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Biomass accumulation and growth curve in sugarcane fertigated with nitrogen doses

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Abstract

This study aims to evaluate the growth curve, biomass and N accumulation in aboveground sugarcane as a function of nitrogen doses applied by subsurface drip irrigation during the crop growth cycle. The experiment was developed under field conditions Jau city, São Paulo state, Brazil. The treatments were four nitrogen doses – namely 50, 100, 150 and 200 kg ha^{-1} N – in urea form, in addition to a control treatment (without N), with completely randomized block and four repetitions. The N doses were applied gradually by subsurface drip irrigation spread throughout the sugarcane crop cycle. Biometrics and physiologic parameters and biomass accumulation were evaluated at five sampling times. Linear and quadratic responses of these parameters were verified as a function of N application. Elevating the N dose from 100 to 200 kg ha^{-1} increased the biomass and the N accumulation of sugarcane above ground by 20 Mg ha^{-1} and 95 kg ha^{-1}, respectively. The nitrogen fertilization applied by subsurface drip irrigation increased the biomass and N accumulation of aboveground sugarcane, as well as the production rate of all parameters. The gap between maximum biomass accumulation rate (BAR) and nitrogen accumulation rate (NAR) was smooth due drip irrigation management. The irrigation management combined with better plant nutrition show highest results to biomass production.

Keywords: *Saccharum* spp., subsurface drip irrigation, water management, plant nutrition.
Abbreviations: AWC_available water capacity; BAR_biomass accumulation rate; CET_crop evapotranspiration; DIA_stalk diameter; DAH_days after harvest; H_heights of the plants; LAI_leaf area index; NAR_nitrogen accumulation rate.

Introduction

Sugarcane (*Saccharum* spp.) has great importance in tropical and subtropical regions around the world, mainly in sugar and ethanol production. Sugarcane presents many possibilities. Besides juice, it is the main feedstock for ethanol production. Furthermore, sugarcane generates expressive amounts of byproducts in their processing such as straw and bagasse, which can be employed to produce bioelectricity or second-generation ethanol, increasing the competitiveness and importance of this crop (Dias et al., 2013; Cardoso et al., 2013). In these circumstances, it is strategic to use new energy sources that satisfy environmental, economic and social demands to ensure the sustainable development of the planet (Santoyo-Castelazo; Azapagic, 2014). Brazil has a leading role in this sector as the world's largest producer of sugarcane (Faostat, 2021).

In Brazil, sugarcane does not require irrigation in most cultivated areas, because of the good amount and regular distributions of rains. However, sugarcane area production has been increased under poor soils with lower and irregular rain like the Brazilian Center-West region (Cerrado). The N is an important element for vegetable production, given that producing 100 Mg ha^{-1} of stalks requires sugarcane uptake ranging from 100 to 250 Kg ha^{-1} (Castro et al. 2018). The uptake and assimilation of organic and inorganic nitrogen sources, as well as N transportation to new organs are essential for vegetable growth and development (Rentscher et al., 2007). However, regardless of nitrogen fertilizer doses applied in sugarcane fields, the use-efficiency is usually less than 50%. This is lower than those of other crops, which range from 50 to 70% (Cantarella et al., 2007).

Several studies indicated that the use of nitrogen in sugarcane fields can vary from 5 to 40% (Franco et al., 2011; Vitti et al., 2011; Megda et al., 2015, Boschiero et al. 2021). The large variation and low nitrogen use efficiency from fertilizer applications are related to N losses in the soil-plant system, even though the longer crop cycle (~12 months) increases the importance of N supplied by the soil. The N losses are attributable to the nitrate lixiviation process (NO_3^-) (Oliveira et al., 1999; Ghiberto et al., 2015), nitrous oxide emissions (N_2O) from the soil and the plant (Soares et al., 2014) and ammonia volatilization (NH_3) (Trivelin et al., 2002).

Thorburn et al. (2003) reported high response to nitrogen fertilization from the irrigated sugarcane in Australia, which contrasts with dryland sugarcane management in Brazil (Mariano et al., 2017). Subsurface drip irrigation presents some distinct effects in relation to crops under other types of irrigation. In this furrow planting system, a region of high humidity occurs that presents intense microorganism activity and high root-system concentration denominating the humid bulb (Thorburn et al., 2003). Fertigation management by subsurface dripping has shown benefits for plants, due to the possibility of splitting the supply of nitrogen fertilizer throughout the crop cycle, thereby increasing the absorption and use efficiency of the nutrient (Singh and Mohan, 1994; Ng Kee Kwong et al., 1999). Variable supply of nutrients according to the crop demand and the lower possibility of losses in the system may occur by this effect.

Due to overall importance of sugarcane as a raw material to produce renewable energy, studies involving the increase of its biomass and the NUE are crucial for augmenting the economic return to the producers and the sustainability of this agrosystem. Despite the widespread recognition of greater productivity of crop stalks when submitted to irrigation in Brazil and other tropical regions (Oliveira et al., 2011; Rhein et al. 2016), the influence of irrigation on N uptake is unknown. As this nutrient arrives at plant root system by mass flow, the water is essential to sugarcane N extractions from the soil. Our hypothesis is that sugarcane shows high response to N applied by fertigation mainly to biomass and N accumulation. This study aims to evaluate the growth curve, biomass and N accumulation in sugarcane aboveground as a function of nitrogen doses applied by subsurface drip irrigation during the growth crop cycle in Brazil.

Results

Biometric variables

The nitrogen fertilization further increased the height, diameter and tillers density of sugarcane at different sampling times (Supl. Table 1). Linear responses were observed for diameter of stalks, and tillers density per meter at times 121, 208, 291 and 381 DAH as a function of nitrogen dose application in sugarcane by fertigation. The tillers density also showed a linear response at 38 DAH. The results of sugarcane plant height related to nitrogen dose application could be adjusted into a linear model only at times 121 and 381 DAH. The quadratic model for these variables was not observed at any time.

The sigmoid model was adjusted properly to the data for plant height and stalk diameter during the sugarcane growth cycle (Fig. 3a and 3b) with R^2 greater than 0.90. High sugarcane tillering was verified at the beginning of the cycle (38 DAH), after which a drastic reduction occurred that is best described by the quadratic model (Supl. Table 1 and Fig. 4).

Physiologic variables

The nitrogen application increased leaf N content, SPAD values and LAI for all evaluated samplings, except for the first evaluation at 38 DAH, where only LAI showed a response to nitrogen doses applied from surface drip irrigation (Supl. Table 2). The SPAD values were increased during the ratoon crop cycle. At the harvest time, SPAD values ranged from 26 to 35 for control and high nitrogen doses (200 kg ha^{-1}), respectively. The data from samplings of leaf N content (Fig. 5a) and SPAD values (Fig. 5b) during sugarcane crop cycle were adjusted properly for a decreasing linear model with R^2 greater than 0.90. A strong positive correlation was observed between SPAD values and leaf N content in sugarcane (R = 0.88; p < 0.05) considering all results from these variables (n=80) (Fig. 6).

In relation to the LAI index, the LAI values at 121 DAH oscillated from 2.1 to 3.0 at the beginning of the maximum sugarcane growth period, whereas at the end of this phase (291 DAH), the values were 4.1 and 5.4, respectively, for control and the high nitrogen dose of 200 kg ha^{-1} N. At the end of the experimental period (381 DAH), the respective LAI values were 4.5 to 6.4 for control and 200 kg ha^{-1} N, respectively. In addition, the LAI data adjusted well to the sigmoid model during the sugarcane crop cycle (Fig. 7), indicating a linear-exponential elevation for this parameter between 75 and 150 DAH.

Accumulation of biomass and nitrogen

There was a linear increase in the accumulation of biomass by the sugarcane due to the application of nutrient doses throughout the seasons, except for the sampling carried out at 208 DAH, which was adjusted to a quadratic model (Supl. Table 3). Specifically for each N dose, the sigmoid model was adequately adjusted to the results on biomass accumulation (Fig. 8a). Further to biomass accumulation rate (BAR), the accumulations peaks presented distinct values and moments between the treatments, as follows: 11.5 (170 DAH), 15.6 (192 DAH), 22.5 (180 DAH), 19.9 (186 DAH) and 22.2 (207 DAH) g m^{-2} d^{-1}, respectively, for the control treatment and the N doses of 50, 100, 150 and 200 kg ha^{-1} (Fig. 8c). The mean values of BAR were 4.6, 7.1, 9.8, 10.4 and 12.3 kg ha^{-1} d^{-1} for the control and N doses of 50, 100, 150 and 200 kg ha^{-1}, respectively. The application of 200 kg ha^{-1}of N elevated the daily biomass production by 7.7g ha^{-1} d^{-1}, compared to the control.

Like biomass, the N accumulation in sugarcane increased linearly for all sampling times evaluated due to applied nitrogen doses (Supl. Table 3). The difference between N accumulation in the control and the highest N dose (200 kg ha^{-1} of N) at the end of the sugarcane crop cycle was 180 kg ha^{-1} of N (Supl. Table 3). The data from nitrogen accumulation in aboveground sugarcane were adjusted to the sigmoid model, as in the case of biomass accumulation (Fig. 8b). The N accumulation in the initial phase (lag phase) occurred until 50 DAH, with an average extraction for all treatments being 14% of total N accumulated. For the second phase, rapid accumulation (exponential phase) occurred from 50 to 300 DAH, which represented 81% of total N uptake. The last phase (stationary phase) characterized by low accumulation, represented only about 5% of total N uptake. The N extraction peaks were 239.3 (170 DAH), 370.0 (192 DAH); 605.7 (180 DAH), 742.1 (176 DAH) and 961.0 (207 DAH) g ha^{-1} d $^{-1}$ for control treatment and N doses of 50, 100, 150 and 200 kg ha^{-1} of N (Fig. 8d). The mean values of nitrogen accumulation rates (NAR) were

97.7, 219.2, 328.9, 402.6 and 557.8 g ha^{-1} d^{-1}, respectively, for the control treatments and N doses of 50, 100, 150 and 200 kg ha^{-1}. The application of 200 kg N ha^{-1} increased the daily average extraction by 460.1 g ha^{-1} d^{-1} in comparison to the control. Lastly, the peaks verified in NAR preceded the BAR peaks by 59, 11, 11, 22 and 23 d for the control treatments and N doses of 50, 100, 150 and 200 kg ha^{-1} de N respectively.

Sugarcane yield

The sugarcane yield showed high response to N fertigation (Fig. 9), with the highest N dose (200 kg ha^{-1} N) increasing sugarcane yield by 104 % in comparison to the control treatments. The data were adjusted to the linear model with R^2 of 0.99.

Discussion

Evaluating the crop growth curve can help strategic management and consequently increase the yield of sugarcane. Our study evaluated the growth by means of biometric variables as height, diameter, tillering and physiological variables like index spad, LAI, and N content, as well as de biomass accumulation during the crop cycle.

The maximum growth of this parameter occurred between 90 and 291 DAH. It was observed that the elongation of stalks kept increasing until 291 DAH under the doses of 50, 100, 150, and 200 kg ha^{-1} N.

The supplying of N jointly with irrigation elevated the response of the plant to photosynthesis in the initial phase of crop growth, as reflected in greater stalk diameter. After this phase of rapid thickness growth, the stalk diameter stabilized at approximately 150 DAH, as also detected by Oliveira et al. (2010) for sugarcane at the first cutting (cane-plant).

The maximum tillering period obtained with fertirrigation (38 DAH) differs from previous studies, as well as the stabilization in the tiller density, which occurred at 275 DAH. At the end of the crop development cycle, there were 16 tillers m^{-1} of sugarcane row on average. These values are superior to those verified in cane fields planted in traditional spacing of 1.5 m between rows (Dalri and Cruz, 2008). The low demand for N in the initial phase soon after cutting the sugarcane ratoons diminished the response of the crop through nitrogenated fertilization in the initial phase (38 DAH), since until 60 DAH the principal N source for the aerial part of the crop is the nutrient reserves contained in the stalk seed.

The decreasing SPAD values and N proportion in the leaves across the cycle evidenced the effect of N dilution in the plants with the evolution of their growth, on account of the BAR being greater than the NAR (Faroni et al., 2009; Oliveira et al., 2013). On the other hand, the N doses applied via subsurface drip irrigation promoted the elevation of the N content of the leaf +1 of the plant, with consequent elevation in N accumulation in the aerial part, corroborating with Franco et al. (2011) on dryland sugarcane management. In addition, the strong positive correlation between N content in leaves and the SPAD value indicate that a chlorophyll meter can be used as a tool for rapid evaluation of the nutritional state of sugarcane throughout the development cycle.

The LAI is a physiological measure obtained in field conditions that presents a relation with accumulation of dry material (liquid photosynthesis) of sugarcane (Wiedenfeld and Enciso, 2008). The strong correlation of LAI with liquid photosynthesis occurs because LAI is associated with the quantity of absorbed light and consequently, the photosynthesis by the plants (Farias et al., 2007), where the productivity of crops is directly related to photosynthetic efficiency (Eptein and bloon, 2006). Nevertheless, the productivity does not rise indefinitely with the elevation of LAI, since from one determined LAI value part of the leaves must be performing photosynthesis, but a great quantity are found to be self-shading.

As to crop growth, it was verified that the first phase of vegetal growth lasted from the cutting of previous ratoon until approximately 90 DAH and accumulated on average 11% of the total biomass of the above ground. This phase was characterized by intense tillering but with low accumulation of biomass (Gava et al., 2001). The second growth phase encompassed the period from 90 DAH to 291 DAH, accumulating on average 81% of the total biomass. The results obtained herein are in concordance with other studies (Inman Bamber et al., 2002; Oliveira, 2010) developed with sugarcane in dryland fertilized with N. They reported a mean accumulation of 80% of total biomass in the above mentioned phase (linear-exponential phase). Thus, it may be stated that the second phase of crop growth occurs throughout the summer and part of the autumn (December to April) for the south-eastern region of Brazil. Another characteristic verified in irrigated management was that, when N was applied in the second crop growth phase, it prolonged the referenced phase in relation to the control that did not receive N. Finally, the third phase was characterized by low biomass accumulation of about 8% of the total and encompassed, a period of 291 to 381 DAH on average. This phase is marked by remobilization of nutrients and accumulation of sucrose in the stalk since the edaphoclimatic conditions in the periods of low temperature and low hydric availability are favorable to this process. The results on the accumulation of biomass and N by the sugarcane are similar to those obtained in studies utilizing irrigation (Ng Kee Kwong et al., 1999; Thorburn et al., 2003; Dalri and Cruz, 2008) and also dryland (Mariano et al., 2016; Leite et al., 2016; Mariano et al., 2017).

The largest gap between NAR and BAR in the control in comparison with N doses is contrary to that obtained by Oliveira (2013) in the dryland crop management. This difference can be explained in part by the availability of N to the crop that is different between the dryland and fertirrigated systems. Since the soluble fertilizers represent an immediate nutrient source to the plants (Dourado Neto et al., 2010), the application of the entire N dose on a single occasion (which is accomplished commonly in the management of dryland) abruptly makes the element available to the plants. Furthermore, the application of N occurs many times during the phase lag (first phase) of growth, when there is a low capacity to absorb the nutrient. Thus, there is immediate consumption of N-fertilizer even without reflecting on the great growth of the aerial part. However, in fertirrigated management, the N is applied partially during the cycle, with N absorption and biomass accumulation occurring throughout the period, being able to meet the demand for the nutrient by the crop in the most efficient manner.

In the management of irrigated sugarcane, the practice of nitrogen fertilization presents greater response potential compared to dryland management (Ng Kee Kwong et al.,

Table 1. Chemical and physical characteristics of the soil 0-0.25 and 0.25 – 0.50 m layer of the Typic Hapludox at the experimental site in Jau, São Paulo State, Brazil.

deph	pH	aTOC	bN-IN	P	K	Ca	Mg	CEC	V	Sand	Silt	Clay
cm		g dm^{-3}	(mg kg^{-1})	mg dm^{-3}	-------mmol$_c$ dm^{-3}------				%	--------g kg^{-1}----------		
0-25	5.2*	8.7	6.0	17	1.7	15	7	70	56	660**	70	270
0 - 50	4.8	7.5	6.6	20	1.2	9	4	32	44	560	100	320

*Analysis performed according to the methodology of Raij (2001), **Analysis performed according to the methodology of Embrapa, (1997). [a]TOC: Total organic carbon; [b]N-IN – Inorganic N (NH_4 +NO_2+NO_3) according to the methodology of Bremmer and Keeeney (1966); [c]CEC: Cation exchange capacity.

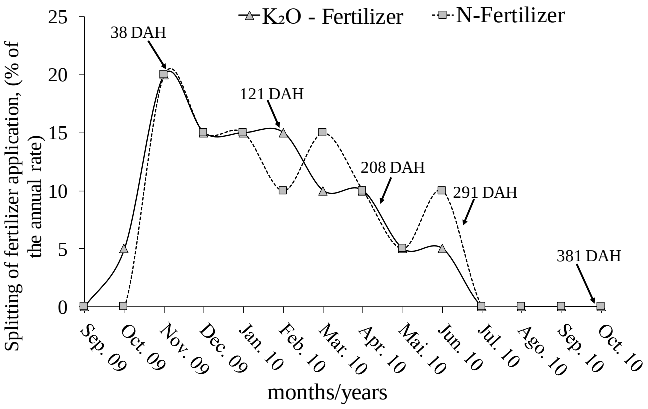

Figure 1. The percentage of distribution of N and K_2O fertilizer annual rates applied through fertigation in 2009/2010, and evaluation times during de crop cycle of ratoon sugarcane.

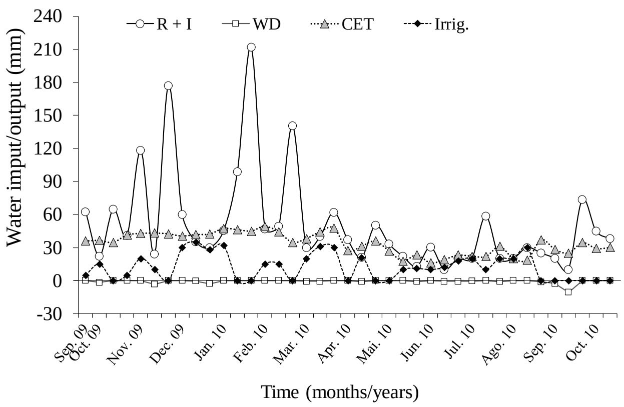

Figure 2. Ten-day water balance for the 2009/2010 period. R + I: rainfall + irrigation, WD: water deficit, CET: crop evapotranspiration, irrig: irrigation.

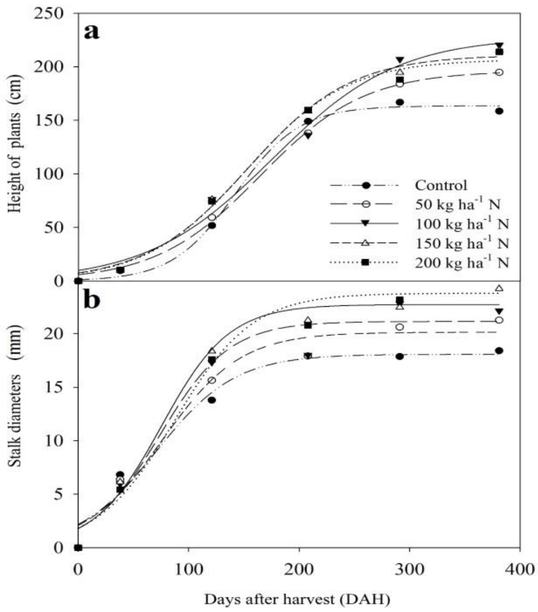

Figure 3. Plant height (cm) **a**, and stalk diameter (mm) **b**, as a function different evaluation times of the cycle related to increasing N doses applied by subsurface drip irrigation in ratoon sugarcane crop.

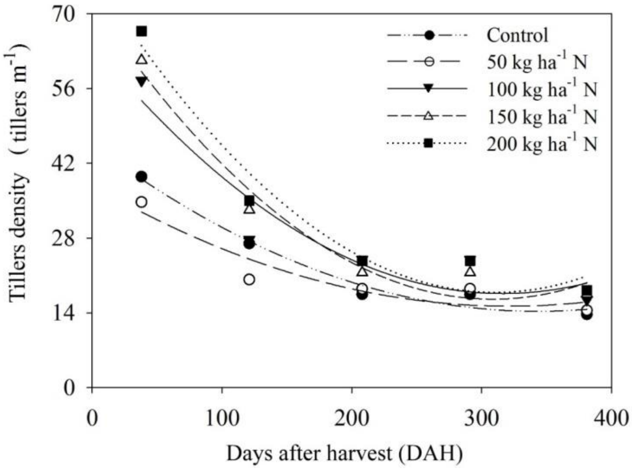

Figure 4. Sugarcane tillers density (number) as a function different evaluation times of the cycle related to increasing N doses applied by subsurface drip irrigation in ratoon sugarcane crop.

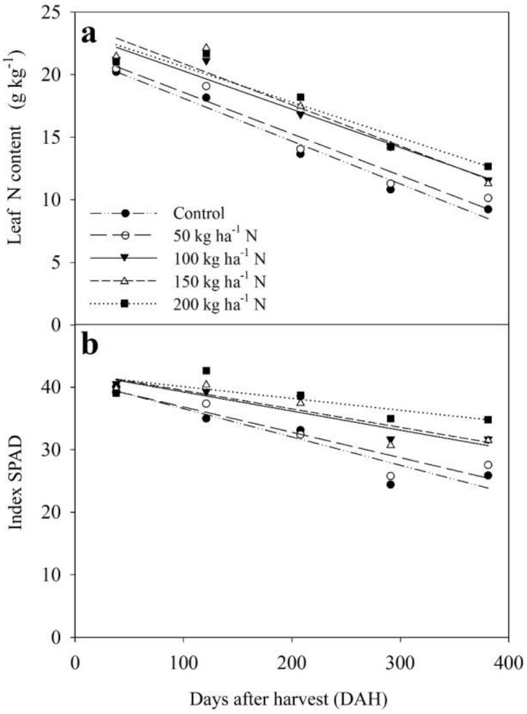

Figure 5. Leaf N content (g kg^{-1}) **a**, and spad index **b,** as a function different evaluation times of the cycle related to increasing N doses applied by subsurface drip irrigation in ratoon sugarcane crop.

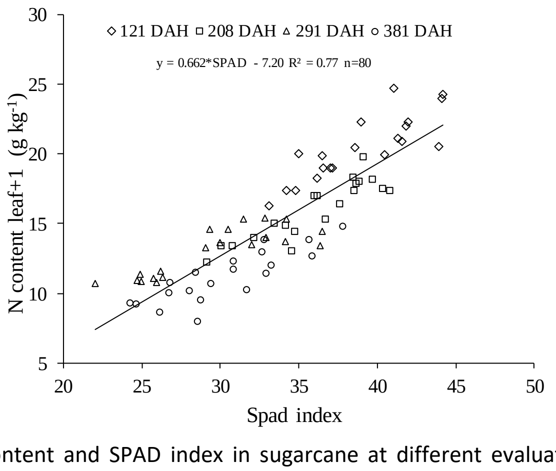

Figure 6. Correlation between N content and SPAD index in sugarcane at different evaluation times of the cycle as a function different evaluation times of the cycle related to increasing N doses applied by subsurface drip irrigation in ratoon sugarcane crop.

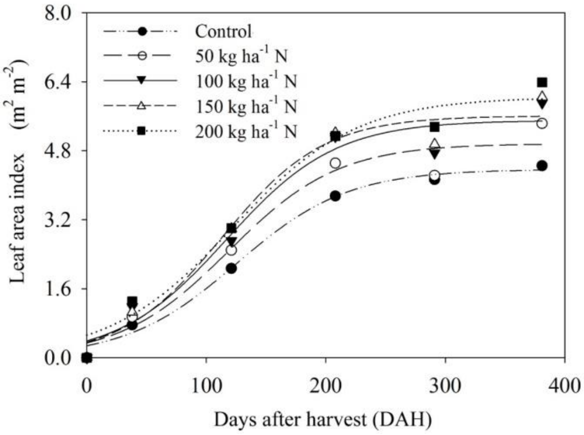

Figure 7. Leaf area index (m^{-2} m^{-2}) as a function of different evaluation times of the cycle related to increasing N doses applied by subsurface drip irrigation in ratoon sugarcane crop.

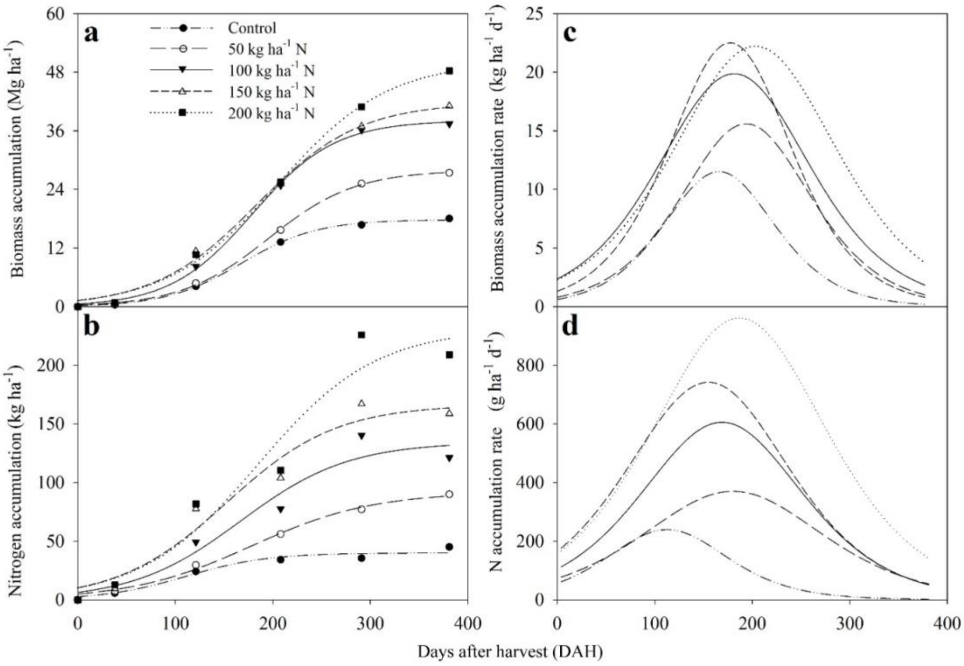

Figure 8. Biomass accumulation (Mg ha^{-1}) **a**, nitrogen accumulation (Kg ha^{-1}) **b**, Biomass accumulation rate (Kg ha^{-1} d^{-1}) **c**, nitrogen accumulation rate (g ha^{-1} d^{-1}) d, as a function different evaluation times of the cycle related to increasing N doses applied by subsurface drip irrigation in ratoon sugarcane crop.

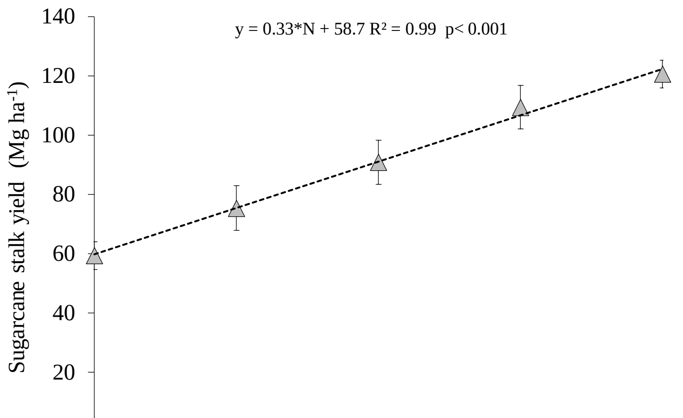

Figure 9. Ratoon sugarcane yield as a function nitrogen doses applied by subsurface drip irrigation. Vertical bars represent the minimum significant difference (p < 1%) in each sampling.

1999; Thorburn et al., 2003; Gava et al., 2010). The direct relationship between water availability in the soil and the response of the crop to applied N is due to the manner of contact of plant roots with ionic forms of the nutrient, which occurs by mass flow. The absorption of water along with a hydric potential gradient in soil draws the NH4+ and NO3- into solution to the region near the roots, being absorbable (Epstein and Bloom, 2006).

Nevertheless, there is still no system available for N recommendation for fertigated sugarcane in Brazil. Therefore, more studies are needed to calibrate the application of the nutrient in the crop. In any case, the results presented herein indicate that parceling of N via subsurface drip irrigation can raise the efficiency of N-fertilizer utilization when compared with a single application in dryland, as verified in other works on irrigated sugarcane (Wiedenfeld and Enciso, 2008; Ng Kee Kwong et al., 1999). The high response of the crop to N also deserves highlighting since the results are extremely heterogeneous for ratoons of the crop managed in a dryland system (Otto et al, 2016; Mariano et al., 2017).

Material and Methods

Characterization of site and Plant material

The sugarcane experiment was developed under field conditions in the municipality of Jau, São Paulo state, Brazil (22°17'S; 48°34'W). The third ratoons of a sugarcane crop (2009/2010 years) were evaluated. The experiment started after harvesting the second ratoon, and ended totaling 381 days. In the experimental location, sugarcane had been cultivated for 20 years, the last 12 years without burning the trash. The cultivar used was SP80-3280 that shows high stalk and sugar productivity, which requires fertile soils and sufficient moisture.

The soil was classified as a Typic Hapludox, according to the Soil Survey Staff (2014). A soil sampling was performed before the experiment. The soil pH was determined in 0.01 M $CaCl_2$ (ratio of 1:2.5 for soil and solution, w/v; Organic C was determined by the tube digestion method through sample oxidation with acidified $K_2Cr_2O_7$. The extraction of P, Ca and Mg was performed with ion exchange resins, with subsequent determination by colorimetry (P), flame photometry (K) and atomic absorption spectroscopy (Ca and Mg). The acidity was measured by the sum of the K, Ca and Mg available and potential acidity content (H + Al). Saturation of bases (V%) was calculated by dividing the sum of cations exchangeable by CEC, multiplied by 100. All the above mentioned chemical parameters were quantified according to Van Raij et al. (2001). For the extraction of mineral N forms (NH_4^+, NO_2^-, and NO_3^-), 4 g of soil was shaken with 2 M KCl (ratio of 1:5 for soil and solution, w/v) on an orbital shaker (MA–140, Marconi Equipamentos para Laboratórios LTDA, Piracicaba, Brazil) at 200 rev min^{-1} for 1 h. The supernatant was then filtered through N sampling. Extracts were analyzed for NH_4^+ and NO_3^- (NO_2^- is included) by conductimetry and colorimetry, respectively, using flow injection systems (Giné et al., 1980; Reis et al., 1997). The clay, silt and sand contents were determined according to Embrapa (1997) (Table 1).

Experimental design and treatments

The experimental design used was a randomized complete block with four replications. The treatments were four nitrogen fertilizer doses (50, 100, 150 and 200 kg ha^{-1}, in the form of urea), besides a control treatment. Together with nitrogen fertilizer we applied 150 kg ha^{-1} of potassium in the form of KCl. Nitrogen and potassium were split-applied twice weekly by subsurface drip irrigation in small amounts throughout the crop cycle. The parceling of the respective doses for the two abovementioned nutrients was scheduled according the sugarcane growth stages. The initial phase from 0 to 90 days after harvest (DAH) received 20 to 25% of the K_2O and N doses, respectively. The remaining nutrient percentage mentioned above was applied at the second growth phase (maximum growth development) between 90 and 210 DAH. Around 4 months before harvest (July/2010) the application of nitrogen was stopped. This phase corresponded to maturation of the sugarcane (Fig 1). The plots consisted of five 30-m rows of sugarcane. In all treatments the paired-row planting arrangement (planting in W) was used, with a spacing of 1.80 m between double rows and 0.4 m between paired sugarcane rows, with a dripline installed between them for irrigation. The drip-line adopted was the DRIPNET PC 22135 FL model (Adana, Turkey), with a 1.0 L h^{-1} flow rate and equipped with drip nozzles every 0.5 m, which were buried at a depth of 25 cm beneath the soil surface.

The total rainfall occurred throughout the crop cycle was 1,435 mm. The water amount applied by subsurface drip irrigation was 390 mm, spread across the sugarcane growth cycle, with the objective of replacing 100 % of the crop evapotranspiration (CET), according to the Penman–Monteith Method (Howell and Evett 2004). The irrigation frequency was estimated based on the 70 mm available water capacity (AWC) of the soil, water supplied by rainfall (R), and the atmospheric demand due to evapotranspiration of sugarcane (CET). The 10-day water balance and the water deficit (DEF) estimated for the crop cycle are shown in Fig. 2. The mean maximum and minimum temperatures during the sugarcane crop cycle were 29.2 and 16.4 ºC, respectively, measured at a meteorological station close to the experimental area.

Evaluated crop variables

Five evaluations were carried out during the crop cycle, at 38, 121, 208 and 381 DAH (Fig. 1). At each evaluation, physiological and biometric sugarcane parameters were measured. Leaf area index (LAI) was measured by ceptometer PAR/LAI (model LP-80, Decagon, Pullman, WA, USA). The evaluations occurred always in high solar radiation conditions at midday, generally at 1:00 pm. The measurements were made by inserting the ruler of the equipment horizontally into the middle of the sugarcane row and maintaining the secondary sensor in place where there was total solar radiation. The SPAD index was measured by chlorophyllometer (model SPAD-502 Plus, Konica Minolta, New Jersey, USA). The values from plots were obtained by averaging 20 sugarcane top visible dewlap leaves (first leaf with visible ligule, as proposed by Kuijper in Van Dillewijn 1952). Next, these leaves were collected; the mid-rib was removed and 20 cm blades from the middle leaf region were used for analysis. These samples were dried in a forced-air-circulation oven at 65 ºC, ground in a Wiley mill and stored in snapcap plastic containers. The N content of the samples was determined in a mass spectrometer (ANCA-GSL Hydra 20–20 model, SERCON Co., Crewe, GBR) coupled to an automatic C and N analyzer (Barrie and Prosser 1996). The other sugarcane parameters evaluated included: (i) heights of the plants (H) measured from soil surface until top visible dewlap leaf; (ii) stalk diameter (DIA) considering the medial part of sugarcane stalk; these parameters were measured in all tillers in 2 meters of sugarcane rows; (iii) tiller density (T) accounting for all the tillers in 2 meters of sugarcane rows, and (iv) biomass accumulation by the crop.

Each abovementioned evaluation was comprised of collecting 2 m of the sugarcane row per plot for the determination of aboveground plant biomass. Tops (green leaves), dry leaves and stalks were separated and weighed. The fresh material was subsequently ground in a forage chopper and subsamples were taken for the determination of plant dry matter after drying in a forced-air-circulation oven at 65 ºC. Dried samples were ground in a Wiley mill and the N content was determined by the Kjeldahl Method (Nelson and Sommers, 1973). At the end of the cycle (381 DAH), plants from 30 m of the sugarcane row were manually dehusked and cut at the soil surface level (without burning), and were weighed for the determination of stalk yield megagram per hectare (Mg ha^{-1}). At the same time, ten stalks were collected per plot for determination of sugar and fiber content. Sugar yields were calculated by taking into account the concentration of total sugars, measured as Brix degrees, sucrose concentration, determined by polarimetry (% pol), and fiber content, using the procedures described by ca (2003).

Calculations and statistical analysis

To estimate the biomass and N accumulation and LAI of sugarcane during the experimental period, a sigmoid function was used (Equation 1) according to Lucchesi, (1984).

$$y = \frac{ymax}{\left[1 + \mathrm{e}\ -\left(\frac{DAH - a}{b}\right)\right]} \qquad 1$$

Where: *y* represents the biomass (Mg ha^{-1}) and N (kg ha^{-1}) accumulation and LAI (m^2 m^{-2}) for sugarcane; *ymax* is the maximum for each variable; DAH represent days after harvest; *a* and *b* are function adjustment coefficients. From the results of biomass and N accumulation, two rates for these variables were calculated: biomass accumulation rate (BAR) and Nitrogen accumulation rate (NAR), which were obtained from the first derivative of the abovementioned sigmoid model equation (Lucchesi, 1984).

To describe the leaf N content dewlap and SPAD index during the sugarcane crop cycle, the following linear function was used (Equation 2), as described by Ferreira (1999):

$$y = y0 - (a \times DAH) \qquad 2$$

Where: *y* represents the leaf N content (g kg^{-1}), *y0* is the *y* intercept and *a* is the angular coefficient.

To estimate the tillers density evolution during the crop cycle of sugarcane, a quadratic model was used according to the formula below (Equation 3) (Ferreira, 1999).

$$y = y0 + (a\ \times\ DAH) + (b\ \times\ DAH^2) \qquad 3$$

Where: y is the tillers density (tillers m^{-1}), *y0* is the y intercept; *a* and *b* are the function adjustment coefficients.

The results were subjected to analysis of variance (p>0.05) and the treatments were evaluated by regression analysis. Regressions were determined using the software SigmaPlot (Version 11.0, Systat Software Inc., San Jose, USA). When significant, the means of variables were adjusted into linear or quadratic models through orthogonal polynomials.

Conclusion

Nitrogen fertilization together with subsurface drip irrigation increased the accumulation of biomass and nitrogen in the aboveground part of the sugarcane, because the main mechanism of N movement in the soil is by mass flow, a process that requires water and consequently, more water availability, higher nutrient uptake and more biomass accumulation. Similarly, the nitrogen application by subsurface drip irrigation increases all the biometric, physiological and production parameters of the sugarcane crop. The irrigated management combined with better plant nutrition show highest results to biomass production. The great benefits of fertirrigated management are that N is applied gradually in several small doses during the cycle, with N absorption and biomass accumulation occurring throughout the period. Thus, the demand for the nutrient by the crop can be met in the most efficient way.

Conflict of Interest

The authors declare that there is no conflict of interest

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