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PREDICTION OF SUGARCANE YIELDS IN COMMERCIAL FIELDS BY EARLY MEASUREMENTS WITH AN OPTICAL CROP CANOPY SENSOR

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Abstract. *As a grass (Poaceae), sugarcane needs supplemental mineral nitrogen (N) to achieve high yields on commercial production areas. In Brazil, N recommendations for sugarcane ratoons are based on expected yield and the results of N response trials, as soil N analyses are not a suitable basis for decisions on optimum N fertilizer rates under tropical conditions. Since the vegetative parts in sugarcane are harvested, yield components such as the number of stalks and stalk height are directly correlated with crop biomass, which, at early growth stages, can be determined by a vehicle mounted optical crop canopy sensor. With the aim to investigate the relationship between the vegetation index (VI) obtained from early season crop canopy sensing and final yield, a study on three commercial sugarcane fields located in the state of São Paulo, Brazil was conducted between 2010 and 2013. The fields included in the investigation ranged in size between 10 and 16 hectares and represented typical soils for sugarcane production, with soil textures ranging from sandy to clayey, where sugarcane of different ages (1st, 2nd, and 3rd ratoon crops) was grown. The harvest of the cane occurred in September/October (end of the dry season). After the previous harvest, all fields* *were soil sampled (0 - 0.25 m depth) on a 0.5 ha regular grid for chemical and physical soil attributes. After sprouting, during the early season, fields were scanned with an optical crop canopy sensor (N-Sensor® ALS, Yara International ASA). On one field, these measurements were repeated three times (at approximately 0.2, 0.4, and 0.6 m stalk height) and on the two other fields just once, at 0.4 m of stalk height. After maturation, fields were mechanically harvest (no burning) with a harvester that was equipped with a yield monitor system, logging data points every two seconds. The yield data was filtered to eliminate errors and noise. Using a GIS software, buffer zones with a diameter of 20 m were created around the georeferenced soil sampling points. Average values for the measured sensor VIs and yields were calculated for the data points located within a certain buffer zone and related to each other and the respective soil properties. Finally, all factors were correlated in a matrix. From all the sampled parameters, optical sensor VI was the only one with stable good correlation with yield on all three study fields. At a stalk height of approx. 0.4 m on average in the field, correlation coefficients (r) for this relationship ranged between 0.5 and 0.6. The optical canopy sensor seems to be a valuable tool to predict in-field variability of yields. As the expected yield is the predominant factor for decisions on optimum N fertilizer supply in sugarcane production systems, this gives the opportunity for a crop sensor based variable rate nitrogen fertilizer application, aiming for improved nitrogen use efficiency (NUE) in this crop.*

Keywords. *N-uptake, proximal sensing, N-Sensor*

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Introduction

Sugarcane (*Saccharum officinarum*) is the main crop for sugar and ethanol production in the tropics and sub-tropics, with Brazil being the leading producer with circa 750 million tons of cane produced over 10 million hectares (FAO, 2016).

As a grass (Poaceae), sugarcane needs supplemental mineral nitrogen (N) to achieve high yields on commercial production areas. In Brazil, sugarcane is produced primarily under rainfed conditions and nitrogen recommendations vary from 60 to 140 kg N ha^{-1}. As soil N analyses are not a suitable basis for decisions on optimum N fertilizer rates under tropical conditions, N recommendations are based on the average expected yield for a given field situation, estimated by the farmer/consultant and entered into a recommendation table based on results of N response trials from research institutions (Raij, 1997). This recommendation system does not take into account the infield variability of sugarcane yield potential and subsequent N demand.

Adoption of precision agriculture (PA) to manage soil/crop according to its spatial needs is a likely prerequisite for higher yields (Bramley, 2009) and to improve sugarcane nitrogen use efficiency (NUE). In this respect, the use of a ground-based active crop canopy reflectance sensor (canopy sensor) has been proposed by Singh et al. (2006), aiming at detecting infield spatial variability and adapting N rates accordingly.

Sugarcane is cultivated as a semi perennial crop that is replanted to counteract yield degradation every 3 - 10 years under Brazilian conditions. The yield potential is reduced year after year from the first ratoon, due to stubble damage, especially caused by harvest operations, which increases natural infield variability. Sugarcane yield potential is defined by three elements: number, length and thickness of the stalks, with the number and height of stalks being the major factors (Silva, et al., 2009). Both parameters are closely related to early season crop biomass that can be measured by vehicle mounted optical crop canopy sensors (Portz, et al., 2012; Amaral et al., 2015).

Crop fertilization based on canopy sensing is a reality, especially in cereals. But for sugarcane the implementation of such an approach is slow, in parts because of the difficulty to obtain reliable yield maps, due to the present lack of a robust, commercially available sugarcane yield monitoring system (Jensen et al., 2010).

Working with small field plots and handheld sensors, Lofton et al. (2012) and Amaral et al. (2015) showed a consistent positive correlation between in season vegetation index (VI) measurements and final sugarcane yields. Based on that, the present study conducted on commercial sugarcane fields, aims to investigate the relationship between early season VI readings obtained from a crop canopy sensor mounted on top of a high clearance vehicle and final yield obtained by an improved yield monitoring system mounted on a sugarcane harvester.

Material and methods

Description of Fields: A study on three commercial sugarcane fields located around the São Martinho Mill (21º19´11´´S, 48º07´23´´W) in the state of São Paulo, Brazil was conducted between 2010 and 2013. The fields included in the investigation ranged between 10 and 16 hectares and represented typical local soils for sugarcane production, with soil textures ranging from sandy to clayey. The study also comprised of sugarcane crops of different ages (1st, 2nd, and 3rd ratoon crops). The harvest of the cane occurred in September/October (end of the dry season) (Table 1).

Table 1. Characteristics of the study site

Field	1	2	3
Variety	Sp80-3280	CTC 2	CTC 2
Size (ha)	12	10	16
Harvest	Sep 11	Oct 13	Sep 12
Soil	claye	sandy	sandy to claye
Ratoon	2nd	1st	3rd

Data collection: After the previous harvest, all fields were soil sampled (0 - 0.25 m depth) on a 0.5 ha regular grid for chemical and physical soil attributes. After sprouting, during the early season, fields were scanned with an optical crop canopy sensor (N-Sensor® ALS, Yara International ASA) mounted on top of a high clearance vehicle (Jacto Uniport NPK). The scanning was done with a distance of nine rows (13.5 m) between passes, at a travel speed between 12 and 15 km ha^{-1} and a data logging frequency of one second.

The Yara N-Sensor ALS is comprised of a transmitter with a xenon flashlight, providing high intensity illumination between 650-1100 nm and a 10Hz receiver with two photodiodes and interference filters of 730-760 nm in front of them measuring the proprietarily defined vegetation index (Jasper at al., 2009). On Field 3, these measurements were repeated three times (at approximately 0.2, 0.4, and 0.6 m stalk height) and on the two other fields just once, at 0.4 m stalk height.

After maturation, fields were mechanically harvest (no burning) with a one row harvester Case IH 8800 (Case IH Agriculture, Piracicaba, SP, Brazil) that was equipped with a yield monitor system (SIMPRO – Enalta, São Carlos, SP, Brazil) that consists of a weight cell platform installed on the stalk elevator as described by Magalhães and Cerri. (2007). Data logging was improved from provider default of 15 seconds to record yield points every two seconds, aiming at a consistent amount of data to be filtered without deterioration of the final yield data set (Fig. 1).

Fig 1. Data collection by crop canopy sensor scanning (A) at early season and harvest with yield monitor (B)

Data analysis: The canopy sensor VI data were processed by using a geographic information system (QGIS, 2016) to cut data outside field boundaries and display collected VI points as classified values (Natural Breaks) on a five-color legend for better visual map analysis.

As sugarcane yield monitors are still under development, yield data had to be intensively processed (Fig. 2). After cutting points outside field boundaries, yield raw data had to be normalized and adjusted by the weight of the trucks coming from each field: This was followed by a geospatial data filtration to eliminate errors and noise, comparing the values point by point with their neighbors on a radius of 15 m and eliminating values with a coefficient of variation above 20%, using the filtering method proposed by Spekken et al. (2013).

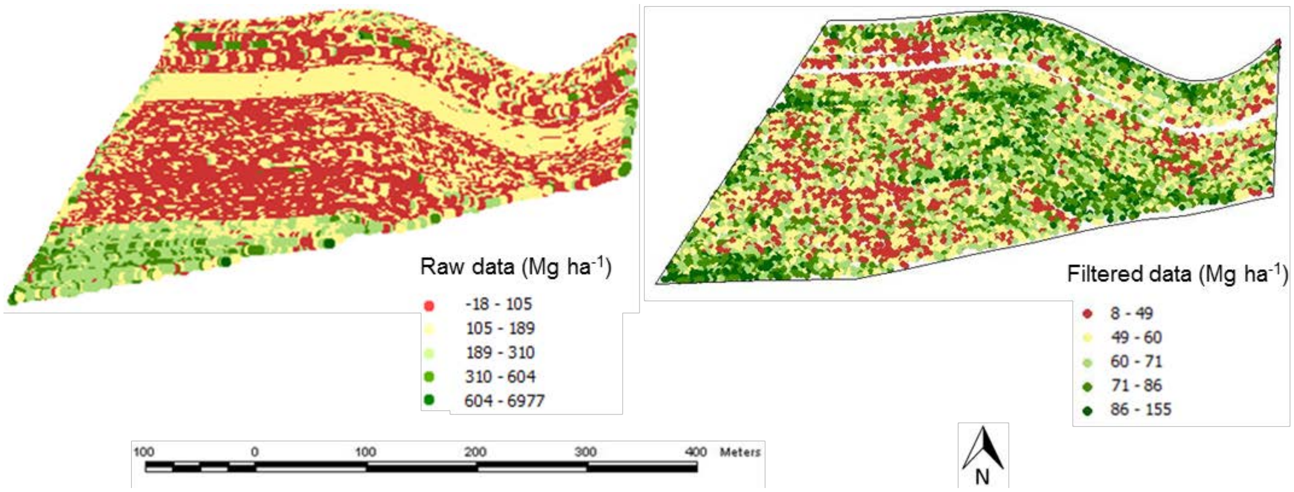

Fig 2. Field 2 yield monitor raw data map (left) and filtered yield data map (right)

After this pre-processing, buffer zones with a diameter of 20 m were created around the geo-referenced soil sampling points for early season sensor VI and final yield maps. Average values for the measured sensor VIs and yields were calculated for the data points located within the buffer zones (Fig. 3) and related to each other and the respective soil properties by a correlation matrix. Finally, early season VIs were correlated with final yields using a simple linear model.

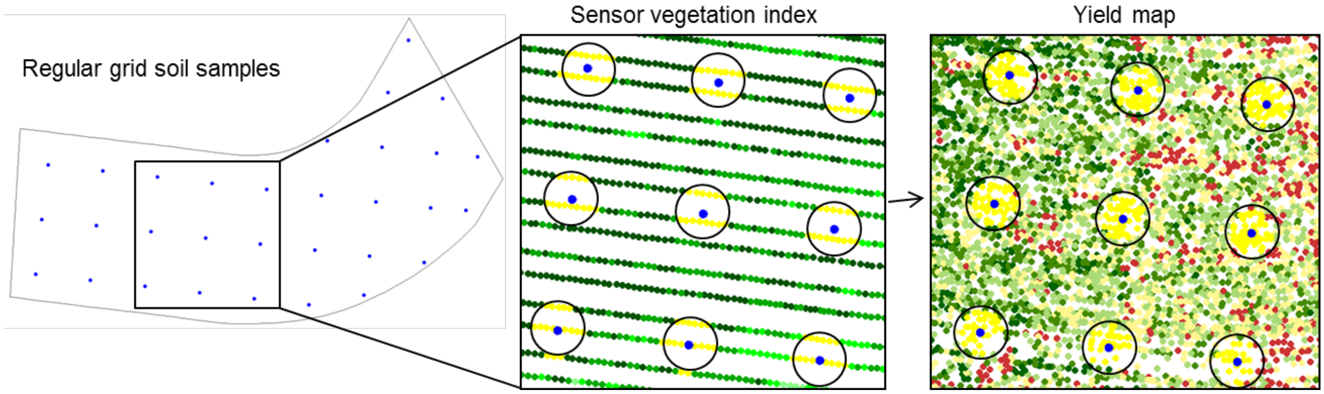

Fig 3. Extraction of average sensor VIs and yield values from 20 m buffers around soil sample points

Results and discussion

Figure 4 shows maps of the filtered and classified sensor VIs and yield data for Fields 1 and 2.

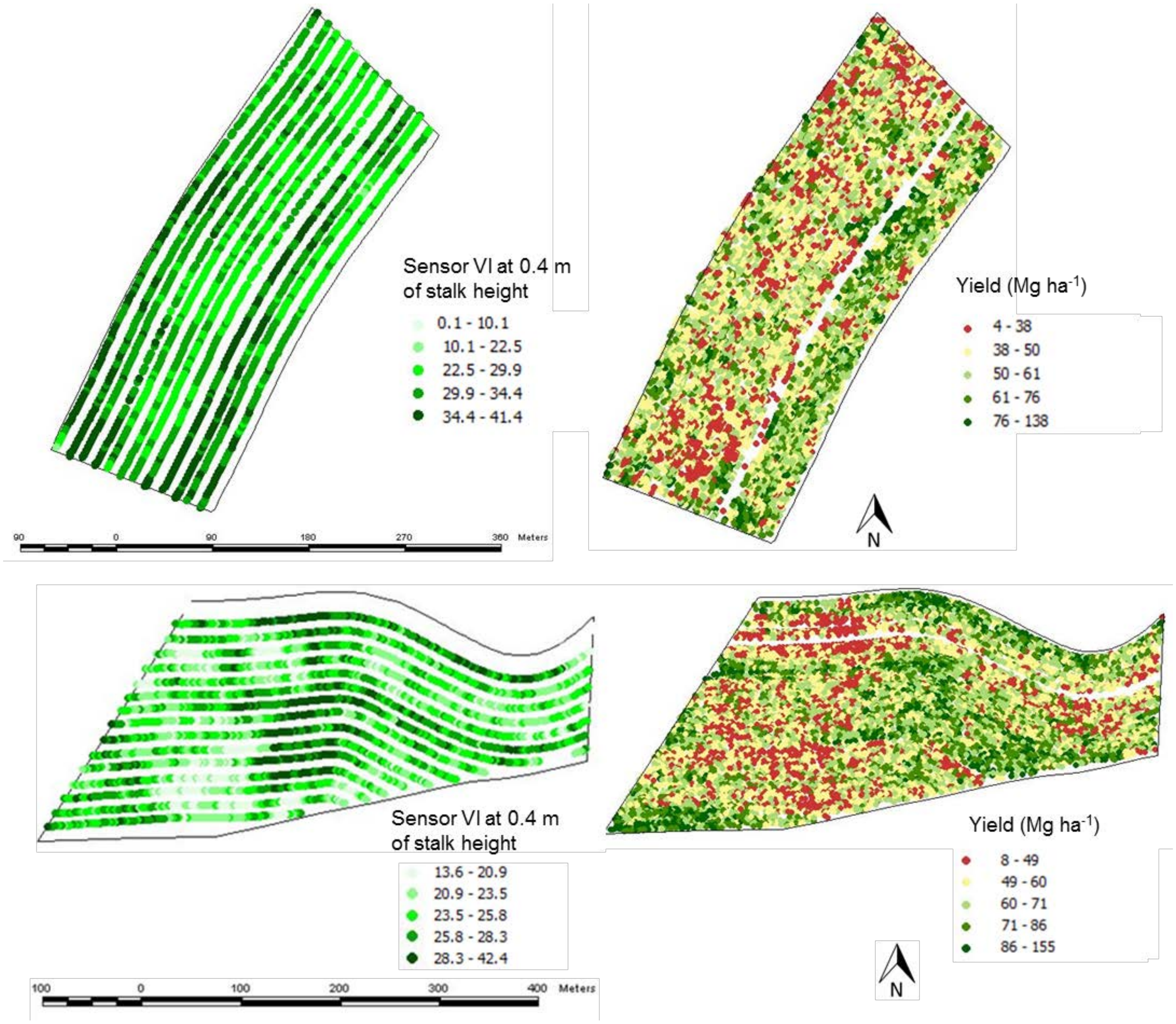

Fig 4. Sensor VI and yield monitor points for Field 1 (above) and Field 2 (below)

Canopy VI and yield maps both are showing distinct spatial variability inside the fields. By a critical visual inspection of the two maps of one field, it is possible to detect similar spatial patterns despite the differences in sensors technologies and crop age (8 to 10 months' time interval between the data acquisition). Table 2 shows the correlation matrix of soil parameters, canopy sensor VI and yield data for fields 1 and 2.

Table 2. Pearson correlation matrix of sensor VI, yield and soil parameters for the buffers on Field 1 and Field 2

Field 1	pH	OM	P	S	Ca	Mg	K	H - Al	CEC	CLAY	VI 0.4	YIELD
VI 0.4	0.19	0.31	0.13	-0.06	0.21	0.32	0.02	-0.05	0.27	-0.26	1.00	
YIELD	0.35	0.22	0.05	-0.25	0.35	0.30	-0.14	-0.34	0.01	-0.01	**0.56**	1.00
Field 2												
VI 0.4	-0.19	0.34	0.15	-0.19	0.06	-0.06	-0.15	0.05	0.04	-0.31	1.00	
YIELD	-0.03	0.38	0.64	-0.13	-0.03	-0.19	-0.38	-0.32	-0.15	-0.61	**0.60**	1.00

Analyzing the Pearson correlations among all analyzed parameters for Field 1, revealed that on this clay soil field only sensor VI had an expressive correlation with final yield (r = 0.56). On Field 2, the final yield was also strongly correlated with sensor VI (r = 0.60), but also with the phosphorus and organic matter content of the soil (r = 0.64 and r = 0.38, respectively), showing that on this sandy soil yield was influenced by these two factors. For some unknown reason, clay also correlated negatively with yield, but the clay content in this sandy field just varied between from 7-16 %. Figure 5 shows the linear correlation of normalized yield and VI for Field 1 and Field 2 using the sample point buffer values.

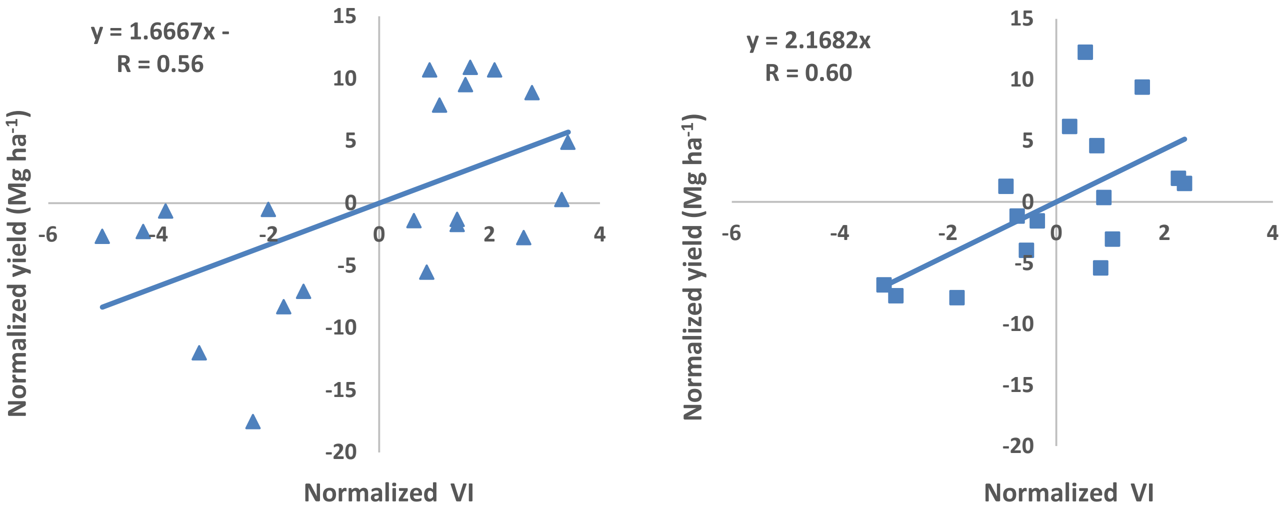

Fig 5. Correlation of normalized VI and yield points for the buffers around soil samples on Field 1 (left) and Field 2 (right)

Early season VI and final yield were positively correlated on both fields, with similar correlation coefficients (0.56 on the clayey and 0.60 on the sandy soil). On the clayey soil (Field 1) a difference of one sensor VI unit show yield difference of 1.67 tons, whereas on the sandy soil (Field 2) a VI difference of one unit resulted in a difference of 2.17 tons of final yield. Figure 6 shows sensor VIs at 0.2, 0.4 and 0.6 m average stalk height and the yield data map for Field 3.

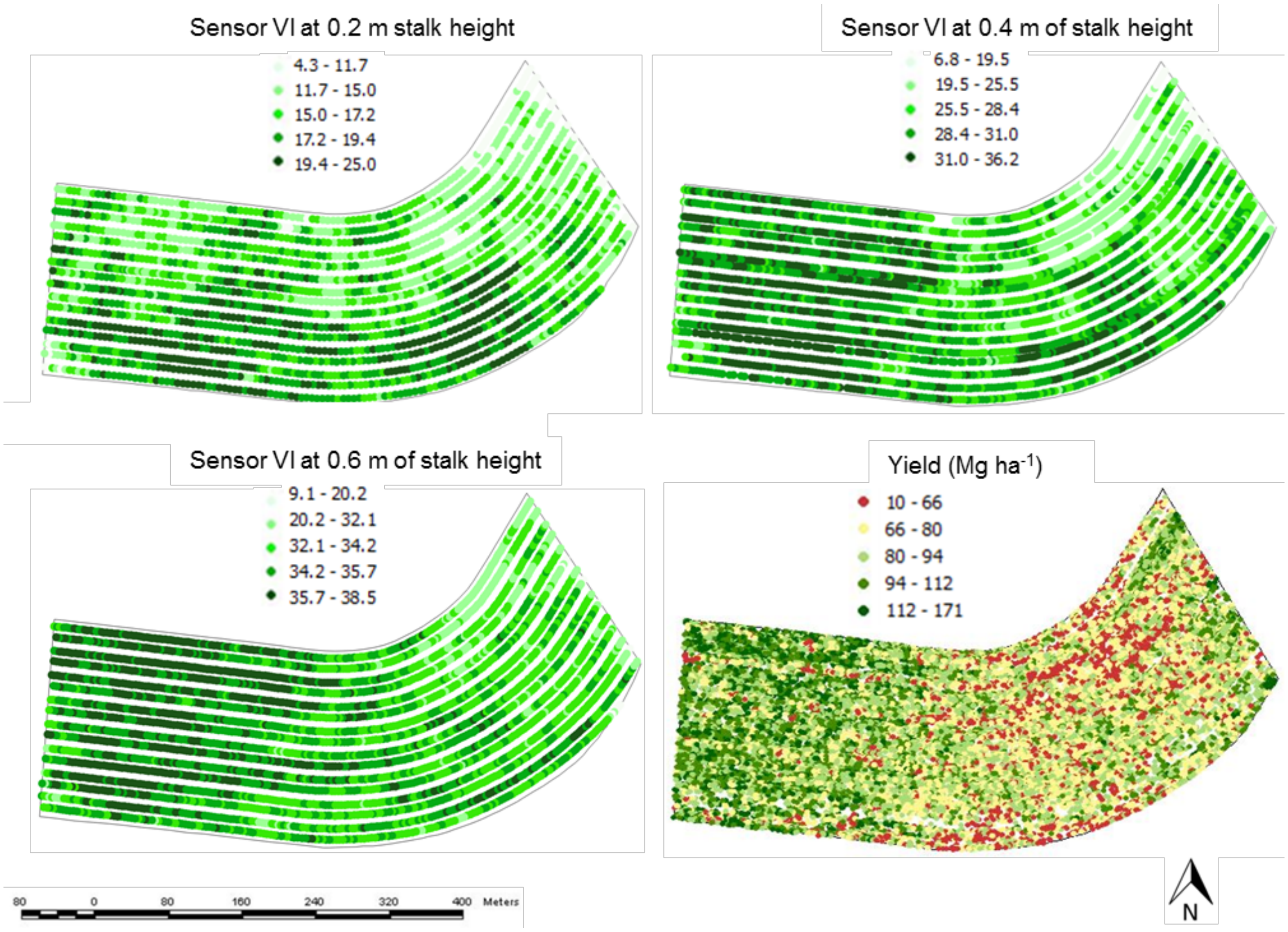

Fig 6. Sensor VI (0,2, 0.4 and 0.6 m) and yield monitor points maps for Field 3

As on Field 1 and Field 2, distinct spatial variability of sensor VI and yield can be seen on the data point maps of Field 3, with similar areas of low and high values among the dates of data acquisition, except for VI at 0.2 of stalk height. By comparing the maps of sensor VI (0.4 and 0.6 m of stalk height) and yield, spatial patterns similarities among early season VI and final yield on the sugarcane crop are visible. Table 3 shows the correlation matrix of soil sampling results and sensors data for Field 3.

Table 3. Pearson correlation matrix of sensor VI, yield and soil parameters for the buffers on Field 3

Field 3	pH	OM	P	S	Ca	Mg	K	H -Al	CEC	CLAY	VI 0.2	VI 0.4	VI 0.6	YIELD
VI 0.2	0.04	0.35	0.11	0.10	- 0.16	0.14	0.35	0.30	0.03	0.32	1.00			
VI 0.4	0.05	0.53	0.16	0.02	0.19	0.33	0.59	0.53	0.40	0.69	0.77	1.00		
VI 0.6	0.20	0.54	0.29	0.12	0.39	0.42	0.62	0.44	0.54	0.70	0.55	0.84	1.00	
YIELD	0.31	0.74	0.34	0.27	0.65	0.60	0.75	0.51	0.79	0.91	0.27	0.66	0.65	1.00

As Field 3 was scanned three times during the season, it was also possible to determine differences between the scanning dates and their suitability for decision making. Vegetation Index at 0.2 m of average stalk height showed low correlation with yield and soil parameters. This was due to the fact that at this early stage, crop sprouting was still ongoing and damage caused by the harvest (deeper or higher cuts) still influenced the above ground biomass development (Portz, et al., 2012). On the second and third scans (0.4 and 0.6 m stalk height), conducted about eight months before harvest, the VI data already showed similar patterns as the yield maps (Figure 6), indicating that, a productivity prediction based on the sensor scan was possible at this early growth stages already (r =

0.66 and r = 0.65, Table 3).

As this field had a soil gradient (20 to 60% clay) moving from sandy (east side) to clayey (west side) soil texture and productivity followed this gradient. Others parameters like OM, Ca, Mg, K, H-Al, and CEC that are correlated with soil texture, also showed a correlation with final yield and sensor VI. Figure 7 shows the linear correlation of normalized yield and canopy sensor VI (0.4m) using the sample points buffer values of Field 3.

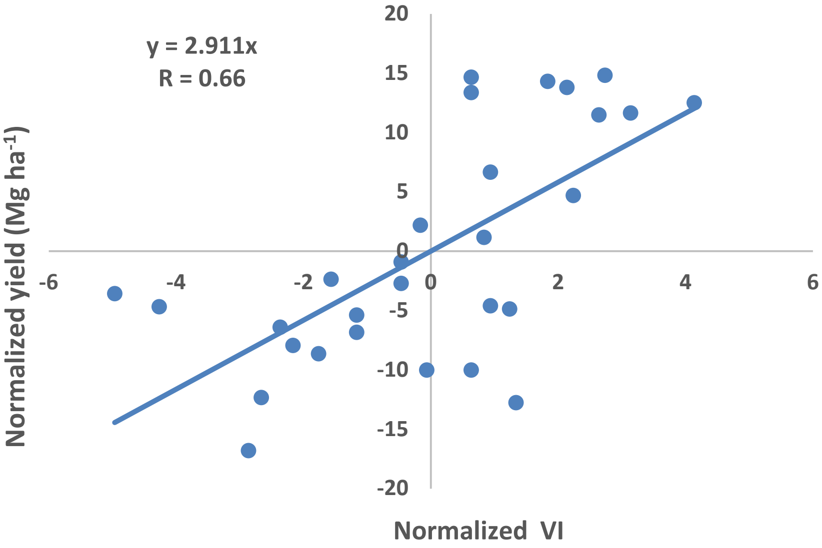

Fig 7. Correlation of normalized sensor VI and yield monitor points for the buffers around soil samples on Field 3

As on the other two fields of the investigation there was a positive relationship between early season VI and final yield, with one unit difference in canopy sensor VI measured at early season reflecting a yield difference of 2.9 tons.

Figure 8 shows the linear correlation of normalized yield and sensor VI using the data (measured at 0.4 m stalk height) from the sample point buffers of all studied fields.

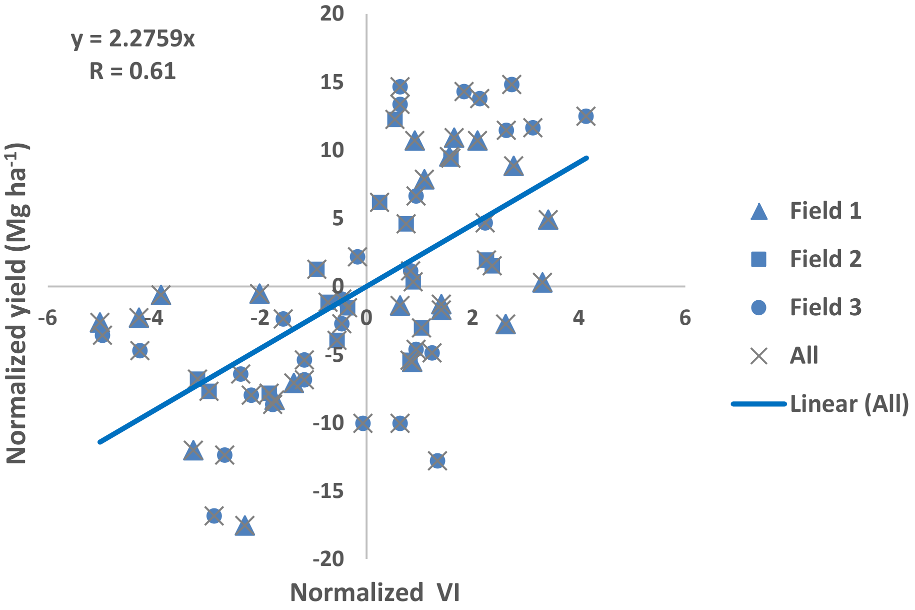

Fig 8. Correlation of normalized sensor VI and yield monitor points for the buffers around soil samples on all fields

A single linear regression could be fitted to the data, showing a positive correlation between yield and sensor VI. The slope of the correlation line indicates that for every unit difference in the VI a yield difference of 2.3 tons of harvested stalks can be expected. This relationship appears to be rather robust, taking into account that we are dealing with a biological production system, where data acquisition (VI and Yield) come from three fields, cultivated on different years and obtained by two distinct sensors, employed with 8 to 10 months apart. This knowledge could be used to do early season variable rate nitrogen fertilization based on canopy sensor yield prediction, aiming at improved fertilizer use efficiency.

Conclusions

The vegetation index (VI) obtained by measurements with a vehicle mounted crop canopy sensor at a sugarcane stalk height of approximately 0.4 m correlated with the final sugarcane yield, with correlation coefficients (r) ranging between 0.5 and 0.6. The optical canopy sensor therefore seems to be a valuable tool to predict in-field variability of sugarcane yields.

As the expected yield is the predominant factor for decisions on optimum N fertilizer supply in sugarcane production systems, this gives the opportunity for a crop sensor based variable rate nitrogen fertilizer application, aiming for improved nitrogen use efficiency in this crop.

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