OPTIMUM SUGARCANE GROWTH STAGE FOR CANOPY REFLECTANCE SENSOR TO PREDICT BIOMASS AND NITROGEN UPTAKE

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ABSTRACT

The recent technology of plant canopy reflectance sensors can provide the status of biomass and nitrogen nutrition of sugarcane spatially and in real time, but it is necessary to know the right moment to use this technology aiming the best predictions of the crop parameters by the sensor. A study involving eight commercial fields located in the state of São Paulo, Brazil, varying from 16 to 21 ha, planted with four varieties, was conducted during two growing seasons (2009/10 - 2010/11). Conditions varied from sandy to heavy soils and the previous harvesting occurred in May and October (early and late season), including first to fourth ratoon stages. Fields were scanned with the reflectance canopy sensor (N-Sensor^{TM} ALS, Yara International ASA) three times in the first season (approximately at 0.2, 0.4, and 0.6 m of stem height) and two on the second season (0.3 and 0.5 m), followed by tissue sampling for biomass, crop height and nitrogen uptake on ten spots inside the area, guided by the different values shown by the canopy sensor. At 0.2 m of field average stem height, sugarcane biomass is low for a good sensor prediction of the parameters; at 0.6 m height starts the saturation, where the ability of the sensor to predict biomass and nitrogen begins to be affected. Between 0.3 and 0.5 m of stem height results show the best correlation between real and sensor predicted biomass and nitrogen uptake for sugarcane crop, indicating that this is the right period for using the sensor to guide variable rate nitrogen application.

Key words: nitrogen management, proximal sensing, N-Sensor.

INTRODUCTION

Sugarcane (Saccharum ssp.) is the main crop that supplies sugar, and the second for ethanol production, growing in tropical and subtropical areas, which provides around 80% of the sugar world production and 35% of the ethanol. Brazil is the worldwide main sugarcane producer (FAO 2012).

Sugarcane producers, despite research on the nitrogen nutrition contributions, continue with the challenge of making better use of the input, especially due to the spatial variability of the nutrient and soils found in production areas, often in short distances (Solie et. al., 1999).

The recent technology of canopy sensors using vegetation reflectance at certain wavelengths can provide georeferenced information about biomass and nitrogen nutrition of the crop in real time, which can guide the implementation of variable N application. The sugar-ethanol industry in São Paulo state, which produces 60% of the commercial sugarcane of Brazil, indicated that precision agriculture technologies can provide improvements, higher yield, lower costs, minimize the environmental impacts and bring improvements in sugar cane quality, suggest a research made by Silva et. al., (2010), that also says that 96% of the sector wants to expand the use of precision agriculture practices.

One of the existing canopy sensors for nitrogen management is the N-Sensor (N-Sensor^{TM} ALS, Yara International ASA). According to Jasper et al. (2009) and Reusch (2005), it uses an optimum waveband selection to generate a vegetation index (VI) to determining the nitrogen uptake from crops by active remote sensing, being superior to “classical” reflectance ratios, with one waveband in the visible and one waveband in the near infrared region of the electromagnetic spectrum. In particular, the resulting relationship seemed to be largely independent of growth stage and variety, and showed less saturation at high N uptake levels.

According to Singh (2006), there is a great scope for use the N-Sensor for optimize nitrogen application in sugarcane cultivation, but the sensor needs to be tested and validated for sugar cane cropping systems. This research activity is already being done in Brazil since 2009 (Portz et. al., 2012), showing that the sensor is capable to predict biomass and nitrogen uptake with accuracy independent of soil, variety and year season during a long period of the initial development of the crop, also showing the first data set capable to provide an algorithm to guide variable rate application of N over commercial sugarcane fields.

This optimized VI used by the sensor uses the beginning of the near infrared (NIR) at 760 nn and the slope of reflectance between the red and the NIR named REIP (Red Edge Inflection Point), at 730 nn.

Also Mutanga and Skidmore (2004), Heege et, al., (2008) and Mokhele and Ahmed (2010) showed that the red edge area contains more information on biomass quantity as compared to other parts of the electromagnetic spectrum and that narrow wavelengths located in the red edge slope contain information at full canopy cover, having the highest correlation coefficients with biomass if obtained with a waveband located in the shorter red edge portion (706 nm) and a band located in the longer red edge portion (755 nm) for a better estimation of biomass at high canopy density. However Portz et al. (2012) indicate that in a high biomass sugarcane, at 0.6 m average of stem height, saturation starts to appear on the sensor signal using the VI from red edge.

This paper shows an improvement and validation of the results presented by Portz et al. (2012) by proposing the right moment to use the N-Sensor aiming to indicate biomass accumulation and nitrogen application demands based on the N-uptake on commercial sugarcane fields.

MATERIALS AND METHODS

During the 2009/10 and 2010/11 growing seasons eight commercial fields of sugarcane located around the São Martinho Sugar Mill (21°19'11"S, 48°07'23"W), in the state of São Paulo, Brazil, were evaluated. Conditions varied from sandy to clay soils, with all crops being mechanically green harvested (with no burn). On four fields, harvesting of the previous crop occurred at the beginning of the season (May/Jun) corresponding to the dry time of the year, and on the other four fields, in late season (Oct/ Nov), corresponding to the wet time of the year. The crops under investigation included first, second, and third ratoon stages in 2009/10 and second, third and fourth ratoons in 2010/11. The first four fields were planted with the varieties CTC 9 over sandy soil and RB 855453 over clay soil and all were harvested in the dry season. The last four fields were planted with the varieties CTC 2 on sandy soil and SP 80–3280 on clay soil, and harvested during the wet season (Table 1).

Table 1: Variables of the studied areas

Field	1	2	3	4	5	6	7	8
Varity	CTC 9		RB 855453		CTC 2		SP 803280	
Size (ha)	21	16	18	17	20	18	21	16
Harvest	may/jun (dry season)				oct/ nov (wet season)			
Soil	sandy		clay		sandy		clay	
Ratoon 09/10	1°	2°	1°	3°	1°	2°	1°	3°
Ratoon 10/11	2°	3°	2°	4°	2°	3°	2°	4°

Shortly after harvesting all fields were fertilized with a uniform dose of 100 kg ha^{-1} of nitrogen using ammonium nitrate (30 % N) as the N source, spread over the sugarcane rows surface.

The sugarcane fields were scanned using the N-Sensor™ ALS (Yara International ASA, Duelmen, Germany) (Jasper et al., 2009). The sensor was mounted behind the cabin of a high clearance vehicle.

The target parameter for the agronomic calibration of the sensor readings is the N-uptake of the above-ground biomass of the crop (Link, 2005). As the relationship between sensor readings and crop N uptake might be growth stage specific, each of the eight fields was scanned with the sensor three times in the 2009/10 growing season (at 0.2, 0.4, and 0.6 m average stem height) and two times during the 2010/11 (at 0.3, and 0.5 m average stem height) (Fig. 1).

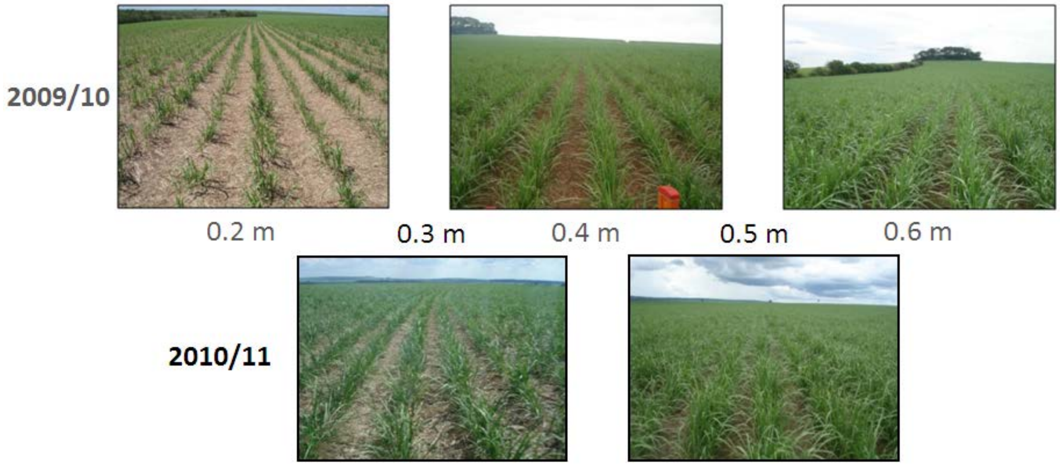

Figure 1: Grow status of sugarcane at the measurement moments

The sensor was connected to a GPS receiver and the vehicle was driven through the whole field spaced by 10 rows of 1.5 m. After the scanning, the sensor data was processed generating sensor VI index maps of the fields, over this maps 10 sample plots were located guided by the different values shown by the canopy sensor and followed by tissue sampling for biomass, crop height and nitrogen uptake as explained by Portz et al. (2012).

Sensor readings of the respective sample plots were related to the crop parameters, specific calibration functions were derived, and the capacity of the sensor measurements to predict the actual crop biomass and N-uptake was investigated.

An exploratory analysis of the data was done running box plot test using Sigma plot 10. Sensor data of each field were correlated with biomass and nitrogen uptake from the respective sample points. Also simple linear regression models were used to compare sugarcane N-uptake collected data against sensor predicted N-uptake for each of the field stem height average evaluated.

RESULTS AND DISCUSSION

In order to observe the individual behavior of the variables in each of the eight fields evaluated in five crop heights during two years, the data from the studied fields were compared first independently side by side by box plot analyses for biomass (Fig. 2 and 3) and for N-uptake (Fig. 4 and 5)

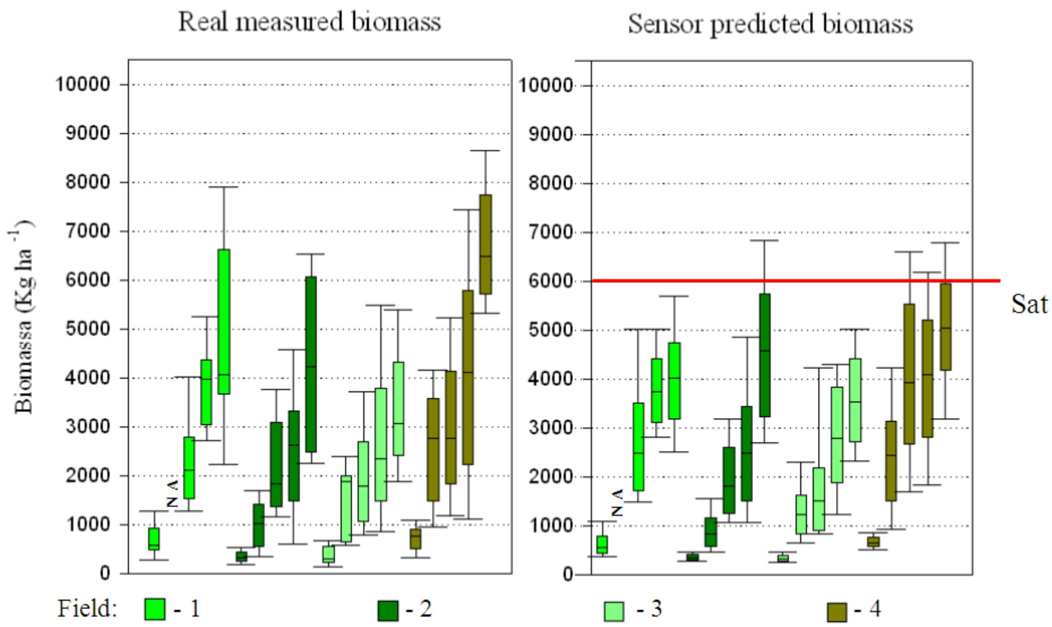

Figure 2: Sugarcane real measured biomass compared to sensor predicted biomass for the four fields of the early season (dry season).
Observations: Sat = saturation point, NA = Not available data.

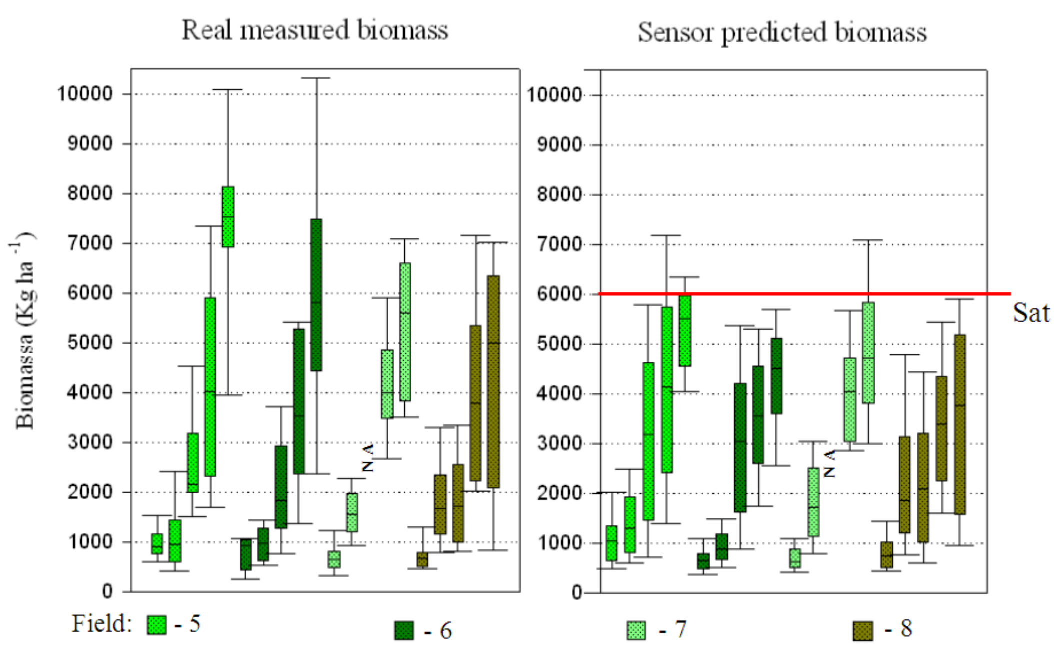

Figure 3: Sugarcane real measured biomass compared to sensor predicted biomass for the four fields of the late season (wet season).
Observations: Sat = saturation point, NA = Not available data.

Analyzing the biomass data it is possible to see that the 2010/11 data (0.3 and 0.5 m) fitted right in the 2009/10 data (0.2, 0.4 and 0.6 m), even with climate differences between years (data not shown) and one ratoon older crops on the fields.

The first measurement (0.2 m) shows low and concentrated values, usually below 1000 kg ha^{-1} of dry matter, especially in the early season that is in the dry and colder period of the year.

The real biomass measured in field (left graph) for the early season (Fig. 2) and for the late season (Fig. 3) reached around 8000 kg ha^{-1} of dry matter, with higher values in the late season, that is in the rainy and warmer period of the year. However when we analyze the sensor predicted values for the same field points (right graph), at around 6000 kg ha^{-1} of dry matter an upper limit is achieved, indicating that the phenomenon of sensor saturation begins (red line).

The sensor saturation happens when the biomass increases but the values of the sensor for the same biomass increase in a lower rate or stop to increase. The saturation is related to the VI index used by the sensor and also to the narrow bands involved on it. The major limitation of using vegetation indices based on the red and NIR portion of the electromagnetic spectrum is that they asymptotically approach a saturation level after a certain biomass density (Tucker 1977, Todd et al. 1998, Thenkabail et al. 2000). The results are indicating that the red edge sensor used is accurately working until biomass covers the entire surface, as happens when the sugarcane is at 0.6 m of stem height, (Fig. 1).

For N-uptake the behavior is similar, as shown on Figures 4 and 5.

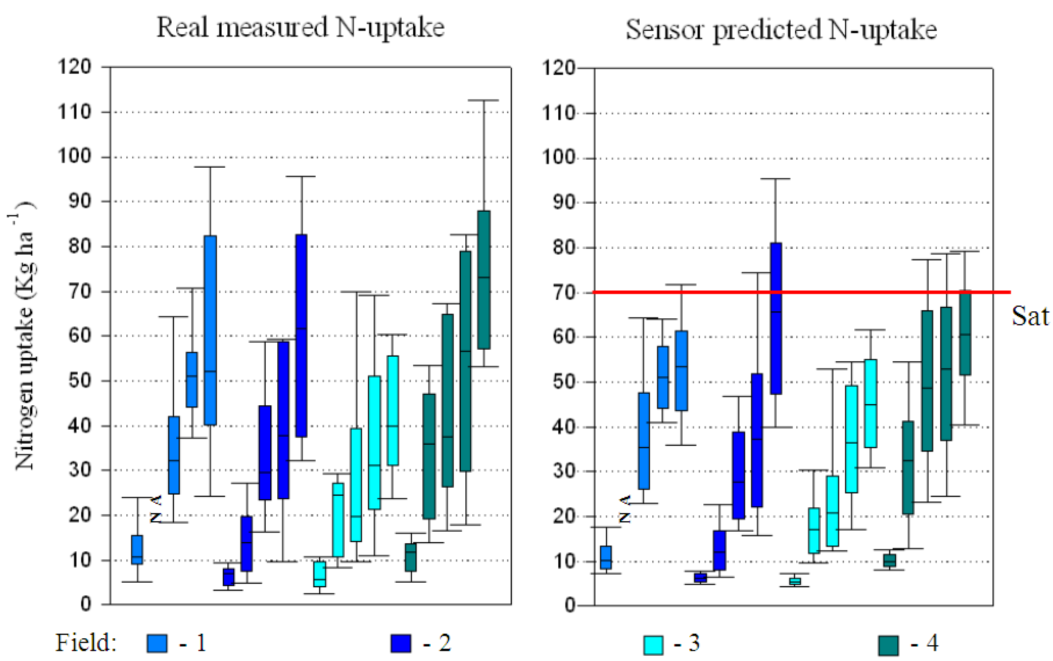

Figure 4: Sugarcane real measured N-uptake compared to sensor predicted N-uptake for the four fields of the early season (dry season).
Observations: Sat = saturation point, NA = Not available data.

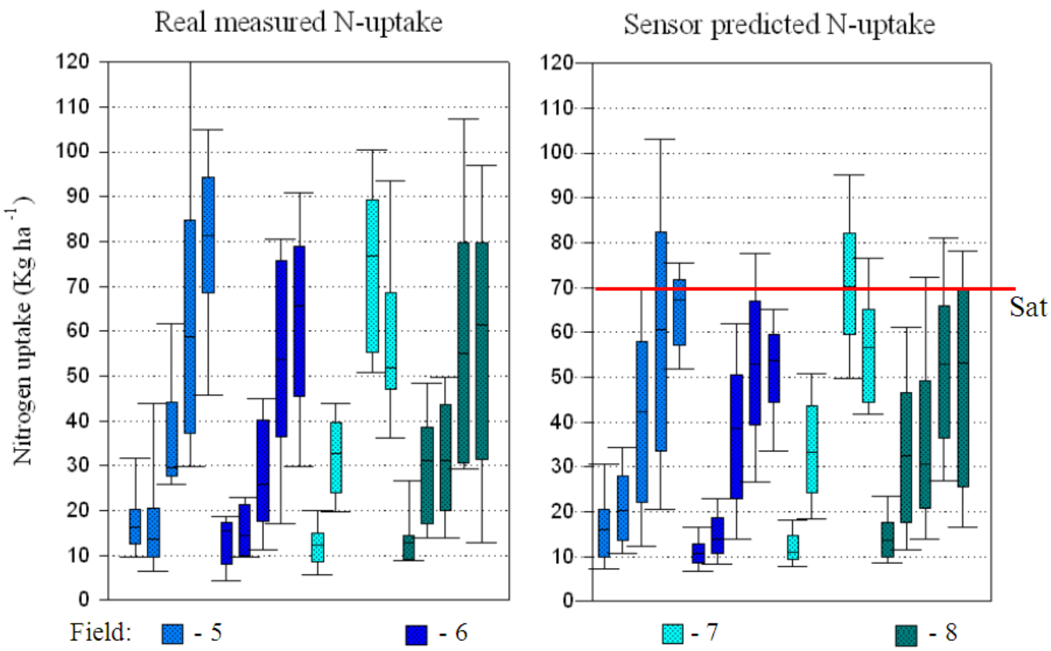

Figure 5: Sugarcane real measured N-uptake compared to sensor predicted N-uptake for the four fields of the late season (wet season).
Observations: Sat = saturation point, NA = Not available data.

The N-uptake values follow the biomass trend as they are the dry matter multiplied by the N concentration of the field samples. But the sensor saturation is not so clear on the N-uptake, partly explained because when the plant grows the biomass increases but the N concentration decreases (data not shown). In this way sensor saturation does not show so early when the intention is to predict nitrogen and not biomass, what is good because the main target is to predict N use by the crop.

The sensor can predict N-uptake until around 70 kg N ha^{-1} with high accuracy, but having deviations in some fields and heights. There is an explanation for the second field (Fig. 4) not showing saturation at the 0.6 m height like the others; the sensor scanning was made in a very warm day in the afternoon (2:00 pm) during a very drought period and the crop was presenting closed leaves to preserve water. This plant reaction led to a decrease in canopy cover reducing the values read by the sensor without biomass decrease.

On the wet season (Fig. 5), fields 5 and 7 had predicted N-uptake values over the proposed sensor saturation line of 70 kg of N ha^{-1} on the 0.5 m measurement, but at the 0.6 m stem average height both field presented lower values indicating that the saturation phenomenon appears.

At 0.5 m stem height the sugarcane canopy is almost closed (Fig. 1). Further increase of biomass is mainly due to stem elongation and not to the development of additional leaves. This is a crop characteristic that also has a negative impact on the sensitivity of the sensor reading, and contributes to the signal saturation at 0.6 m crop height.

Aiming to solve all doubts about a the N-uptake during the growth stages and the performance of the sensor, a second analyses was done comparing directly real N-uptake and sensor predicted N-uptake by correlation curves as shown in Figure 6.

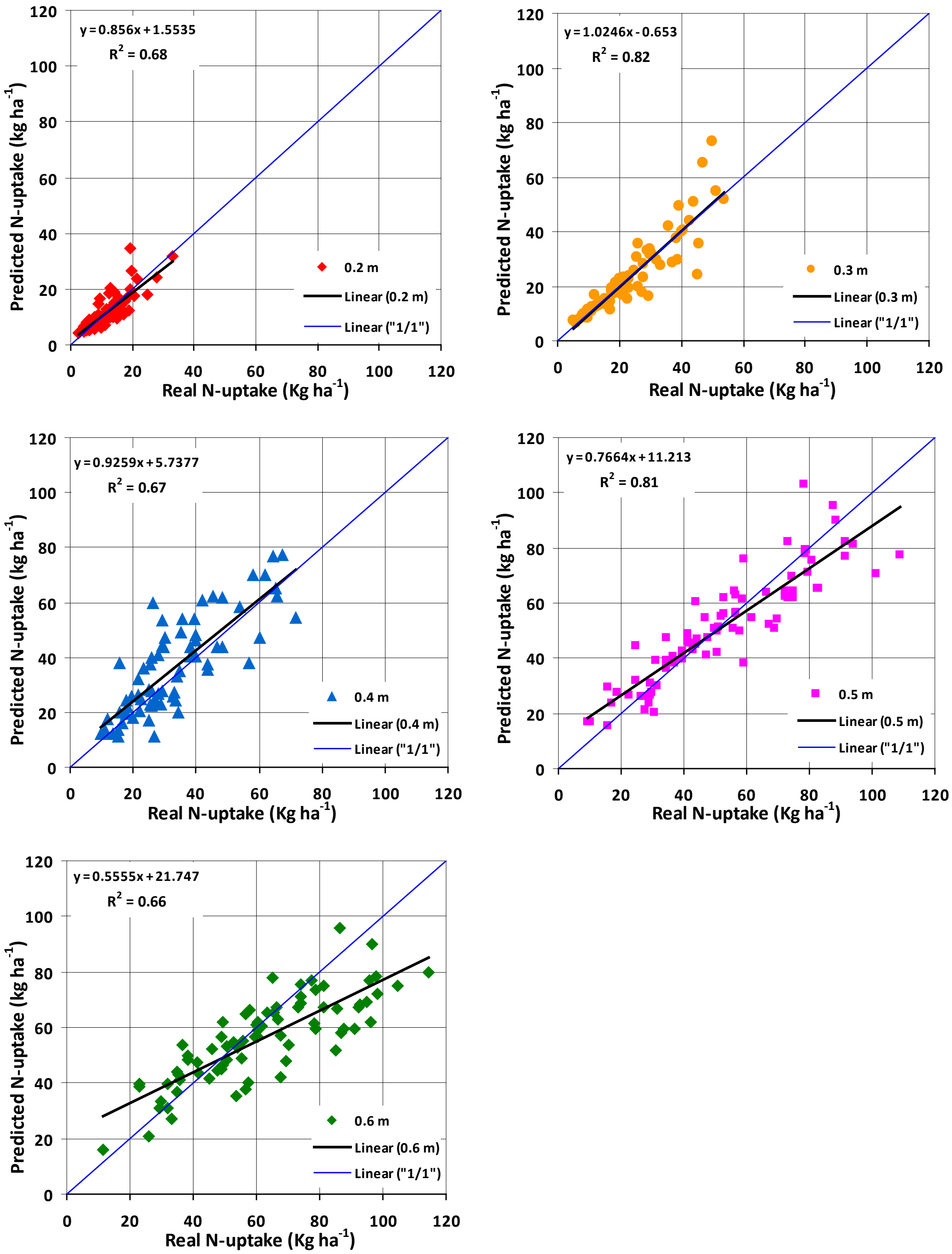

Figure 6: Sugarcane real measured N-uptake compared to sensor predicted N-uptake for the five measurement heights.

As noted by Portz et al. (2012), pooling the data of different fields in a single set is possible, as the relationship is not affected by soil and variety properties and season effects. This is very important when looking for agronomic algorithms to guide nitrogen application, because there is no need for growth stage or soil specific algorithms, which simplifies the task significantly. At 0.2 m stem height the values are low and concentrated, with most values under 20 kg N ha^{-1}, indicating that measurements at this height are too early to obtain good information about in-field variability from the sensor. The 0.3 m and 0.4 m crop height data show a good N uptake prediction from 10 to 60 kg N ha^{-1} and 15 to 70 kg N ha^{-1} respectively. The 0.5 m crop height data represent a wider range of N-uptake predictions (20 to almost 100 kg N ha^{-1}), but the saturation phenomenon starts to appear. At 0.6 m average crop height many spots exist in the field with even higher crop, i.e. stems heights of 0.7 to 1.0 m, what causes saturation on the sensor decreasing the sensor accuracy on these places. The data of the three most suitable measurement heights combined in a single data set are presented in Figure 7.

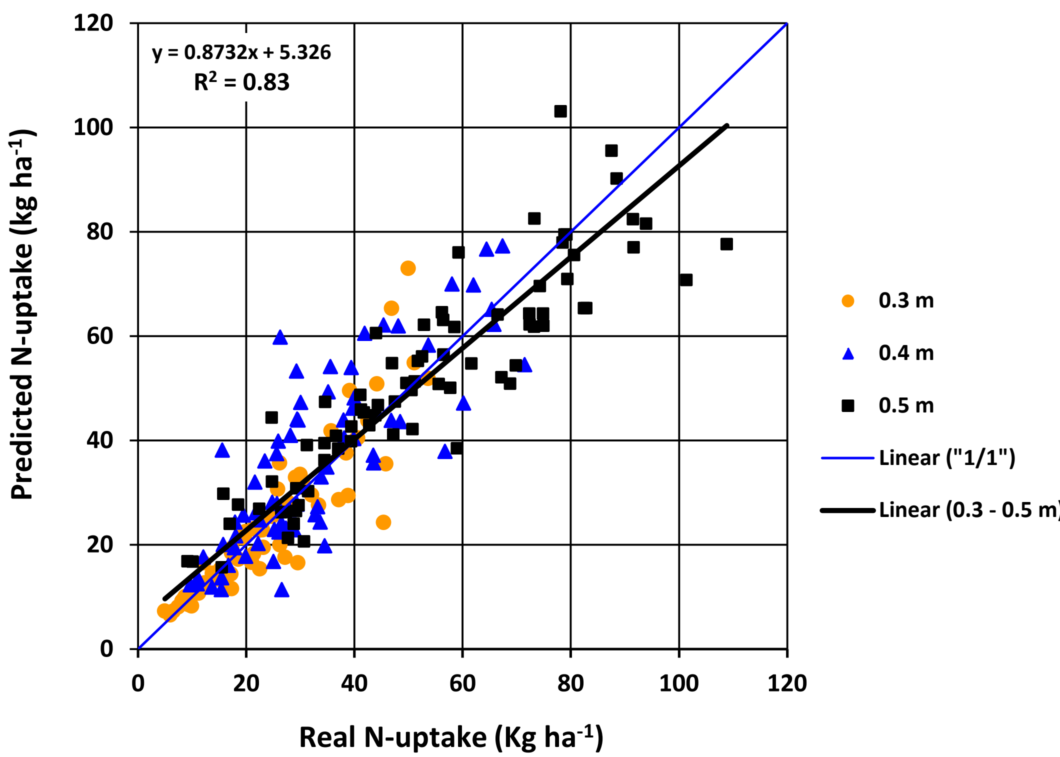

Figure 7: Integration of sugarcane real measured N-uptake compared to sensor predicted N-uptake for the 0.3 to 0.5 meter heights.

Using only the crop heights of 0.3 to 0.5 m there is a significant improvement in the prediction of nitrogen uptake initially presented by Portz et al. (2012). Not by a higher coefficient of determination (R^2) for the correlation, but by its slope that is closer to the 1 to 1 line, indicating less deviation of the predicted N uptake from real values.

CONCLUSIONS

At 0.2 m of field average stem height, sugarcane biomass is too low for a good sensor based prediction of in-field variability of crop biomass and N-uptake.

At 0.6 m crop height the phenomenon of signal saturation begins to affect the ability of the sensor to accurately predict biomass and nitrogen uptake.

Between 0.3 and 0.5 m of average stem height results show the best correlation between real and sensor predicted biomass and nitrogen uptake for a sugarcane crop, indicating that this is the right period for using the sensor to guide variable rate nitrogen application.

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REFERENCES

FAO. 2012. Food and Agriculture Organization, Faostat. Accessed on April 05, 2012.: Available on-line at <http://faostat.fao.org/>.

Heege, H.J.; Reusch, S.; Thiessen, E. 2008. Prospects and results for optical systems for site-specific on-the-go control of nitrogen-top-dressing in Germany. Precision Agriculture, Dordrecht, v. 9, n. 3, p. 115-131.

Jasper, J., Reusch, S. and Link, A. 2009. Active sensing of the N status of wheat using optimized wavelength combination – impact of seed rate, variety and growth stage. In: Van Henten, E.J., D. Goense and C. Lokhorst (eds.), Precision agriculture ’09. Proceedings of the 7th European Conference on Precision Agriculture. July 5-8, Wageningen, The Netherlands: 23-30.

Link, A., J. Jasper, and S. Reusch. 2005. Suitability of different crop parameters for the determination of site-specific nitrogen fertilizer demand. In: Stafford, J. V. (ed.), Precision Agriculture ’05. Proceedings of the 5th European Conference on Precision Agriculture. June 9-12, Uppsala, Sweden.

Mokhele, T.A.; Ahmed, F.B. 2010. Estimation of leaf nitrogen and silicon using hyperspectral remote sensing. Journal of Applied Remote Sensing, Amsterdam, v. 4, p. 18, Nov.

Mutanga, O. & A. K. Skidmore (2004) Narrow band vegetation indices overcome the saturation problem in biomass estimation. International Journal of Remote Sensing, 25, 3999-4014.

Portz, G.; Molin, J.P.; Jasper, J. (2012) Active crop sensor to detect variability of nitrogen supply and biomass on sugarcane fields, Precision Agriculture. Volume 13, 1, Page 33-44. DOI 10.1007/s11119-011-9243-4.

Reusch, S. (2005). Optimum waveband selection for determining the nitrogen uptake in winter wheat by active remote sensing. P. 261-266. In: Stafford, J. V. (ed.), Precision Agriculture '05. Proceedings of the 5th European Conference on Precision Agriculture. June 9-12, Uppsala, Sweden. Wageningen Academic Publishers, Wageningen, The Netherlands.

Silva, C. B., M. A. F. D. de Moraes & J. P. Molin (2010) Adoption and use of precision agriculture technologies in the sugarcane industry of SÃ£o Paulo state, Brazil. Precision Agriculture, 1-15.

Singh, I., Srivastava, A. K., Chandna, P., & Gupta, R. K. (2006) Crop sensors for Efficient Nitrogen Management in Sugarcane: Potential and Constraints. Sugar Tech.

Solie, J.B.; Raun, W.R.; Stone, M.L. Submeter spatial variability of selected soil and Bermuda grass production variables. Soil Science Society of America Journal, Madison, v. 63, n. 6, p. 1724-1733, Nov./Dec. 1999.

Thenkabail, P. S., Smith, R. B., and De Pauw, E., (2000) Hyperspectral vegetation indices and their relationships with agricultural crop characteristics. Remote Sensing of Environment, 71, 158–182.

Todd, S. W., Hoffer, R. M., and Milchunas, D. G., (1998). Biomass estimation on grazed and ungrazed rangelands using spectral indices. International Journal of Remote sensing, 19, 427–438.

Tucker, C. J., (1977), Asymptotic nature of grass canopy spectral reflectance. Applied Optics, 16, 1151–1156.