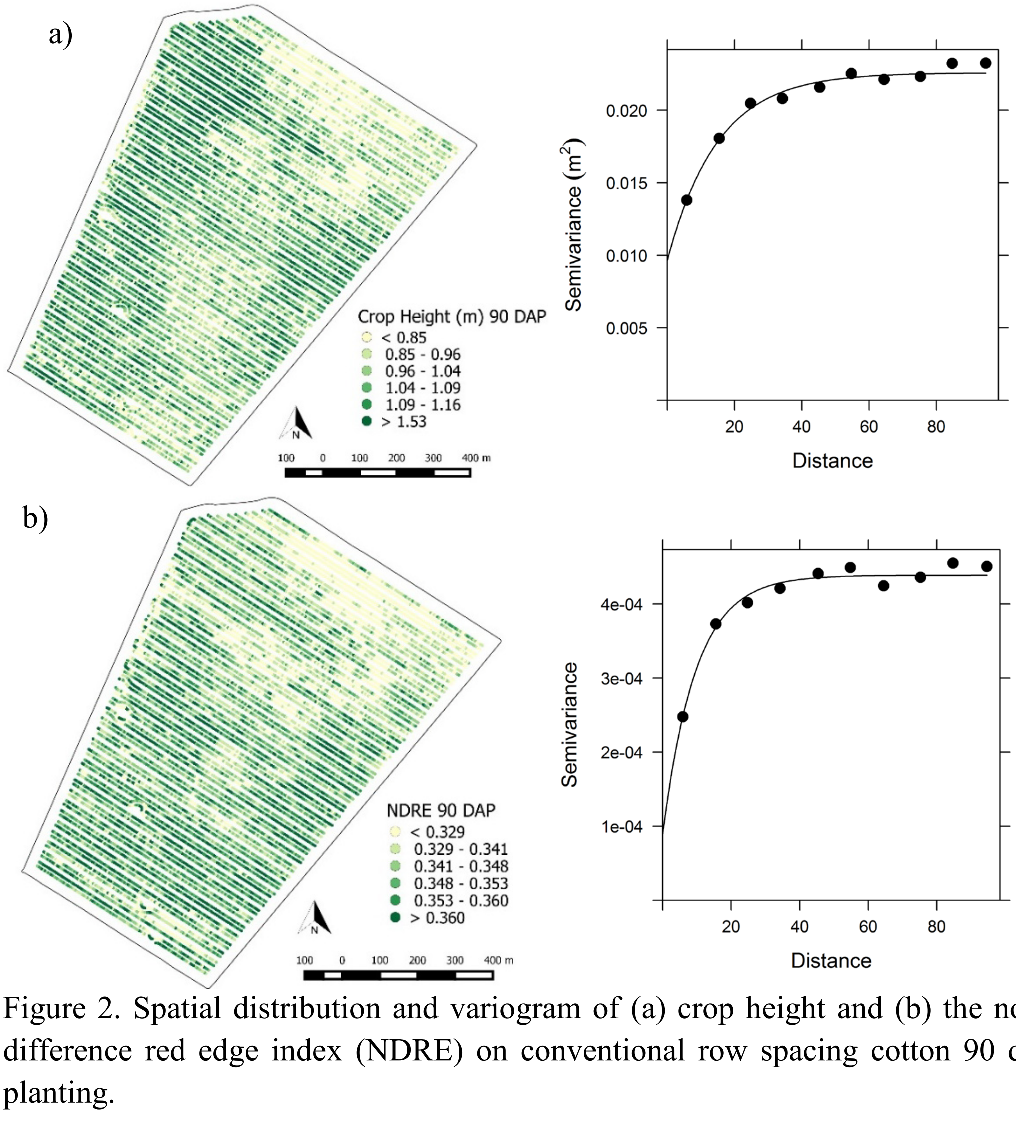

Figure 2. Spatial distribution and variogram of (a) crop height and (b) the normalized difference red edge index (NDRE) on conventional row spacing cotton 90 days after planting.

The spatial dependence in this field was evident, characterized by the semi-variograms generating a range value of about 30 m, with higher relative nugget effect for the ultrasonic readings.

The field cultivated with narrow row spacing cotton (Figure 3), also exhibited spatial dependence for the sensors data, although in this field the range was limited to about 10 m, which was smaller than the swath width used. Due to this small scale variability, it was harder to define plant patters in different condition within the field, besides, most of the field had a variation in crop height within a range of 0.10 m, making it feasible to treat the field as homogeneous.

Aboveground biomass was log transformed before analysis in order to meet the assumptions of data normality and homoscedasticity of variances. There was a significant interaction between the predictors and the cropping planting system, and so, the data were analyzed separately for each system. It is important to note that row spacing was not the only difference between the two areas studied. The two sites were planted on different dates, had different clay contents, crop history and climate conditions throughout the season.

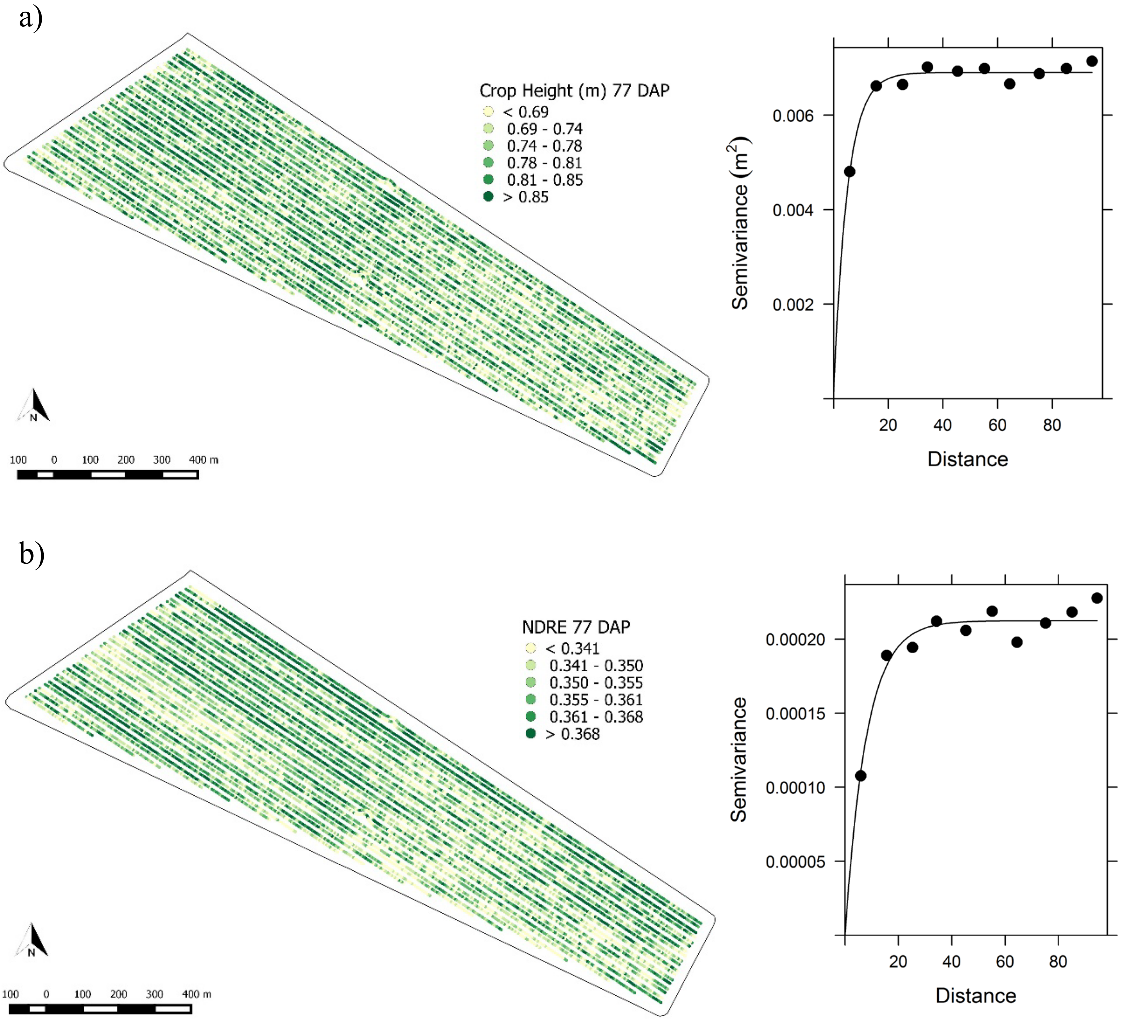

Figure 3. Spatial distribution and variogram of (a) crop height and (b) the normalized difference red edge index (NDRE) on narrow row spacing cotton 77 days after planting.

The coefficient of determination of regression (R^2) was selected to evaluate the performance of the predictors (Table 1). Considering only single factors, manually measured plant height performed better in estimating aboveground biomass in both systems at all dates evaluated. This performance may be related to the sampling methodology adopted. While manual measurements of plant height were taken in the exact same location where aboveground biomass was measured, the sensor readings were taken in just one row of the crop, close to the machine tracks. It was clear that short scale variability was an important part of total variability. This hypothesis was also supported by the low correlation coefficients between crop height manually measured and using ultrasonic sensors, which were always lower in the narrow row system, where short scale variability was predominant.

Table 1. Coefficients of determination (R^2) for the regression analysis of aboveground biomass versus different predictors.

Predictors[1]	Narrow Row			Conventional		
	56 DAP[2]	77 DAP	111 DAP	56 DAP	90 DAP	127 DAP
OS	0.53	0.02	0.17	0.65	0.86	0.15
MMH	0.72	0.84	0.24	0.93	0.90	0.58
US	0.27	0.00	0.00	0.67	0.77	0.41
OS*MMH	0.80	0.84	0.27	0.95	0.93	0.60
OS*US	0.57	0.03	0.30	0.74	0.90	0.54
(MMH,US)[3]	0.33	-0.02	0.54	0.87	0.92	0.75
CV (%)[4]	24.8	24.7	11.5	51.7	42.1	16.9

[1] OS - Optical Canopy Sensor, MMH - Manually Measured Plant Height and US - Ultrasonic Sensor; [2] DAP - Days after Planting; [3] Correlation between MMH and US; [4] Coefficient of variation of aboveground biomass.

The optical sensor readings had better performance ($R^2 > 0.5$) in the first evaluation period in the narrow row system and in the first two evaluations for the other field. Poor performance occurred for all other dates. These results reinforced the importance of proper use of optical canopy sensors, and the existence of an optimal timing for their use. The combination of manually measured plant height and the optical sensor readings provided the best overall performance. This could be related to the good performance of manually measured plant height rather than improvements in the performance of the optical sensor.

The fusion of optical and ultrasonic sensors also improved the system performance, but the improvements were more pronounced only at the last sampling date. At this stage, the crop had a very dense canopy and the optical sensor readings could be saturated (Gutierrez et al., 2012; Portz et al., 2014).

The better performance of manually measured crop height, when compared to ultrasonic readings, is a problem requiring further investigation. An alternative means may be the use of high data acquisition rates combined with a running average or a real-time filtering method. This would make it possible to better understand plant-to-plant variability and to differentiate smaller plants from gaps caused by poor stand emergence. Another possibility would be the use of a higher beam angle and distance between sensor and crop canopy or combining more sensors to avoid the influence of short scale variability.

Conclusion

Plant height can be a good predictor of cotton aboveground biomass accumulation in all dates evaluated, from 56 to 127 days after planting. The ultrasonic system used to collect georeferenced plant height showed poor correlations (<0.55), with manually measured crop height when overall variability was low or short distance variability was pronounced. The better performance of manually measured crop height, when compared to ultrasonic readings, could be due to the high plant-to-plant variability observed in the fields, causing noisy data. The use of ultrasonic sensors is a good alternative to improve the prediction of mid-season cotton biomass, but some adjustments are needed to achieve results more similar to those obtained with manually measured crop height.

References

Andújar, D., Escolà, A., Dorado, J., Fernández-Quintanilla, C. 2011. Weed discrimination using ultrasonic sensors. Weed Research, 51:543–547.

Cao, A., Borenstein, J. 2002. Experimental Characterization of Polaroid Ultrasonic Sensors in Single and Phased Array Configuration. University of Michigan, 5 p.

Escolà, A., Planas, S., Rosell, J. R., et al. 2011. Performance of an Ultrasonic Ranging Sensor in Apple Tree Canopies. Sensors, 11:2459–2477.

Gutierrez, M., Norton, R., Thorp, K. R., & Wang, G. 2012. Association of spectral reflectance indices with plant growth and lint yield in upland cotton. Crop Science, 52(2), 849-857.

Horler, D. N. H., Dockray, M., and Barber, J. 1983. The red-edge of plant leaf reflectance. International Journal of Remote Sensing, v. 4, p. 273–288.

Kerby, T., Plant, D., Hofmann, W., and Horrocks D. 1990. Predicting Pix response using the expert system Calex/Cotton. In: Proceedings of the Beltwide Cotton Production Research Conferences, 658-659.

Leon, C. T., Shaw, D. R., Cox, M. S., Abshire, M. J., Ward, B., Wardlaw III, M. C., Watson, C. 2003. Utility of remote sensing in predicting crop and soil characteristics. Precision Agriculture, 4, p. 359-384.

Munier, D. J., Weir, B. L., Wright, S. D., Kerby, T. A. 1993. Applying pix at variable rates when plant height varies in a cotton field. In: Proceedings of the Beltwide Cotton Conferences, p.1206-1207.

Neves, M. F., Pinto, M. J. A. 2013. A Cadeia do Algodão Brasileiro - Safra 2012/2013: Desafios e Estratégias. (The Brazilian Cotton Chain - Season 2012/2013: Challenges and Strategies). Brasília: Associação Brasileira dos Produtores de Algodão, 2ed. 196p.

Portz, G., Amaral, L. R., Molin, J. P. and Adamchuk, V. I. 2013. Field comparison of ultrasonic and canopy reflectance sensors used to estimate biomass and N-uptake in sugarcane. In: Stafford, J. V. (Ed.) Proceedings of the 9th European Conference on Precision Agriculture, Wageningen Academic Publishers, The Netherlands. pp. 103-110.

Portz, G., Vilanova Jr., N. de S., Trevisan, R. G., Molin, J.P., Portz C. and Posada, L. V. 2014. Cotton field relations of plant height to biomass accumulation and N-uptake on conventional and narrow row systems. In: Proceedings of the 12th International

Conference on Precision Agriculture, ISPA, IL, USA. https://www.ispag.org/presentation/3/1521/ (Last accessed: 03/03/2015)

R Development Core Team. 2014. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Sharma, L. K., Franzen D. W. 2014. Use of corn height to improve the relationship between active optical sensor readings and yield estimates. Precision Agriculture. 15:331–345.

Sui, R., Fisher, D. K., Reddy K. N. 2013. Cotton Yield Assessment Using Plant Height Mapping System. Journal of Agricultural Science; Vol. 5, No. 1.

Sui, R., Thomasson J.A. 2006. Ground-based sensing system for cotton nitrogen status determination. Transactions of the ASABE, 49:1983-1991.