OPTICAL SENSORS TO PREDICT NITROGEN DEMAND BY SUGARCANE

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ABSTRACT

The low effectiveness of nitrogen (N) from fertilizer is a substantial concern worldwide and has been threatening the sustainability of sugarcane production. The increment of nitrogen use efficiency (NUE) by sugarcane genotypes associated to the best practices of fertilizer management and nutritional diagnosis methods have a potential to reduce environment impacts of nitrogen fertilization. Due to the difficult to determine N status in soil test as well as there is no crop parameters to recommend N for sugarcane in Brazil, emerge the possibility to use optical sensor to monitor crop nutritional demand, such as those used to measure indirectly chlorophyll content as N status indicator. This technique is very common for scientific purposes, but for commercial fields it has few adoption. On the other hand, precision agriculture techniques may be one alternative to increase sustainability and crop production, and for localized management of fertilizers, mainly N-fertilizers, which will contribute to reduce N-fertilizer rate as well as decreasing environmental impacts. Therein it is evident that the application of N-fertilizer for sugarcane might not only be associated to the expected yield, methodology that has been applied by experts for recommendation of nitrogen fertilization. The diagnosis of nutritional status of N in sugarcane made by optical sensors "on-the -go" (real-time reading) seems to be one of the promising options to overcome this technological bottleneck. The aim of this work was to assess the nutritional diagnosis of sugarcane crop in N using active optical sensor, performing evaluation throughout the growth cycle of the crop. For this two experiments were established in sugarcane ratoon (2^{nd} ratoon), which has been green harvesting. The N-fertilization has increased crop yield in one of the experiments, where the maximum stalks yield was obtained using 100 kg ha^{-1} of N. In this experimental area, the Pearson correlation showed that NDVI data obtained at 90 days after harvest (DAH) by the optical active sensor was able to predict sugarcane yield showing a strong correlation to N rates applied (>90%). The N content in leaves (L+1) has the best correlation to N rates at 120 DAH, and at this time both optical sensor were able to predict the differences among treatments having correlation to N content in leaves. The results from this work showed an interesting possibility of predict N demand, which has been encouraging our group to evaluating more areas in order to obtain a N fertilizer response functions that relate sensor readings to the amount of N fertilizer needed to overcome crop N stress.

Keywords: NDVI sensor, nitrogen fertilization, precision agriculture, *Saccharum spp*.

INTRODUCTION

Brazilian agribusiness is currently characterized by the concept of sustainability, with socioeconomic implications and active environmental innovations in agricultural, agro-forestry and agro-industrial sectors. Bioenergy features prominently in the global economy, with emphasis on projected demand of ethanol from sugar cane, which offers a lower energy demand in the productive process (Pimentel; Patzek, 2007). The fact that the world sugar cane grown in Brazil stands out for the high photosynthetic efficiency in the tropical environment, giving high biomass productivity, sugar and derivative products, presents environmental competitive advantages to petroleum derivatives (Oliveira, 2011).

In this context, the search for increased efficiency of resource use by the culture, one of the alternatives is the use of precision agriculture (PA). Precision agriculture is a production system that involves the management of the crop according to the spatial variability of production (Seelan et al., 2003). Thus, the technologies inherent in the technology package of precision agriculture can be used individually or combined with a focus on sustainability of all agricultural production (Tey et al., 2012). These technologies (acquisition of spatial information, monitors productivity, remote and proximal sensors) present technological advances in the production of cereals (Srinivasan, 2006), but needs more research and development to be used in the sugar cane production (Zamykal et al., 2009). In sugar cane production, a major challenge is the development of a diagnostic method for predicting the demand for N by the crop, given that today it is performed based on the expected productivity (Espironello et al., 1996).

The great importance of N for sugar cane sugar is related to the fact that being a *Poaceae* with carbon metabolism of the C4 type, characterized by high rates of net photosynthesis, being highly efficient in dry matter production

(Arruda, 2011). However, the use efficiency of this nutrient is still very low due to climate factors and especially the management. The lack of synchrony between N demand by the crop and fertilizer supply and the various sources of N in the soil-plant-atmosphere system is a cause of the low efficiency of this practice in sugarcane, associated with application uniform rate without taking into account the existing spatial variability within each plot (Solari et al., 2008). These facts can result in losses to farmers and environmental damage such as increased emissions of N_2O soil (Cerri et al., 2011). Thus, the N responsiveness by sugar cane sugar is presented as a crucial variable to be considered when recommending the application of N.

In order to overcome this challenge, we start from the hypothesis that N deficiency causes changes in the spectral behavior of the reflected light by the plants leaves (Tarpley et al., 2000), which makes it possible, by measuring these changes, perform the recommendation and nitrogen application. Optical sensors, which are characterized by using own source of light, have the principle that the spectral properties of plants leaves is modified by N deficiency, allowing the differentiation between zones for variable rate nitrogen fertilization. However, most studies have been conducted in crops such as wheat and corn (Portz et al., 2012).

One of the most studied vegetation index for the estimation of nutrition by N (Eitel et al., 2008), productivity (Teal et al., 2006) and chlorophyll content in leaves (Wu et al., 2008) is the Normalized Difference Vegetation Index (NDVI). Using the NDVI becomes possible, from different methodologies, the recommendation of fertilizer nitrogen in variable rate, either with real-time applications or governed by a recommendation map (Amaral and Molin, 2011). In the culture of sugar cane, research using Optical Sensors were performed in order to measure the concentrations of N and K applied to the soil. The sensor was unable to detect the different doses of potassium applied, however, the reflectance index followed an increasing trend with N levels, thus demonstrating the ability of the sensor to be used in the identification of nitrogen deficiency in culture (Inamasu et al., 2006). Similar results for detecting a deficiency of N in sugar cane were also observed by other authors in Brazil (Frasson, 2007; Solari et al., 2008; Molin et al., 2010; Amaral et al., 2012; PORTZ, 2011; PORTZ et al., 2012). In the U.S. Lofton et al. (2012), working with optical sensor in sugar cane, showed a positive correlation exists between NDVI and sugar cane yield when compared the treatments with N application at a variable rate and without the application of N.

Thus, the researches to evaluate the correlation between the N applied in the sugar cane with NDVI, in order to achieve the application of variable rate, are new and require new information due to the fact that the culture present a long cycle, being susceptible to interference from weather phenomena which may be the cause of the great variability of production in crop area (PORTZ et al., 2012), and most importantly, not be consolidated for use in commercial sugarcane fields. The aim of this work was to assess the nutritional diagnosis of sugarcane crop in N using active optical sensor, performing evaluation throughout the growth cycle of the crop.

MATERIAL AND METHODS

Study Area

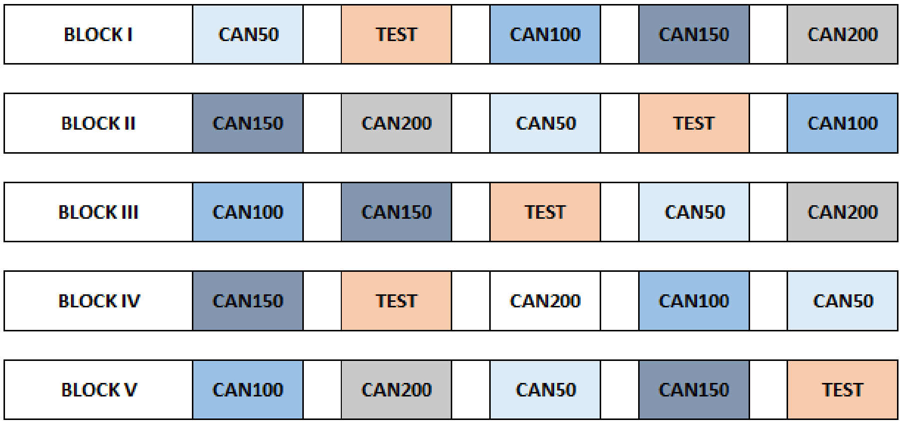
The experiment was developed in two commercial field belongs to Noble Bioenergy sugar mill located in Tabapuã, São Paulo state, Brazil (20º34’00’’ S; 49º00’00’’ W) at 515 m a.s.l. The climate is classified by Köeppen as Aw, with minimal air temperature 19.7º C and maximum in 25.3ºC. The total rainfall accumulated in experimental period was 1389.1 mm. The soils was classified as a Utisols (Soil Survey Staff, 2010) whose chemical and physical characteristics determined in the layers 0–0.20, 0.20 – 0.40, 0.40 – 0.60, 0.60 – 0.80 and 0.80 – 1 m are shown in Table 1..

Table 1. Chemical and physical characteristics of the soil in the experimental area.

Without vinasse – Site 1											
Depth	pH	^{a}TOC	P	K	Ca	Mg	CEC^{b}	V	Sand	Silt	Clay
m		g dm^{-3}	mg dm^{-3}	--------mmol$_{c}$dm^{-3}--------				%	-----------g kg^{-1}----------		
0- 20	5.9*	6	21	3.6	12	4	39.1	49	800**	24	176
20- 40	4.8	3	14	2.1	24	9	54.5	63	767	32	201
40- 60	5.0	5	6	2.9	15	4	38.6	57	694	30	276
60- 80	5.1	2	4	2.6	19	5	43.0	64	653	21	326
80- 100	5.4	1	3	2.8	24	5	45.9	70	643	31	327
With Vinasse – Site 2											
0- 20	6.1	7	76	5.6	31	7	52.7	84	824	51	125
20- 40	5.3	5	22	2.4	19	5	39.5	67	804	45	150
40- 60	5.8	4	5	2.7	26	6	46.9	74	685	39	276
60- 80	5.8	4	3	3.5	34	6	56.5	77	609	40	351
80- 100	5.9	3	3	2.6	37	7	61.4	75	592	32	377

*Analysis performed according to the methodology of Raij (2001), **Analysis performed according to the methodology of Embrapa (1997). ^{a}TOC: Total organic carbon;; ^{c}CEC: Cation exchange capacity.

The experiment was installed into two sites, one without vinasse application and other with application of 90 m^{3} vinasse which equivalent about 40 kg ha^{-1} N, the sugarcane cultivar used in both areas was RB955970 which was a third ratoon. The plots consisted of six rows of 10 m spacing 1.5 m apart. The all data was collected in center of four rows, discarding one each side of the plot with border. The treatments consisted of four doses of N (50, 100, 150 and 200 kg N ha^{-1}) as well as one control treatment, under a randomized block experimental design, with five replications (Figure 1). Nitrogen was applied in the form of Calcium ammonium nitrate (27 % N), manually after last harvest over the layer of straw at 0.20 m from the row.



BLOCK I	CAN50	TEST	CAN100	CAN150	CAN200
BLOCK II	CAN150	CAN200	CAN50	TEST	CAN100
BLOCK III	CAN100	CAN150	TEST	CAN50	CAN200
BLOCK IV	CAN150	TEST	CAN200	CAN100	CAN50
BLOCK V	CAN100	CAN200	CAN50	CAN150	TEST

Fig. 1. Experimental design: TEST-control; CAN-Calcium Ammonium Nitrate, and 50, 100, 150 and 200 kg ha^{-1} are the N rates applied.

Conduct of the Experiment, Sampling and Analysis of leaf N content

During sugarcane crop growth was performed evaluation of nutritional status of crop. This analyses happen at 60, 90, 120 and 180 DAH (Days After Harvest) where three method were used: collected of samples of standard leaves (leaf +1 - Top Visible Dewlap) to analyze N content; measurement of chlorophyll content of leaf+1 using a SPAD sensor (SPAD 502, Konica Minolta, Toquio, Japão) and crop canopy reflectance measurement made by active optical sensor (SOAT -ACS – 430, Crop Circle Holland Scientific, Lincon, NE, EUA). The values measured by SPAD 502 correspond to the amount of chlorophyll present in the plant leaf. The values are calculated based on the amount of light transmitted by LED in the leaf in two wavelength regions, a red LED (peak wavelength approx. 650nm) and an infrared LED (peak wavelength approx. 940nm). The Crop Circle ACS-430 incorporates its own polychromatic light source technology to illuminate plant canopy. The light source technology simultaneously emits visible and near infrared light from a single LED light source. The sensor measures reflectance in three bands simultaneously, 670 nm, 730nm and NIR bands, enabling the user to calculate classic vegetation indexes from a plant canopies such as the NDVI.

For determination the N content, samples of the 10 leaves dewlap (first leaf with visible ligule) purpose by Kuijper in Van Dillewijn (1952) were taken. After collection, the mid-rib was excised and 20 cm of the middle region was separated. These samples were dried in a forced air circulation oven at 65ºC. The samples were ground in a Wiley knife mill and stored in plastic containers with a snap-on lid. After dry and ground, was determined N content by the Kjeldahl method, as described by Malavolta et al. (1997). The chlorophyll content was determined using a chlorophyll meter (model SPAD-502, Konica Minolta, New Jersey, EUA), in each treatment five replications with 10 measurements each was performed, totaling 500 measurements per treatment. For NDVI measurements the sensor was passed about 1.0m above of canopy. In each sugarcane row within of plot 50 readings was made, being monitored four central rows per plot. At the end of each evaluation a means of NDVI was calculated.

The final harvest was performed at 360DAH in May of 2013. The sugarcane yield was obtained weighting the stalks from four central rows of each plot. The harvest was manual under green cane system.

Data Analysis

All the collected data were submitted to a statistical treatment. Measures of central tendency and dispersion were evaluated. The data that have a high density, such as NDVI and SPAD, were subjected to a pre-treatment in order to remove possible "*noise*" coming from the sensors and outliers. The pre-treatment was based on data standardization to mean zero and standard deviation 1 (one) by removing the normalized data outside the range of ± 3 of the normal distribution of data. Then, was calculated the means for all N indexes analyzed. The Pearson correlation test was used to check the trend of response obtained by sensors measurements and plant parameters analyzed during crop growth. After to check the best crop stage where the correlation was high, regression polynomial analyzes were performed.

RESULTS AND DISCUSSION

The first concern that must be taken into account to analyze our data is that the NDVI and SPAD indices should be evaluated separately (Table 2). SPAD index has become highly sensitive to changes in plant metabolism and chlorophyll content, whilst NDVI reflects variations of the biomass color and crop canopy. In addition, these indexes are obtained in different ways, being the SPAD measurements made directly on leaves whereas NDVI reflect the size of canopy. Further, NDVI is more susceptible to "noise" present in the environment, such as soil and straw in the early crop growth, when canopy is not completely established. This fact may be explained by coefficient of variation of both indexes. For instance, due to NDVI has low precision in the beginning of crop cycle, the CV obtained during first evaluation (60DAH) was almost always higher than 20%, regardless to experimental site (Table 2). During the others evaluation the CV of NDVI measurements decreased substantial achieving data smaller than 6% at 180DAH. For SPAD this behavior was quite different because the data of CV was often less than 10%. Probably this took place because this methodology of plant nitrogen nutrition not suffers interference of noise from field. For N content of leaves +1 the CV data were very similar those calculated to SPAD data, varying from 1 to 17%, showing small variation at 180DAH.

Table 2. Descriptive statistics of NDVI, SPAD and N+1 performed at 60, 90, 120 and 180 DAH

DAH	N	Trat.	NDVI					SPAD					N+1				
			Mean	Min.	Max.	S.D.	C.V.	Mean	Min.	Max.	S.D.	C.V.	Mean	Min.	Max.	S. D.	C.V.
60	0	V	0.386	0.30	0.48	0.095	24.68	41.539	39.08	43.01	1.839	4.43	23.400	21.10	25.30	1.913	8.18
		NV	0.365	0.24	0.46	0.103	28.06	45.692	43.37	50.29	3.148	6.89	23.600	21.60	26.00	1.818	7.71
	50	V	0.379	0.26	0.48	0.112	29.68	42.575	41.04	43.50	1.078	2.53	25.050	23.80	27.30	1.584	6.32
		NV	0.466	0.36	0.63	0.118	25.27	48.141	45.70	49.68	1.707	3.55	25.100	22.80	27.30	1.838	7.32
	100	V	0.318	0.26	0.41	0.070	21.97	42.378	37.18	46.90	4.045	9.55	23.100	19.90	25.10	2.270	9.83
		NV	0.355	0.30	0.41	0.046	12.96	45.948	40.20	51.63	5.078	11.05	24.875	19.90	27.80	3.551	14.28
	150	V	0.336	0.25	0.48	0.111	33.11	44.086	42.57	45.74	1.644	3.73	24.350	23.50	25.90	1.136	4.66

		NV	0.382	0.29	0.47	0.091	23.86	46.399	43.41	49.50	3.123	6.73	25.000	23.20	26.30	1.512	6.05
	200	**V**	0.375	0.29	0.41	0.055	14.77	43.695	41.77	44.63	1.301	2.98	24.875	22.80	26.50	1.535	6.17
		NV	0.477	0.44	0.51	0.031	6.60	47.219	43.54	51.91	3.890	8.24	26.825	22.40	31.10	3.553	13.24
90	**0**	**V**	0.428	0.33	0.57	0.113	26.43	41.825	39.09	44.03	2.574	6.15	21.700	19.70	23.10	1.608	7.41
		NV	0.534	0.46	0.64	0.077	14.42	40.295	38.66	43.20	2.010	4.99	20.950	17.00	22.90	2.671	12.75
	50	**V**	0.516	0.41	0.58	0.072	14.03	44.055	40.84	47.64	2.785	6.32	23.775	22.40	24.70	0.978	4.11
		NV	0.564	0.49	0.61	0.056	9.84	42.868	40.07	46.03	2.696	6.29	21.450	19.50	23.60	1.678	7.82
	100	**V**	0.472	0.40	0.54	0.054	11.37	42.524	36.97	49.89	5.378	12.65	24.700	23.90	25.90	0.864	3.50
		NV	0.605	0.54	0.66	0.051	8.42	42.760	41.52	45.58	1.895	4.43	21.650	20.70	22.70	1.047	4.84
	150	**V**	0.520	0.42	0.61	0.102	19.69	46.930	41.44	49.62	3.773	8.04	26.575	24.20	30.30	2.711	10.20
		NV	0.644	0.62	0.67	0.021	3.21	48.106	43.66	50.42	3.087	6.42	22.675	21.40	24.10	1.118	4.93
	200	**V**	0.548	0.41	0.62	0.098	17.85	44.808	40.04	47.23	3.358	7.49	23.925	23.10	24.60	0.618	2.59
		NV	0.630	0.51	0.70	0.085	13.55	47.896	46.43	49.96	1.622	3.39	21.475	18.60	23.70	2.268	10.56
120	**0**	**V**	0.458	0.39	0.50	0.048	10.54	39.978	35.31	44.15	3.745	9.37	13.875	12.60	15.00	1.024	7.38
		NV	0.428	0.30	0.52	0.097	22.65	41.178	36.15	44.91	3.675	8.92	12.850	10.70	14.10	1.502	11.69
	50	**V**	0.501	0.47	0.58	0.056	11.11	43.412	40.60	46.10	2.319	5.34	16.275	15.30	17.50	1.097	6.74
		NV	0.461	0.37	0.56	0.079	17.08	39.954	36.61	43.07	2.851	7.13	13.400	11.90	15.80	1.734	12.94
	100	**V**	0.423	0.32	0.51	0.081	19.14	42.001	38.97	48.33	4.274	10.18	16.825	16.00	18.00	0.954	5.67
		NV	0.537	0.50	0.62	0.055	10.19	41.376	37.40	44.86	3.386	8.18	14.800	14.10	16.60	1.208	8.16
	150	**V**	0.521	0.41	0.63	0.091	17.53	45.875	38.96	50.39	4.866	10.61	16.600	15.40	17.20	0.816	4.92
		NV	0.504	0.42	0.57	0.059	11.64	42.353	38.23	46.58	4.041	9.54	15.500	12.70	17.50	2.028	13.08
	200	**V**	0.465	0.44	0.50	0.026	5.50	44.279	38.51	50.33	4.859	10.97	16.950	14.60	18.60	1.682	9.92
		NV	0.488	0.32	0.55	0.110	22.46	41.642	39.21	44.89	2.376	5.71	16.150	15.00	18.80	1.784	11.05
180	**0**	**V**	0.693	0.66	0.72	0.028	3.98	40.675	35.27	44.24	3.881	9.54	14.175	10.80	16.40	2.480	17.49
		NV	0.684	0.64	0.73	0.039	5.74	40.625	39.10	43.30	1.875	4.62	18.300	17.80	19.10	0.560	3.06
	50	**V**	0.702	0.66	0.72	0.029	4.19	40.760	38.31	41.79	1.640	4.02	15.600	14.30	17.60	1.568	10.05
		NV	0.702	0.69	0.71	0.007	1.06	40.525	38.00	42.60	2.081	5.13	20.250	20.00	20.70	0.311	1.54
	100	**V**	0.699	0.69	0.71	0.005	0.67	41.704	38.82	43.61	2.099	5.03	15.700	14.90	16.50	0.770	4.91
		NV	0.703	0.68	0.72	0.014	1.95	39.975	39.30	41.20	0.842	2.11	19.975	18.50	21.80	1.401	7.01
	150	**V**	0.717	0.69	0.77	0.035	4.93	41.250	38.35	43.42	2.566	6.22	16.650	15.40	18.30	1.212	7.28
		NV	0.692	0.68	0.70	0.007	0.94	39.050	38.50	39.60	0.532	1.36	20.575	19.60	23.00	1.626	7.90
	200	**V**	0.710	0.70	0.72	0.010	1.47	41.639	40.70	42.38	0.705	1.69	16.975	16.00	17.90	0.877	5.17
		NV	0.710	0.69	0.74	0.024	3.41	39.350	38.10	40.50	1.034	2.63	20.525	20.10	20.90	0.386	1.88

Trat.: Treatment; V:With Vinasse; NV:Without Vinasse; DAH:Days After Harvest; Dos.:N Rate Applied kg.ha^{-1}. N+1: N content of Leaf +1; S.D.: standard desviation; C.V.: coefficient of variation;

As commented above, the NDVI presents low precision to identify crop canopy at the beginning of sugarcane crop cycle, showing high variability of data at the first evaluation (60DAH), which was verified in both experimental sites (Figure 2). On the other hand, at 90DAH in the area without vinasse application is possible to verify differences among N rates (treatments). The lack of strong differences among treatment in experiment under vinasse application may be related to extra N supply from vinasse, decreasing the benefits of N fertilizer application. However, at this moment (90DAH) seems to be the best option to monitor the crop relation to N demand due to the discrimination of N treatments in area without vinasse application. Indeed, the subsequent evaluation time there not was differences among treatments mainly at 180DAH indicating that the Crop Cycle was not able to detect the nutritional status of N of sugarcane.

For SPAD data measured at 60DAH and 90DAH show the differences among treatments, decreasing the differences and the value at 120DAH and 180DAH. The same behavior was noted to N+1 content (Figure 2). The decline of N content during crop season is expected and it is explained by dilution effect associated to increases of biomass production (Oliveira et al., 2013). Nevertheless, at 120DAH and 180DAH this methodology was able to separate N rates treatments indicating increases of N content as function of high N rates applied for both sites. For São Paulo, Brazil, Espironello et al. (1997) recommend that foliar diagnosis in sugarcane must be performed around 120DAH, because during this growth phase there is a stronger correlation to nutritional state and crop yield.

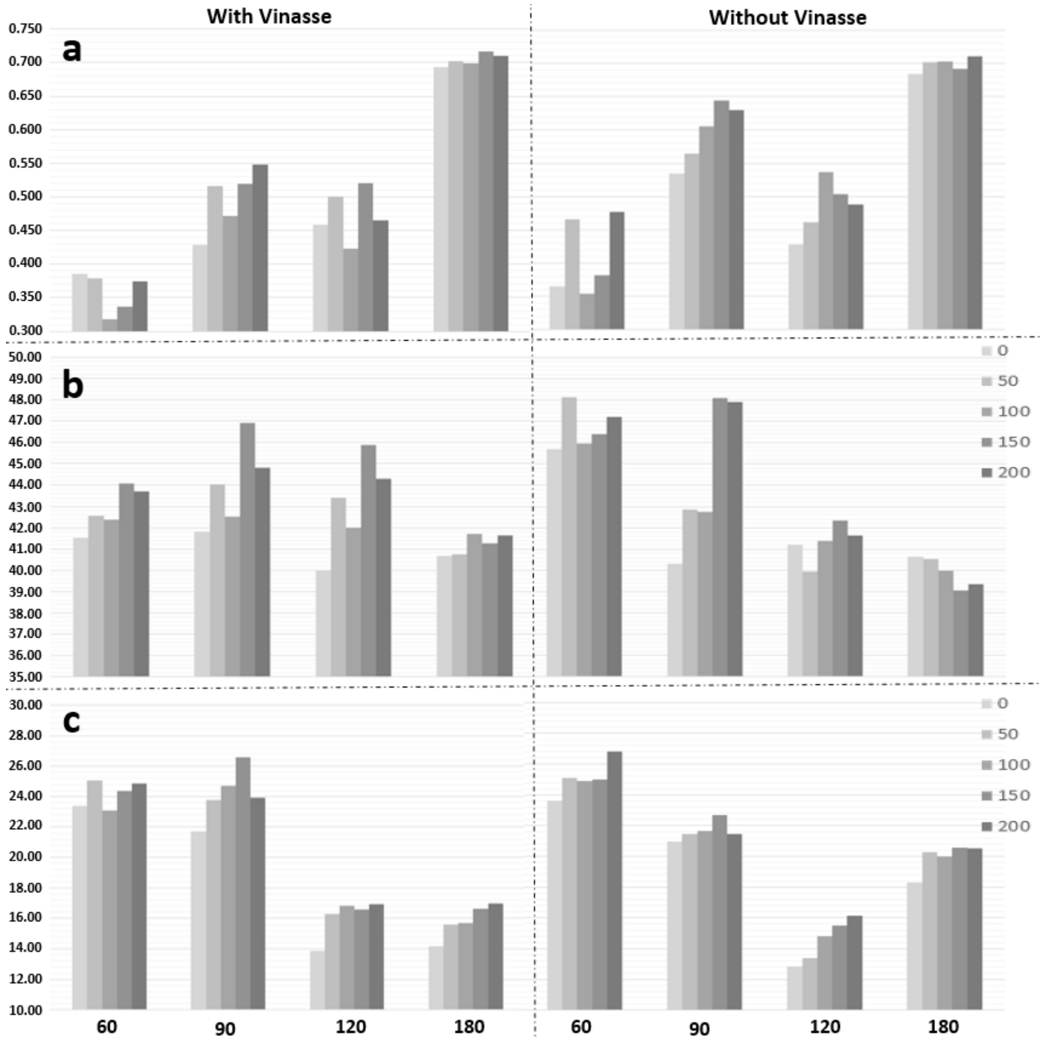


Fig. 2. NDVI (a), SPAD (b) and N+1 (c) evaluated at 60, 90, 120 and 180 days after harvest related to N rates (0, 50, 100, 150 and 200kg ha^{-1}) .

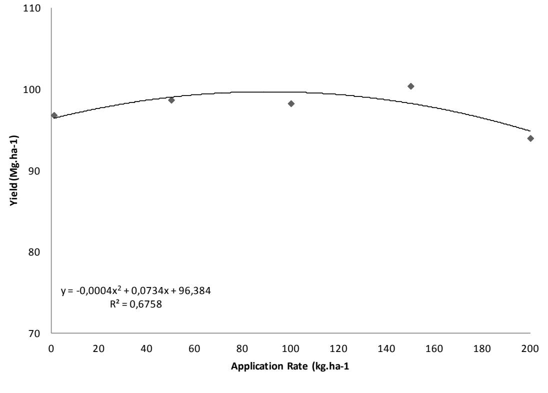
The N-fertilizer application promotes increases of sugarcane yield, being the highest crop yield obtained to 150 and 100 kg ha^{-1} N respectively in the area without vinasse and with vinasse (Table 3), showing quadratic behavior as function of N rates application (Figure 3). However at the vinasse application site low increments were obtained to N fertilizer application, which may be explained by N present in vinasse, because the sugarcane crop yield was similar between sites. Indeed, sugarcane fields under vinasse application during long time present low probability to have increments in crop yield due to N fertilizer application (Otto, 2012) as demonstrated by Franco et al. (2010) and Otto (2012). According to Trivelin et al. (1998) vinasse has high amounts of potassium and around 30 to 60 kg ha^{-1} N which can be used by sugarcane crop. This fact highlights the need to calibrate a method to predict N demand in sugarcane to avoid environmental impacts and economic losses from N fertilization practices.

Correlation analysis between N rates and methods of N diagnosis were performed during crop growth until 180DAH (Table 4). AT 60 DAH the best correlation was obtained between SPAD and N rates in the experiment under vinasse application, whereas in the area without vinasse the best correlation took place between N content of leaf+1 and N rates. For both sites NDVI had week correlation to N rates at 60DAH. Nevertheless, at 90DAH in both sites, but especially in experiment without vinasse), the Crop cycle was able to identify the differences among N rates (Table 4), having R^2 of 0.7 and 0.9 respectively to area with vinasse and without vinasse (Figure 3). Amaral (2014) using the crop cycle in many sugarcane fields to monitor the N sugarcane crop under diferent N rates, verifying that the crop cycle sensor was able to detected the differences regarding to crop performance under different N regimes in 70% of fields, took place quadratic curve in 3 sites and linear adjust in 4 sites. In our work was obtained a quadratic curve as function of N rates application related to NDVI measurements performed at 90DAH (Figure 4).

Table 3. Sugarcane Yield (Mg ha^{-1}) evaluated at 360 DAH (Days After Harvest) related to N rates in two experimental areas.

Dos.	Mean	Min.	Max.	S. D.	C.V.
		With Vinasse			
0	96.9	81.1	117.1	15.4	15.9
50	98.7	94.0	102.6	4.5	4.6
100	98.3	85.5	111.1	11.	11.2
150	100.4	94.0	111.1	8.2	8.1
200	94.0	85.5	102.6	6.9	7.4
		Without Vinasse			
0	79.7	63.1	100.9	17.9	22.6
50	90.2	85.5	92.3	3.2	3.6
100	102.1	94.0	112.8	7.9	7.8
150	91.9	88.9	97.4	3.8	4.1
200	94.0	88.9	100.9	6.1	6.5

S.D.: standard desviation; C.V.: coefficient of variation; Dos.: N Rate Applied (kg ha^{-1}).



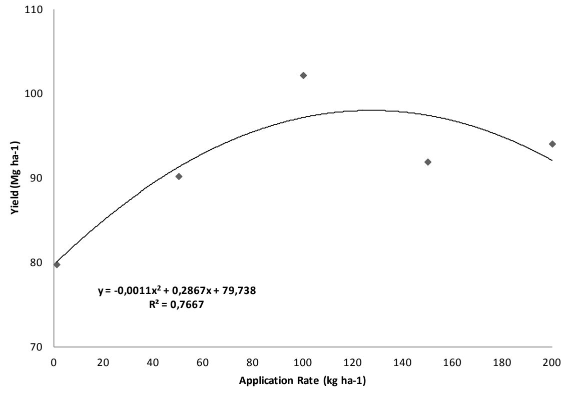


Fig. 3. Effect of N rates applied in sugarcane yield in areas with vinasse application (left) and without vinasse (right).

The results verified at 90DAH between N rates and NDVI data it is a good indicator about the possibility to use this sensor (Crop Cycle) during this stage of crop growth as predictor of N demand by crop. In sugarcane during this stage (90DAH) the plants are under intensive tillering (Casagrande, 1991), requiring substantial amounts of N to set up its photosynthetic apparatus, which indeed was noted by Oliveira et al. (2013) in sugarcane experiments (high rates of N accumulation around 90 DAH).

Relating to others times of evaluation it is possible to see at 120 and 180DAH there is a high correlation among N rates and N content of standard leaf for nutritional diagnosis in both sites. According to Espironello et al. (1996), this stage in sugarcane growth is ideal to collect samples of leaves to do nutritional diagnosis, which is proved by our results for N.

Table 4. Pearson´s correlation for the parameters measured during crop growth (60, 90, 120 and 180 DAH) and N rates.

Periods	N rate			
Parameters	60	90	120	180
With Vinasse				
NDVI	-0.341	0.818	0.135	0.830
SPAD	0.892	0.695	0.778	0.797
N+1	0.407	0.650	0.802	0.960
Without Vinasse				
NDVI	0.378	0.938	0.619	0.655
SPAD	0.205	0.934	0.604	-0.913
N+1	0.873	0.566	0.989	0.801

N+1: N content of Leaf +1;

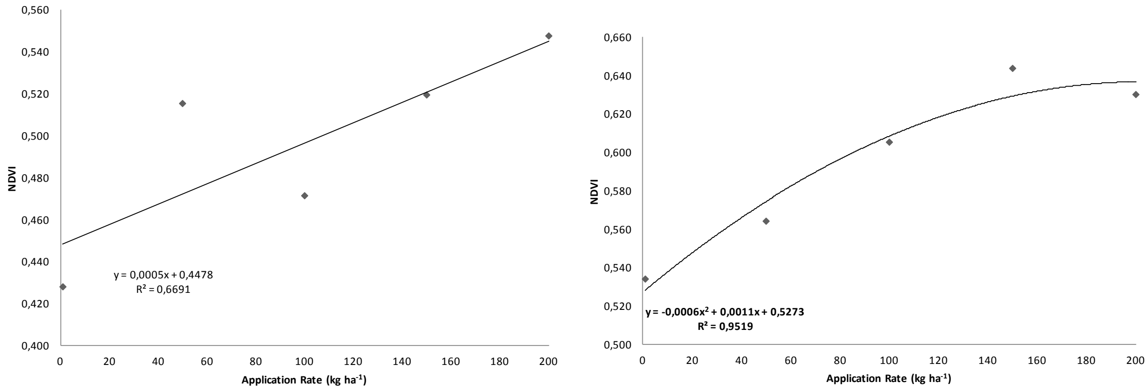


Figure 4. Relationship between NDVI parameter and N rate applied in sugarcane in two areas: with vinasse (left) and without vinasse (right) measured at 90DAH.

For correlation among N sensors (SPAD and Crop cycle) and N content f sugarcane leaves (Table 5) was obtained positive correlation between SPAD values and N content of L+1 during almost evaluation, except at 180DAH in site without vinasse. Probably this happened because at this growth stage there is an intensive N remobilization (Franco, 2008) from leaves to stalks which may be decrease the correlation between SPAD value and N content of L+1. Similar results were obtained by Argenta et al. (2003) and Ciganda et al. (2009). Further, this kind of results may be related to chlorophyll sensor performance under water stress condition. According to Jangpromma et al. (2010) the SPAD sensor is unable to predict N differences among treatment under differents N regimes because the measurement is impaired under water stress. Likewise, at 180 DAH the water balance (data not presented) was favorable to crop growth

For correlation between NDVI and N content of L+1 was noted for most part of evaluation took place positive correlation, indicating that NDVI may be used as predictor of N demand by sugarcane (Table 5).

Table 5. Pearson´s correlation for the parameters measured during crop growth (60, 90, 120 and 180 DAH) and N content of leaf +1.

Periods	N content of leaf +1			
Parameters	60	90	120	180
With Vinasse				
NDVI	0.456	0.579	0.091	0.902
SPAD	0.581	0.808	0.752	0.690
Without Vinasse				
NDVI	0.741	0.798	0.695	0.718
SPAD	0.565	0.725	0.683	-0.707

Finally, all data obtained by N diagnosis methods (NDVI, SPAD and N+1) were correlated to sugarcane crop yield performed at 360DAH (Table 6). In the site under vinasse application where the N fertilization was few effective to increase sugarcane yield the correlation were quite weak for all N diagnosis methods. However, the results of NDVI from the site without vinasse application were able to predict the sugarcane yield in 66% at 90DAH, 95% at 120DAH and 73% at 180DAH. This fact highlights the possibility of use of this sensor as N demand predictor in sugarcane associating the results of NDVI to variable N rate application. Mainly at 90DAH when still is possible to apply N fertilizer by machines coupled to tractors, because the size of crop is adequate. Further, it is possible to check the same behavior of response curve between NDVI measured at 90DAH and yield (Figure 6), and N rates against sugarcane yield (Figura 3) and NDVI at 90 DAH against N rates (Figura 4), which can be useful to set up a algorithm to apply N by variable rates using crop cycle as N diagnosis method.

Table 6. Pearson´s correlation for the parameters measured during crop growth (60, 90, 120 and 180 DAH) and Sugarcane Yield (Mg ha^{-1}).

Periods	Yield (Mg ha^{-1})			
Parameters	60	90	120	180

	With Vinasse			
NDVI	-0.512	-0.139	0.469	0.183
SPAD	0.083	0.314	0.258	-0.257
N+1	-0.142	0.560	0.060	-0.084
	Without Vinasse			
NDVI	0.010	0.661	0.950	0.727
SPAD	0.098	0.387	0.188	-0.457
N+1	0.528	0.413	0.638	0.693

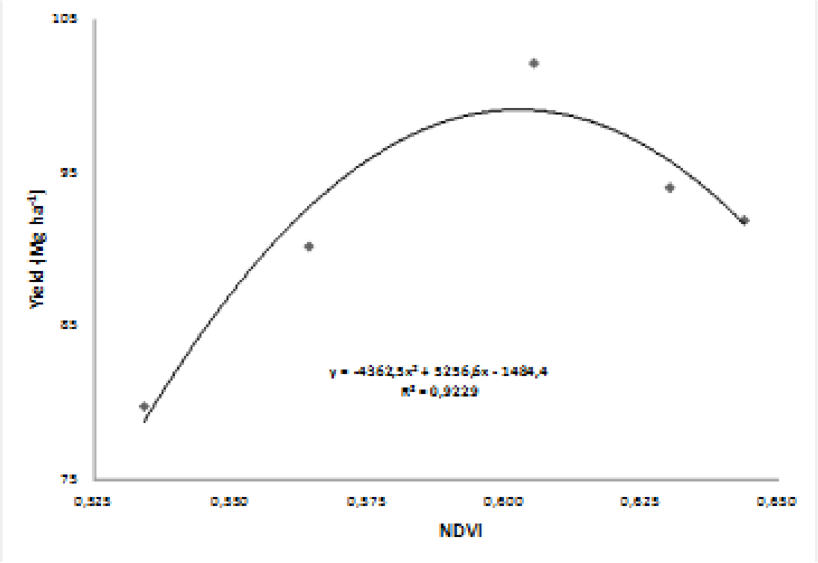


Fig. 5. Relationship between NDVI parameter and Yield in sugarcane crop in areas without vinasse application measured at 90DAH.

CONCLUSION

The N-fertilization has increased crop yield in one of the experiments, where the maximum stalks yield was obtained using 100 kg ha^{-1} of N. In this experimental area, the Pearson correlation showed that NDVI data obtained at 90 days after harvest (DAH) by the optical active sensor was able to predict 66% of sugarcane yield and to show a strong correlation to N rates applied (>90%). The general results appoint to a strong correlation between NDVI index and N demand by sugarcane, mainly in areas where N is missing into the soil. However, it is essential to obtain more data from field experiment to parameterize algorism of this measurement focusing N application by variable rate in sugarcane fields.

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