THE INTERNATIONAL SOCIETY OF PRECISION AGRICULTURE PRESENTS THE
13th INTERNATIONAL CONFERENCE ON
PRECISION AGRICULTURE
July 31-August 4, 2016 • St. Louis, Missouri USA

USE OF CROP CANOPY REFLECTANCE SENSOR IN THE MANAGEMENT OF NITROGEN FERTILIZATION IN SUGARCANE IN BRAZIL.

Sergio G. Quassi de Castro[1,2]; Guilherme M. Sanches[1]; Aline E. A. Silva[2]; Gabriel D. A. C. Moraes[2]; Henrique C. Junqueira Franco[1;] Paulo S. Graziano Magalhães[1,2]

[1] *Brazilian Bioethanol Science and Technology – CTBE/CNPEM - Brazil*

[2] *College of Agricultural Engineering, University of Campinas – FEAGRI/UNICAMP – Brazil*

Email: sergio.castro@bioetanol.org.br

A paper from the Proceedings of the
13th International Conference on Precision Agriculture
July 31 – August 4, 2016
St. Louis, Missouri, USA

Abstract. Given the difficulty to determine N status in soil testing and lack of crop parameters to recommend N for sugarcane in Brazil raise the necessity of identify new methods to find crop requirement to improve the N use efficiency. Crop canopy sensor, such as those used to measure indirectly chlorophyll content as N status indicator, can be used to monitor crop nutritional demand. The objective of this experiment was to assess the nutritional status of the sugarcane fertilized with different nitrogen rates applied at different periods after harvest, through diagnostic sensors in order to determine the parameters for sustainable application of N-fertilizer in sugarcane. This experiment was conducted during two seasons (2013-2014 and 2014-2015) and the experimental design was a randomized block with split plot with four replications. The plots were divided into different application periods of N fertilizer after the sugarcane harvest (0, 30, 60, 90, and 120 days after the harvest - DAH), and the split plots in five rates of nitrogen (0, 50, 100, 150 and 200 kg ha-1N). During the experimental period (30, 60, 90, 120 and 150 DAH), the biometric measurement was performed to evaluate the aboveground performance (number of tillers/stalks, and the number of green and dry leaves, into the split plots). The crop N status was evaluated through vegetation index (NDVI and NDRE) readings using a crop canopy reflectance sensor (ACS 430 Crop Circle – Holland Scientific). The N-fertilizer application period as well as, the rate of nitrogen applied to the ratoon, influenced the sugarcane yield. In the first crop season, the best N rate was 140 kg ha-1, applied at 0 or 60 DAH. In the second year, the best N rate to improve sugarcane yield was 100 kg ha-1 N, applied at 0 or 30

DAH. Crop Circle sensor was better correlated with the application periods and N rates during crop development, with good correlations with yield when the evaluations were done at 90 and 150 DAH. NDVI reading had a good correlation with the applications periods of N fertilizer and NDRE was more sensitive to N rates. The best time to use the crop canopy reflectance sensor is associated with lack of water stress. Crop Circle sensor can be considered an auxiliary tool to predict the real need of N fertilizer in sugarcane.

Keywords. *Precision Agriculture; Vegetation index; Yield.*

Introduction

The sugarcane crop (*Saccharum* spp.) is cultivated in tropical and subtropical regions of the world, mainly to obtain sugar, ethanol, and bioenergy from the straw and bagasse. Brazil has an extensive area with sugarcane crop (8.9 million hectares), and processed in the last season 655 million tons of sugarcane, whose average yield was 73 Mg ha^{-1} (CONAB, 2015). Therefore, Brazil is the world leader in the sugarcane production (FAOSTAT, 2015).

The nitrogen (N) is the most limiting nutrient for crop productivity worldwide (Malhi et al., 2001). Recommended N fertilizer applications for sugarcane are generally 60 – 150 kg N ha^{-1} year in Brazil (Cantarella & Rossetto 2014), and even more in other countries, such as India, Australia and Guatemala (Thorburn et al., 2011). This practice is due to many factors that affect the nitrogen use efficiency (NUE), such as soil characteristics (pH, CEC, organic matter, texture, clay, aeration and compaction), climatic conditions (temperature and rainfall) and agronomic practices (soil cultivation and crop rotation) (Subbarao et al., 2006).

The difficulties of assessing the availability of N in the soil, due to lack of diagnostic methods to quantify N in soil analysis, have driven the research for sensors that enable the realization of indirect measures of N nutritional status in the plants (Cantarella & Montezano, 2010). In this context, an alternative is the use of crop canopy reflectance sensors for N rate recommendation and measurement of plant development submitted N application (Amaral et al., 2015a).

In general, researchers have shown that the canopy reflectance sensor is able to predict the N rate and estimate the biomass plant, assisting in the N fertilization management in sugarcane crop (Lofton et al, 2012ab; Amaral et al, 2014; Franco et al, 2014; Amaral et al, 2015ab; Rosa et al, 2015). The literature also reported a study comparing the ability of three crop canopy reflectance sensors in predicting the N rate and biomass production by the plant (Amaral et al., 2015a), which mentions that the crop canopy reflectance sensor (ACS 430 Crop Circle) through NDVI and NDRE indexes achieved better correlation to the N rate applied in sugarcane, when compared to other sensors.

In this context, the main of this work was to assess the nutritional status of the sugarcane fertilized with different nitrogen rates applied at different periods after harvest, through canopy sensors in order to determine parameters for the sustainable application of N-fertilizer in sugarcane.

MATERIAL AND METHODS

The research was conducted in commercial area, with more 18 years of sugarcane cultivation, located in Sales Oliveira (20º52'31''S, 47º57'56'' W), Sao Paulo State, Brazil. The experimental area was cultivated with sugarcane variety IACSP95-5000, and the sugarcane is harvest in the beginning of crop season (April/May) in center south region of Brazil.

After harvesting the plant cane (2013) and before the installation of the treatments soil samples were taken to evaluate the soil fertility in the area (Table 1) according Raij et al. (2001). The soil was classified as Oxissol typical Eutrustox (Soil Survey Staff, 2010).

Table 1. Soil fertility in experimental area.

Depth	pH	SOM	S-SO_4	P	K	Ca	Mg	H+Al	Al	SB	CEC	V
m	$CaCl_2$	g dm^{-3}	--------mg dm^{-3}-------		-------------------------- $mmol_c$ dm^{-3} --------------------							%
0-0.2	5.2	40	6	11	1.3	30	12	39	0	43.0	82.0	52

0.2-0.4	5.3	38	9	10	1.8	37	10	39	0	48.1	86.7	53
0.4-0.6	5.5	32	13	9	0.7	37	8	33	0	45.5	78.3	57
0.6-0.8	5.8	20	10	8	0.7	29	6	24	0	35.1	59.3	56
0.8-1.0	5.7	14	46	5	0.7	22	4	23	0	27.0	50.4	47

PS: SB - Sum of Bases; CEC - Cation exchange capacity; V - Base saturation; SOM – Soil Organic Matter

The experimental design was a randomized block with split plot in four replications. The main treatments were N-fertilizer application time (0, 30, 60, 90 and 120 days after the harvest - DAH), and secondary treatments (split plots) were N rates (0, 50, 100, 150 and 200 kg ha^{-1} of N), totaling 100 plots. The nitrogen source was ammonium nitrate (33% N) applied on both sides of the sugarcane ratoon at 0.12 m of depth.

During the sugarcane growth cycle, assessments of nutritional status and crop morphological parameters in each split plot were conducted. The first evaluation was performed 30 DAH and the other at 60, 90, 120, and 150 DAH. The morphological parameters evaluated were: population density, by counting the plants at 20 meters in the four central rows of each split plot; height of 10 tillers/stalks (m) measured at the insertion of the TVD leaf (Top Visible dewlap), and counting the number of dry leaves and green leaves expanded, evaluated in the plants in which we measured the height.

The crop canopy reflectance sensor (ACS 430 Crop Circle - Holland Scientific, Lincon, NE) was used to perform reading while maintaining a fixed distance of 0.8 m in relation to the plant canopy as recommended by the manufacturer and adopted by Amaral & Molin (2011). The readings were always performed in two rows in each split plot, with an average of 150 points per row. Thus, the average value of NDVI (Normalized Difference Vegetation Index) and NDRE (Normalized Difference Red Edge Index) was calculated.

The sugarcane yield was evaluated in each sub plot, by counting in 2 m of the sugarcane row the number of stalks. After, the stalks were manually harvest and separated in dry leaves, tops, and stalks. All these parts of were weighed and sugarcane yield per hectare (Mg ha^{-1}) estimated.

During the experimental period, the meteorological data were monitored with the automatic weather station (Vantage Pro II - Decagon Devices, California - USA) located near the area, and the water balance (Thornthwaite & Mather, 1955) during the two growing seasons (Figure 1) was calculated.

All data were submitted to variance analysis and when significant, Tukey test was applied with 90% of confidence level (P <0.10) and linear or quadratic regression was used for N rates.

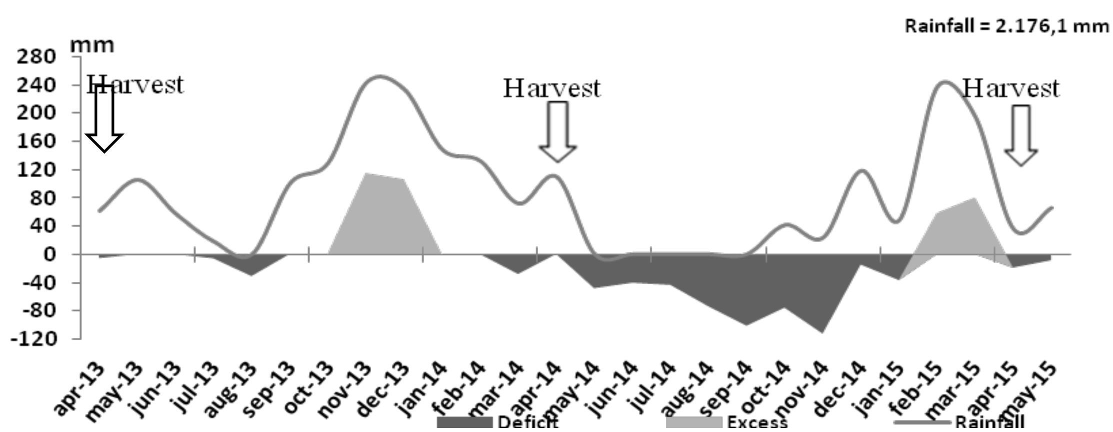

Figure 1. The water balance in experimental area during the experiment.

RESULTS

The sugarcane yield

In the first year of experiment, the applications done at 0, 30, 60 and 120 DAH showed better yields than 90 DAH, which was the lowest TSH – Tons of stalks per hectare (Table 2). The N rate increased the yield and showed a quadratic effect (Figure 2), where the highest sugarcane yield was obtained when applied 140 kg ha^{-1} of N. In the second year of experiment second ratoon, due to the dry year in 2014 (Figure 1a), there was a great decrease than expected in the yield (24%) when compared to the first ratoon. However, the differences between treatments continue to exist, showing that sugarcane harvested in early season can be influenced by the application time and N rate (Table 2). Applications made at 0, 30, 90 and 120 DAH showed higher yield than the 60 DAH, which obtained the lowest yield (Table 2). According to the regression model between N rate and TSH, the best theoretical yield occurred when 108 kg ha^{-1} of N was applied.

Table 2. Sugarcane yield (Mg ha^{-1}) by different rates and application period of N.

	Application Period (DAH)					
N Rate	**0**	**30**	**60**	**90**	**120**	**Mean**
			First Year – 2014[1]			
0	107	100	84	88	113	98
50	103	82	143	118	111	111
100	123	124	122	98	106	115
150	119	112	109	109	111	112
200	126	124	113	83	121	113
Mean	116A	109AB	114A	99B	112AB	
P>n	0.22	0.001	0.001	0.001	0.76	
LMS season (5%)	13.8					
LMS rate (5%)	13.3					
CV season (%)	11.7					
CV rate (%)	12.9					
			Second Year – 2015[2]			
0	66	79	67	72	93	75
50	103	94	67	93	95	90
100	84	93	79	100	76	86
150	87	90	69	87	80	83
200	81	80	81	88	76	81

Mean	84AB	87A	73B	88A	84AB
P>n	0.001	0.05	0.07	0.001	0.001
LMS season (5%)	14.5				
LMS rate (5%)	7.3				
CV season (%)	16.1				
CV rate (%)	9.4				

PS: [1]First year – P>n application season: 0.05; P>n Dose of N: 0.001; P>n interaction: 0.001; [2]Second year – P>n application season: 0.05; P>n Dose of N: 0.001; P>n interaction: 0.001; Capital letters in row to differentiate application time.

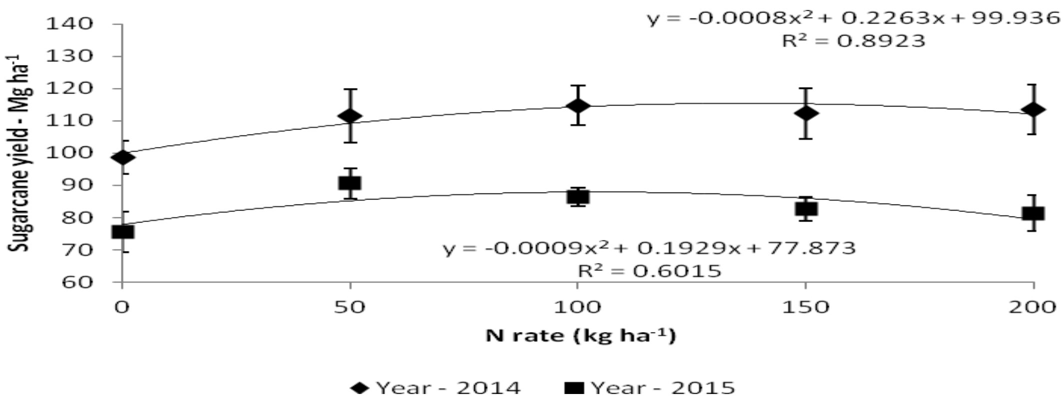

Figure 2. Effect of N rate on sugarcane yield during two years.

The crop canopy reflectance sensor evaluations

In the first year (2013), the difference between treatments was great than the second year (2014) - Table 3, which can be explained by the drought in 2014 (Figure 1). The application period and N rate differed for NDRE in the evaluation performed at 60 DAH in the first year (Table 3). The application made at 0 DAH had a higher value when compared the application period at 30 DAH. Although significant, the NDVI did not fit in any regression model for evaluation of N rate. In field conditions, the stand average was 16 tillers m^{-1}, with plant height 0.16 m and 7 green leaves and 0 dry leaves.

Table 3. P values of each parameter evaluated during the experimental period.

Evaluation	Treatments	NDVI	NDRE	Tillers	Height
	First Year - 2013				
30 DAH	Application period	---	---	---	---
	N rate	0.62	0.42	0.79	0.54
	Application period x N rate	---	---	---	---
60DAH	Application period	0.12	**0.06**	0.11	**0.08**
	N rate	**0.09**	**0.06**	0.80	0.43
	Application period x N rate	**0.04**	**0.05**	0.96	0.73

90DAH	Application period	**0.001**	**0.10**	**0.001**	0.33
	N rate	0.42	**0.02**	0.68	**0.03**
	Application period x N rate	0.16	0.28	0.53	**0.04**
120DAH	Application period	**0.001**	0.22	**0.001**	0.70
	N rate	0.20	0.11	0.55	0.59
	Application period x N rate	0.29	0.80	**0.08**	0.74
150DAH	Application period	**0.03**	0.10	**0.02**	0.16
	N rate	**0.04**	**0.001**	0.54	0.90
	Application period x N rate	0.30	0.24	0.94	0.84
Second Year - 2014					
30 DAH	Application period	---	---	---	---
	N rate	**0.001**	**0.001**	0.71	0.29
	Application period x N rate	---	---	---	---
60DAH	Application period	0.23	0.27	**0.07**	0.19
	N rate	0.69	0.48	0.14	0.11
	Application period x N rate	0.85	0.95	0.63	0.98
90DAH	Application period	0.28	0.39	**0.10**	0.66
	N rate	**0.08**	0.11	0.70	0.80
	Application period x N rate	0.80	0.45	0.33	0.99
120DAH	Application period	**0.05**	**0.05**	0.12	0.52
	N rate	0.99	0.99	0.27	0.60
	Application period x N rate	0.99	0.99	0.83	0.96
150DAH	Application period	0.27	0.21	0.27	**0.05**
	N rate	0.93	0.95	0.98	0.43
	Application period x N rate	0.99	0.99	0.99	0.99

At 90 DAH, when the cane fields had an average 17 tillers m^{-1}, plant height average of 0.2 m and 7 green leaves and 1dry leaf, there were differences between treatments (Table 3). The application made at 0 DAH had higher NDVI, NDRE and tiller stand when compared to the other applications periods (Table 4). The NDRE and tiller height, showed difference with N rate, which the application of 100 kg ha^{-1} of N obtained the highest values (Figure 3).

In the evaluation at 120 DAH, the NDVI and tillers continued showing difference according to the application period (Table 3), which the highest NDVI were obtained for the applications made at 0 and 60 DAH, and the biggest tillers stand was obtained on application made at 0 DAH. At this point, the average of stand and tillers height, number of green and dry leaves, were respectively 18, 0.25 m, 6 and 1.

Table 4. NDVI index, NDRE index and population (tillers m^{-1}) evaluated at 90 DAH, in the first year.

	Application period			
N rate	**0 DAH**	**30 DAH**	**60 DAH**	**Mean**
		NDVI INDEX		
0	0.3685	0.3527	0.4052	0.3755
50	0.3937	0.3690	0.3917	0.3848
100	0.4282	0.4055	0.3920	0.4086
150	0.4385	0.3800	0.3560	0.3915
200	0.4352	0.3422	0.3787	0.3854
Mean	0.4128A	0.3699B	0.3847B	
P>n season	0.001			
P>n rate	0.42			
P>n interaction	0.16			
CV season (%)	7.3			
CV rate (%)	10.9			
		NDRE INDEX		
0	0.1735	0.1572	0.1528	0.1611
50	0.1800	0.1591	0.1884	0.1759
100	0.1834	0.1824	0.1773	0.1810
150	0.1801	0.1622	0.1629	0.1684
200	0.1674	0.1675	0.1642	0.1664
Mean	0.1768A	0.1657B	0.1691B	
P>n season	0.10			
P>n rate	0.02			
P>n interaction	0.28			
CV season (%)	8.0			
CV rate (%)	8.9			
		TILLERS (Tiller m^{-1})		
0	18	16	18	17
50	20	16	15	17
100	20	19	16	18
150	20	17	15	17
200	20	17	17	18
Mean	20A	17B	16B	

P>n season	0.001
P>n rate	0.68
P>n interaction	0.53
CV season (%)	12.0
CV rate (%)	14.2

PS: Capital letters in row to differentiate application period.

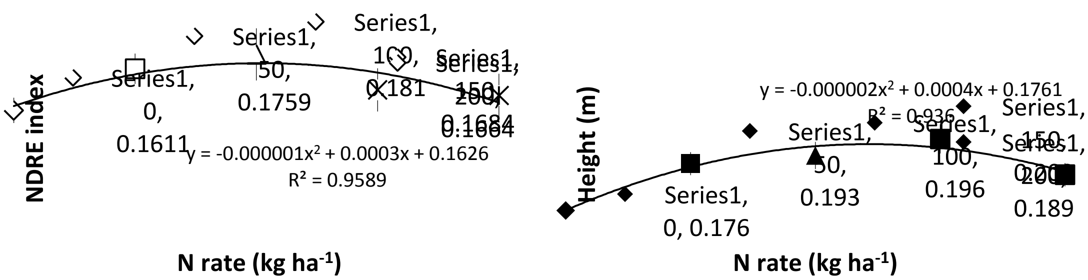

Figure 3. Effect of N rate in NDRE index and plant height (m) evaluated at 90 DAH during the first year.

At 150 DAH (last evaluation) in the first year, the application periods continued to differ in NDVI index measured (Table 5). The application made at 0 and 60 DAH had the highest index. The same index correlated with the N rate that showed the quadratic effect on NDVI according to N rate increase, with the highest value with 125 kg ha^{-1} N (Figure 4). The NDRE correlated with N rate, that according to the regression curve, the highest NDRE was obtained when 150 kg ha^{-1} N was applied (Figure 4). The average of tillers stand, plant height, and number of green and dry leaves in this evaluation were respectively 20, 0.4 m, 7 and 3.

Table 5. NDVI index evaluated at 150 DAH, in the first year.

	Application period					
N rate	**0 DAH**	**30 DAH**	**60 DAH**	**90 DAH**	**120 DAH**	**Mean**
0	0.5135	0.5072	0.5167	0.5062	0.5380	0.5163
50	0.5425	0.4890	0.5232	0.5235	0.5152	0.5187
100	0.5682	0.5615	0.5585	0.5470	0.5102	0.5491
150	0.5957	0.5280	0.5165	0.5197	0.5415	0.5403
200	0.5717	0.5215	0.5562	0.5065	0.5020	0.5316
Mean	0.5583A	0.5214B	0.5342AB	0.5060B	0.5214B	
P>n season	0.03					
P>n rate	0.04					
P>ninteraction	0.30					
CV season (%)	7.2					

CV rate (%)	7.3

PS: Capital letters in row to differentiate application period.

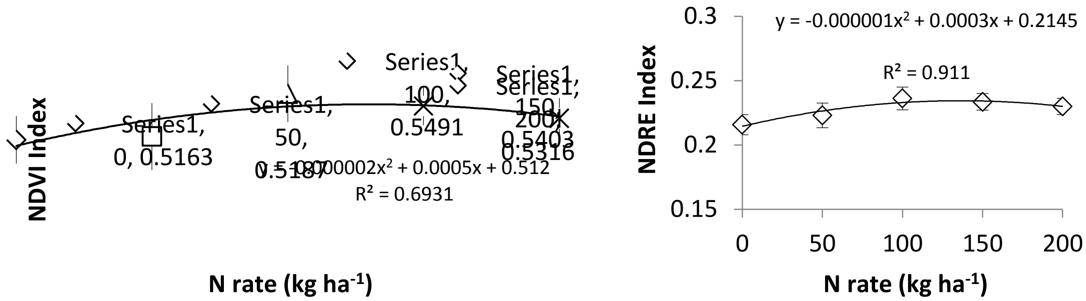

Figure 4. Effect of N rate in NDVI and NDRE index evaluated at 150 DAH during the first year.

In the second experimental year, during the first assessment (30 DAH), the crop canopy reflectance sensor showed differences to the N rate, with quadratic effect on NDVI and NDRE, according to the regression models, where the highest index was obtained when applied 100 kg ha^{-1} N (Figure 5).

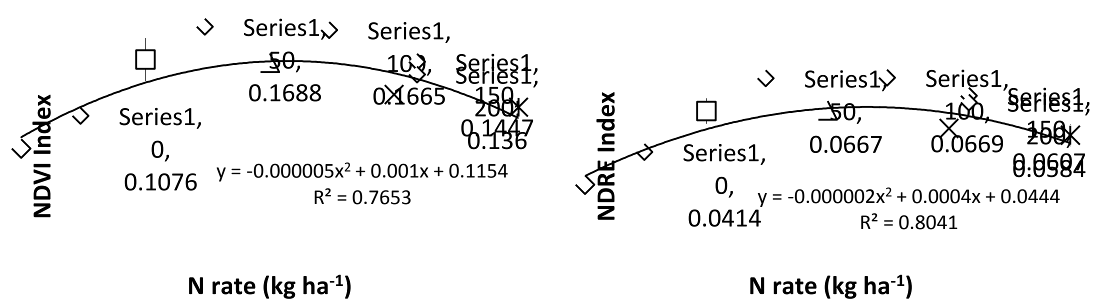

Figure 5. Effect of N rate in NDVI and NDRE index evaluated at 30 DAH during the second year.

At 120 DAH the application period showed changes in the NDVI and NDRE (Table 6). The application at 60 DAH obtained index lower than others periods. In the last evaluation (150 DAH) there was no difference in any parameters (Table 3).

Table 6. NDVI and NDRE index evaluated at 120 DAH, in the second year.

	Application period				
N rate	**0 DAH**	**30 DAH**	**60 DAH**	**90 DAH**	**Mean**
			NDVI INDEX		

0	0.3919	0.4445	0.3422	0.4405	0.4048
50	0.3757	0.4293	0.2784	0.4574	0.3852
100	0.4067	0.4500	0.3267	0.4537	0.4093
150	0.3717	0.4426	0.35	0.4096	0.3934
200	0.3563	0.4354	0.3483	0.4460	0.3965
Mean	0.3805AB	0.4404A	0.3291B	0.4415A	
P>n season	0.05				
P>n rate	0.99				
P>n interaction	0.99				
CV season (%)	30.3				
CV rate (%)	38.7				
			NDRE INDEX		
0	0.1535	0.1707	0.1330	0.1722	0.1573
50	0.1476	0.1666	0.1081	0.1779	0.15
100	0.1621	0.1756	0.1293	0.1762	0.1609
150	0.1452	0.1715	0.1356	0.1598	0.1530
200	0.1397	0.1699	0.1352	0.1744	0.1550
Mean	0.1496AB	0.1709A	0.1283B	0.1721A	
P>n season	0.05				
P>n rate	0.99				
P>n interaction	0.99				
CV season (%)	30.7				
CV rate (%)	39.6				

PS: Capital letters in row to differentiate application period.

DISCUSSION

It is important to analyze the effect of N rate in sugarcane yield associated with the harvest season. In this research the rate of 140 kg ha^{-1} (first ratoon) and 108 kg ha^{-1} (second ratoon) had the highest yield. The results presented here confirm the results showed by Fortes et al. (2013) where the N rate of 120 kg ha^{-1} (in three agricultural cycles) presented the highest yield.

The NDVI is one of the indexes studied in order to predict the potential for biomass production (Eitel et al., 2008), and has a good correlation with the sugarcane yield (Lofton, 2012a; Portz et al, 2012; Amaral et al, 2014). But specifically for research with N application, and evaluation using the crop canopy reflectance sensor, the NDRE seems more sensitive to differences in N rates (Amaral et al., 2015b), because this index less tendency toward saturation, since it is less influenced by the composition and color of canopy plant (Taubinger et al., 2012). Therefore, the NDRE have better performance in N rate prediction than NDVI.

In the first year, the reflectance sensor was able to identify the potential for biomass production, the assessments carried out at 120 and 150 DAH. The sensor showed higher NDVI for fertilization periods (0, 60 DAH), which it was confirmed in the crop harvest, because these periods had higher cane yield (TSH). The NDRE showed differences between the N rate in the last assessment (150 DAH), wherein, according to the response curve and regression, the application of 150 kg ha^{-1} N was considered ideal in order to obtain the greatest TSH. This N rate predicted by NDRE is similar to the maximum point (application of 140 kg ha^{-1} N) of the regression curve for TSH relationship with N rate (Figure 2).

In the second year, due to adverse weather conditions (Figure 1), the indexes presented no differences between the N rates. However, at 120 DAH the NDVI had less potential for biomass production for application at 60 DAH, which was confirmed during harvest, because this period had a lower TSH than other periods (Table 2). Thus, the crop canopy reflectance sensor can be considered as an auxiliary tool to predict the necessity of N by sugarcane (Amaral & Molin, 2011; Lofton et al, 2012b; Amaral et al, 2014).

According to the assessments during the experimental years, the crop canopy reflectance sensor was able to predict crop response to nitrogen fertilization when, the plants had a height between 0.20 - 0.40 m, stand average between 16 - 20 tillers m^{-1}, with 7 totally expanded green leaves, 1 dry leaf and without severe adverse weather conditions (water stress). This characterization of plant development in the field, is similar to that presented in other researchers (Amaral & Molin, 2011; Portz et al, 2012).

In this context, the harvest period associate with the climate conditions are important to help in deciding the best period to apply N fertilizer and choose the correct N rate to increase the NUE in sugarcane.

Conclusion or Summary

The N-fertilizer application period as well as, the rate of nitrogen applied to the ratoon, influenced the sugarcane yield. In the first ratoon, the best N rate was 140 kg ha^{-1}, applied at 0 or 60 DAH. In the second ratoon, the best N rate to improve sugarcane yield was 100 kg ha^{-1} N, applied at 0 or 30 DAH.

Crop Circle sensor was capable to identify the application periods and N rates during crop development, with good correlations with yield when the evaluations were done at 90 and 150 DAH. Crop Circle NDVI reading had a good correlation with the applications periods of N fertilizer and the NDRE identifies the different rates of N.

The best time to use the crop canopy reflectance sensor is associated with lack of water stress, in addition of the sugarcane field conditions such as average height (insert TVD leaf) from 0.20 to 0.4 m, 16 to 19 tillers per meter, and 6 to 8 green leaves per plant. Crop Circle sensor can be considered an auxiliary tool to predict the necessity of N fertilizer in sugarcane.

Acknowledgements

To FAPESP (Process 2013/01417-2), the PhD scholarship granted to the first author, and IPNI the award to this research (IPNI Scholarship Award - 2015).

References

Amaral, L. R., Molin, J. P., Portz, G., Finazzi, F. B., Cortinove, L. 2015a. Comparison of Crop canopy reflectance sensors used to identify sugarcane biomass and nitrogen status. *Precision Agriculture*, 16, 15-28.

Amaral, L. R., Molin, J. P., Schepers, J. S. 2015b. Algorithm for variable rate nitrogen application in sugarcane based on active crop canopy sensor. *Agronomy Journal*, 107, 1513-1524.

Amaral, L. R., Molin, J. P. 2014. The effectiveness of three vegetation indices obtained from a canopy sensor in identifying sugarcane response to nitrogen. *Agronomy Journal*, 106, 173-280.

Amaral, L. R., Molin, J. P. 2011. Optical sensor to support nitrogen fertilization recommendation for sugarcane crops. *Pesquisa Agropecuária Brasileira*, 16, 1633-1642.

Cantarella, H, Rossetto, R. Fertilizers for sugarcane. 2014. In: *Sugarcane bioethanol — R&D for Productivity and Sustainability*., 2014. Cortez, LAB (Ed.). São Paulo: Edgard Blücher, p. 405-422.

Cantarella, H., Montezano, Z. F. Nitrogênio e Enxofre. 2010. In: Prochnow, L. I., Casarin, V., Stipp, S. R. (Ed.) *Boas práticas para o uso eficiente de fertilizantes – volume 2 – nutrientes.* International Plant Nutrition Institute (IPNI), Piracicaba - SP, p.5-72.

CONAB - *Companhia Nacional de Abastecimento*. Acompanhamento da safra brasileira. Cana-de-açúcar. v.2 Safra 2015-16 - Segundo levantamento. Agosto de 2015. Monitoramento Agrícola. Disponível: www.conab.gov.br Acessed: 09 - September - 2015.

Eitel, J. U. H., Long, D. S., Gessler, P. E., Hunt E. R. 2008. Combined spectral index to improve ground-based estimates of nitrogen status in dryland wheat. *Agronomy Journal*, 100 (6), 1694-1702.

FAOSTAT. *Food and agriculture organization of the United Nations*. Statistics Division. Available at: http://faostat3.fao.org/home/E. Acessed: 18 - April - 2015.

Fortes, C, Trivelin, P. C. O, Vitti, A. C., Otto, R., Franco, H. C. J., Faroni, C. E. 2013. Nitrogen responses in the agro industrial production of sugarcane under reduced tillage in southeastern Brazil. *Pesquisa Agropecuária Brasileira*, 48: 88-96.

Franco, H. C. J., Kolln, O. T., Sanches, G. M., Rossi Neto, J., Castro, S. G. Q., Otto, R., Mariano, E., Inamassu, R., Magalhães, P. S. G., Braunbeck, O. A. 2014. Optical sensors to predict nitrogen demand by sugarcane. In: 12th International Conference of Precision Agriculture, 2014, Sacramento, Califórnia. *Proceedings of 12th International Conference of Precision Agriculture*.

Lofton, J., Tubana, B. S., Kanke, Y., Teboh, J., Viator, H. 2012a. Predicting sugarcane response to nitrogen using a canopy reflectance based response index value. *Agronomy Journal*, 104(1), 106-113.

Lofton, J., Tubana, B. S., Kanke, Y.; Teboh, J.; Viator, H.; Dalen, M. 2012b. Estimating sugarcane yield potential using an in-season determination of normalized vegetative index. *Sensors*, 12, 7529-7547.

Malhi, S. S., Grant, C. A., Johnston, A. M., Gill, K. S. 2011. Nitrogen fertilization management for no-till cereal production in the Canadian Great Plains: a review. *Soil & Tillage Research,* 60, 101-122.

Raij, B. van, Gheyi, H. R., Bataglia, O. C. 2001. Determinação da condutividade elétrica e de cátions solúveis em extratos aquosos de solos. In: Raij, B. van, Andrade, J. C., Cantarella, H., Quaggio, J.A. (Eds.) *Análise química para avaliação da fertilidade de solos tropicais.* 1.ed. Campinas, Instituto Agronômico - 2001, p. 277-284.

Rosa, H. J. A., Amaral, L. R., Molin, J. P., Cantarella, H. 2015. Sugarcane response to nitrogen rates, measured by a canopy reflectance sensor. *Pesquisa Agropecuária Brasileira*, 50, 840-848.

Soil Survey Staf. 2010. *Keys to Soil Taxonomy*.USDA - United States Department of Agriculture. 346p.

Subbarao, G.V., Ito, O., Sahrawat, K. L., Bery, W. L., Nakahara, K., Ishikawa, T., Watanabe, T., Suenaga, K., Rondon, M., Rao, M. 2006. Scope and Strategies for regulation of nitrification in Agricultural Systems. *Challenges and Opportunities in Plant Sciences,* 25, 303-335.

Thorburn, P. J., Biggs, J. S., Webster, A. J., Biggs, I. M. 2011. An improved way to determine nitrogen fertilizer requirements of sugarcane crops to meet global environmental challenges. *Plant Soil,* 339, 51-67.

Thornthwaite, C. W., Mather, J. R. 1955. *The water balance.* Centerton, NJ: Drexel Institute of Technology - Laboratory of Climatology, 1955. 104p. (Publications in Climatology, vol. VIII, n.1).