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NITROGEN, PHOSPHORUS AND POTASSIUM CONCENTRATION IN SUGARCANE SUBJECTED TO WATER DEPTHS AND NITROGEN DOSES

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1 ABSTRACT

The amount of nutrients absorbed by plants may vary according to the characteristics of the plant, external factors that influence the process and during the crop cycle. Thus, this work aimed to evaluate the effect of irrigation and nitrogen fertilization on nitrogen, phosphorus and potassium concentrations in the leaf, tip and culm of sugarcane (cane-plant) during the crop cycle. The experiment was conducted at the Experimental Sugarcane Station, in Carpina, Pernambuco, Brazil. The treatments consisted of four water depths, five doses of nitrogen and five evaluation times, arranged in rows and outlined in a randomized block design with four replications. The concentration of nitrogen in the leaf and culm of sugarcane reduced according to plant age and increased with increasing nitrogen rates. As for water depths, they did not affect plant's nitrogen absorption, only influencing phosphorus concentration in the leaf. The potassium concentration in the leaf, tip and culm also reduced due to plant age, but it was not affected by water depths and nitrogen doses.

Keywords: *Saccharum* spp., crop cycle, irrigation, nitrogen fertilization, nutrients.

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CONCENTRAÇÃO DE NITROGÊNIO, FÓSFORO E POTÁSSIO EM CANA-DE-AÇÚCAR SUBMETIDA A LÂMINAS DE ÁGUA E DOSES DE NITROGÊNIO

2 RESUMO

A quantidade de nutrientes absorvidos pelas plantas pode variar em função das características do vegetal, de fatores externos que influenciam o processo e ao longo do ciclo da cultura. Assim,

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objetivou-se por meio desse estudo avaliar o efeito da irrigação e da adubação nitrogenada na concentração de nitrogênio, fósforo e potássio nas folha, ponteiro e colmo da cana-de-açúcar (cana-planta) ao longo do ciclo da cultura. O experimento foi realizado na Estação Experimental de cana-de-açúcar, em Carpina, Pernambuco, Brasil. Os tratamentos consistiram em quatro lâminas de água, cinco doses de nitrogênio e cinco épocas de avaliação, arranjados em faixas e delineados em blocos ao acaso com quatro repetições. As concentrações de nitrogênio na folha e colmo da cana-de-açúcar aumentaram com o incremento das doses de nitrogênio. As lâminas de água não influenciaram a absorção de nitrogênio e potássio pela planta, apenas a concentração de fósforo na folha. A concentração de potássio na folha, ponteiro e colmo reduziu com a idade da planta, mas não foi influenciada pelas lâminas de água e doses de nitrogênio.

Palavras-chave: *Saccharum spp.*, ciclo da cultura, irrigação, adubação nitrogenada nutrientes

3 INTRODUCTION

Brazil is the largest sugarcane (*Saccharum* spp.) producer, one of the most important crops in the world (BRASIL, 2015). It is estimated that Brazilian sugarcane production, for 14/15 crops, reaches about 642.1 million tons. The state of Pernambuco is responsible for 2.3% of the sugarcane national production, with an average yield of 56.63 Mg ha^{-1} (CONAB, 2015).

A significant factor that should be highlighted, given its influence on sugarcane yield, is the availability of water and nutrients to plants. Regarding water, rainfalls do not always meet the actual water requirement of the plants. Irrigation, when well planned, has an unquestionable economic return (DANTAS NETO et al., 2006).

Line source sprinkler system has been widely used in studies of water relations in plants. It consists of sprinklers line closely spaced apart, applying water in decreasing doses in the direction perpendicular to the pipe. This system has used in studies on irrigation and productivity, such Mendonça et al. (1999), Lauer (1983) and Frizzone (1986). Frizzone (1986) cited advantages of using the line source sprinkler system: area, equipment and labor savings economy; installation and operation easy and more treatments in a smaller area than in the conventional sprinkler system.

However, for better efficiency in use of irrigation water is important the use of balanced fertilization, efficiently and profitably (MOURA et al., 2005) noting that, with this practice, each nutrient dynamics should be observed considering each culture.

Thus, it becomes necessary to study a more efficient water use and fertilization management practices and identify plants' main nutritional problems (OLIVEIRA et al., 2012). In this regard, studies that act in identifying potential for absorption and allocating nutrients by sugarcane, during the cycle of the plant, may direct new methods and more efficient fertilization forms.

Franco et al. (2011), evaluating the use of urea nitrogen by sugarcane (cane-plant), observed that nitrogen derived from fertilizer contributes up to 40% of the total nitrogen in sugarcane in early stages of development, decreasing during maturity stages to about 10% of the total nitrogen during harvest.

For Oliveira et al. (2011), maximum concentrations of nitrogen, phosphorus and potassium obtained in the culm occur in early phenological phases, indicating that topdressing fertilization in irrigated conditions should be performed before the conventionally recommended period.

Therefore, the absorption of nutrients differs according to the development of the plant, and the knowledge of nutritional requirements becomes important to establish the levels of nutrient and the most appropriate time to be applied through fertilizers, thereby obtaining better yields.

In this context, considering that the availability of nutrients and their absorption by plants are influenced by various production factors, the effect of water depths and nitrogen doses were studied for concentrations of nitrogen, phosphorus and potassium in sugarcane organs (leaf, tip and culm) according to crop cycle.

4 MATERIAL AND METHODS

The experiment was conducted in the field, in the agricultural area of the Experimental Sugarcane Station of Carpina (EECAC), a research unit of the Rural Federal University of Pernambuco (UFRPE), located in Carpina, PE (7º51'13" S, 35º14'10" W, 180 m above sea level), from November 2012 to November 2013.

The soil of the experimental area was classified as dystrophic abruptic Yellow Argisol (EMBRAPA, 2013), whose physical and chemical characterization was performed on soil samples collected in the 0.0-0.2 and 0.2-0.4 m layers (Table 1).

Table 1. Chemical and physical characterization of the experimental area's soil before the experiment

Layer	**Chemical analysis**									
	pH	**P**	**H+Al**	**Al^{3+}**	**Ca^{2+}**	**Mg^{2+}**	**K^+**	**CEC(1)**	**V(2)**	**m(3)**
m	H_2O	mg dm^{-3}	---------------------cmol$_c$dm^{-3}---------------------						-----%-----	
0-0.2	5.18	17.5	3.45	0.25	1.67	1.63	0.15	6.99	50.64	6.57
0.2-0.4	5.06	17.0	4.00	0.30	1.67	1.13	0.15	7.05	43.26	8.85
Layer	**Physical analysis**									
	Ds(4)	**Sandy**	**Silt**	**Clay**	**$Θ_{CF}$(5)**	**$Θ_{PWP}$(6)**	**Textural class**			
m	mg m^{-3}	---------g kg^{-1}------			---$m^{-3}m^{-3}$---					
0-0.2	1.72	848.7	13.9	137.4	0.15	0.10	Sandy loam			
0.2-0.4	1.86	826.2	16.4	157.4	0.18	0.12	Sandy loam			

(1) Potential cation exchange capacity; (2) base saturation; (3) aluminum saturation; (4) soil density; (5) field capacity; (6) permanent wilting point

The preparation of the soil was done 15 days prior to the experiment and consisted of harrowing (harrow and leveling harrow) for clod breaking, destruction of crop residues, lime incorporation, organization of the area, and subsequent opening of planting rows. For soil correction, limestone at a dose of 465 kg ha^{-1} was applied. When calculating the amount of limestone used, the method of neutralization of exchangeable aluminum was applied.

Fertilization took place on the planting day and exclusively in foundation, with the application of 30 kg ha^{-1} of phosphorus (P_2O_5), 60 kg ha^{-1} of potassium (K_2O) and nitrogen (according to each treatment), using as sources potassium chloride, superphosphate and urea, respectively. Both liming and fertilization were recommended by IPA (2008).

The planting was done manually using seedlings of the RB92579 sugarcane variety. The seedlings were distributed, leaving three buds each billet. The stems were distributed within the planting furrows, totaling 18 buds per linear meter.

The experimental plots were ten rows of sugarcane plants, 1.10 m apart, 6.0 m long, with 66.0 m^2 of total area and 39.6 m^2 of useful area, totaling 80 experimental plots.

The treatments consisted of four water depths (Di) and five doses of nitrogen (Ni). Water depths were determined according to evapotranspiration, namely: D_0 = 1,498; D_1 = 1,614; D_2 = 1,739; and D_3 = 1,854 mm. In these values, the accumulated rainfall and the initial depth (1,360 + 138 mm) are included. Nitrogen doses were determined based on IPA's recommendations (2008) for cane-plant (40 kg ha^{-1}). The other applied doses were determined in percentage terms from the standard dose, as follows: N_0 = 0, N_1 = 20, N_2 = 40 (standard dose), N_3 = 80 and N_4 = 120 kg ha^{-1}, arranged in groups and outlined in a randomized block design with four replications.

The irrigation system was "line source sprinkler system" (sprinkler line), according to methodology developed by Hanks et al. (1976). The system consisted of a central line with seven sprinklers spaced every 15 meters on a pipe located in the center of the experimental area. The sprinklers were mini-gun KS 1500 – PLONA, with 16.0 × 5.0 mm diameter nozzles, 25 mca operating pressure, 13.61 m^3 h^{-1} nominal flow rate and 60 m wet diameter.

The relation between the reference depth D_2 (100%) and the others, as well as the depths applied in each treatment, was obtained by evaluations of the irrigation system. The tests for measuring water depths consisted of collector distribution lines perpendicular to the line of sprinklers, five collectors in each plot, 1 m apart, distributed in each experimental block between the planting rows. The blades were defined by average water volume collected in the five collectors (Table 2).

Table 2. Results from the irrigation system evaluation and volume of water applied

Depths	Ia (mm h^{-1})	Di (%)	Da (mm)	D (mm)	P (mm)	Dt (mm)
D_3	27.8	150	356	138	1,360	1,854
D_2	18.5	100	241	138	1,360	1,739
D_1	9.6	48	116	138	1,360	1,614
D_0	0	0	0	138	1,360	1,498

Ia: irrigation system application rate; Di: irrigation depth based on crop evapotranspiration; Da: depth applied through irrigation during crop cycle (mm); D: initial depth applied; P: rainfall during the experiment; Dt: total depth (mm)

The daily crop evapotranspiration ETc (mm) was calculated by the following equation:

$$ETc = ECA \times Kp \times Kc \qquad (1)$$

Where,
ECA = evaporation of the Class A tank, mm;
Kp = Class A tank coefficient;
Kc = crop coefficient.

Kp values were obtained from wind speed, relative humidity and evaporation of the class A tank data, installed near the experimental area with low surround vegetation with a 10 m border (DOORENBOS; PRUITT, 1976). Kc values were obtained according to values recommended by Doorenbos and Kassam (1994) for plant development stages aiming to determine crop evapotranspiration for each stage (Table 3).

Table 3. Crop coefficients (Kc) for sugarcane in different stages of development

Cane-plant	
Days	**Kc**
1 to 61	0.40
62 to153	0.75
154 to 244	1.10
245 to 334	1.25
335 to 360	0.70

Fonte: (DOORENBOS; KASSAM, 1994)

Irrigation was performed when the difference between the sum of daily crop evapotranspiration (ETc) and rainfall in the period reached 40% of the total soil water available. To determine the total water available in the soil, the results of field capacity and permanent wilting point were considered, as well as depth of the root system. The data from water balance during the cultivation of cane-plant and rainfall during the experiment are shown in Figure 1 and 2, respectively.

Figure 1. Water balance during the cultivation of cane-plant

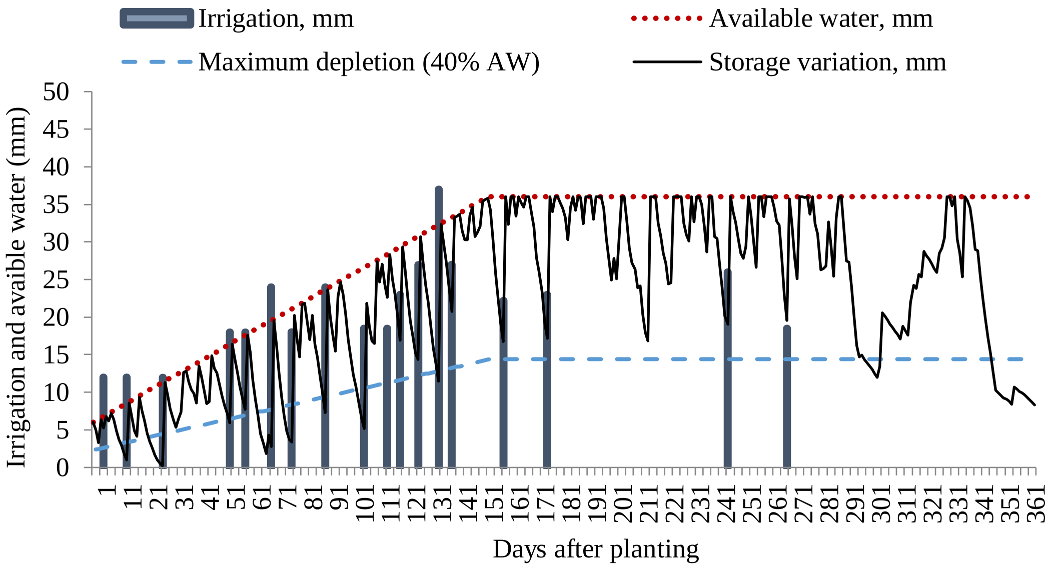
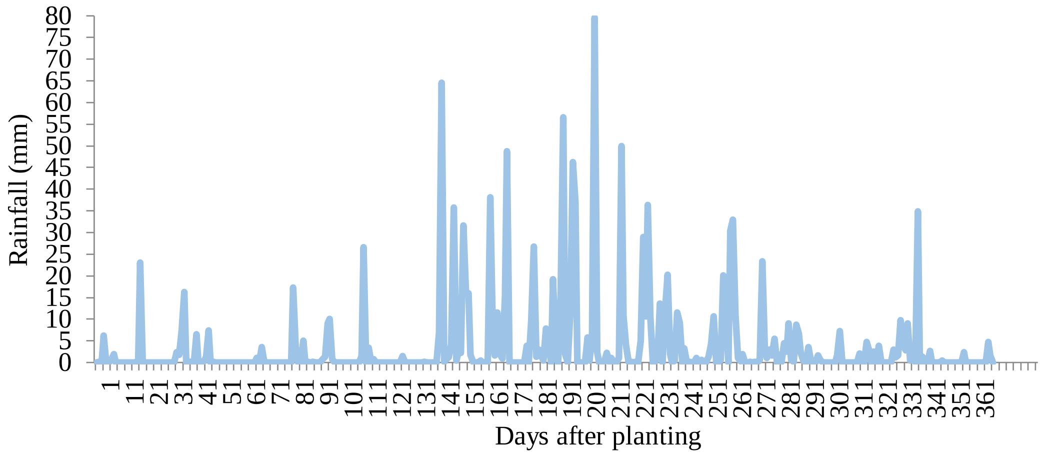


Figure 2. Rainfall during the cultivation of cane-plant



In the first three months of the crop cycle, uniform irrigations in all treatments were made, totaling a 138 mm depth because the planting was done in the summer, the driest season of the year, in order to ensure uniformity of sprouting and establishment of plants. The mobile cylinder-type spraying system was used with four-inch diameter nozzles and 54 m^3 h^{-1} flow, under a 40 m water column pressure. Then, the application of different depths began, using the "line source sprinkler system".

At 270 DAP, the irrigation was interrupted, promoting a water stress on the culture. Water stress aimed to induce maturation and sugar concentration, because, according to Doorenbos and Kassam (1994), during the ripening period, sugarcane requires low water content in the soil.

To obtain nitrogen, phosphorus and potassium concentrations, five collections of plant shoot were made. The first was at 165 DAP, the second at 225, the third at 263, the fourth at 306 and the fifth at 349 DAP. These collections were always held in the outer rows of each plot (1st, 2nd, 9th and 10th rows), so that they were collected in different water depths and nitrogen levels. Ten plants taken randomly for analysis. The aerial part of the plant was separated in leaves, tips and culms.

After separated, this material was triturated with a forage machine and then samples were selected. They were placed in previously identified paper bags and brought to an oven with forced air circulation at 65ºC until constant weight. The dried samples were processed with a Wiley mill. To evaluate the nutritional status of the leaves, tips and culms, a sample of the grinded material was removed. Then, nitrogen, phosphorus and potassium concentrations were determined. To obtain the concentrations of nutrients, nitric (phosphorus and potassium) and sulfuric (nitrogen) digestions were performed according to the methodology by Embrapa (2009) and Bezerra Neto and Barreto (2011), respectively.

The nitrogen was determined by the Kjeldahl distiller method, the concentration of potassium by flame photometry and phosphorus by colorimetric molybdate-vanadate method in a spectrophotometer (BEZERRA NETO; BARRETO, 2011).

The data were submitted to normality test (Shapiro-Wilk) and subsequent analysis of variance and regression by F test at 5% probability.

5 RESULTS AND DISCUSSION

5.1 Nitrogen in sugarcane

There was a significant effect of the interaction between nitrogen doses (N) and days after planting (DAP) in the nitrogen concentration in sugarcane tips. There was also a significant effect of the single factor (nitrogen doses) on nitrogen concentrations in the leaf and culm. Regarding days after planting, a significant effect was observed on nitrogen concentrations in the leaf, tip and culm of sugarcane. However, there was no significant effect of water depths on nitrogen concentration in the different plant organs (Table 4).

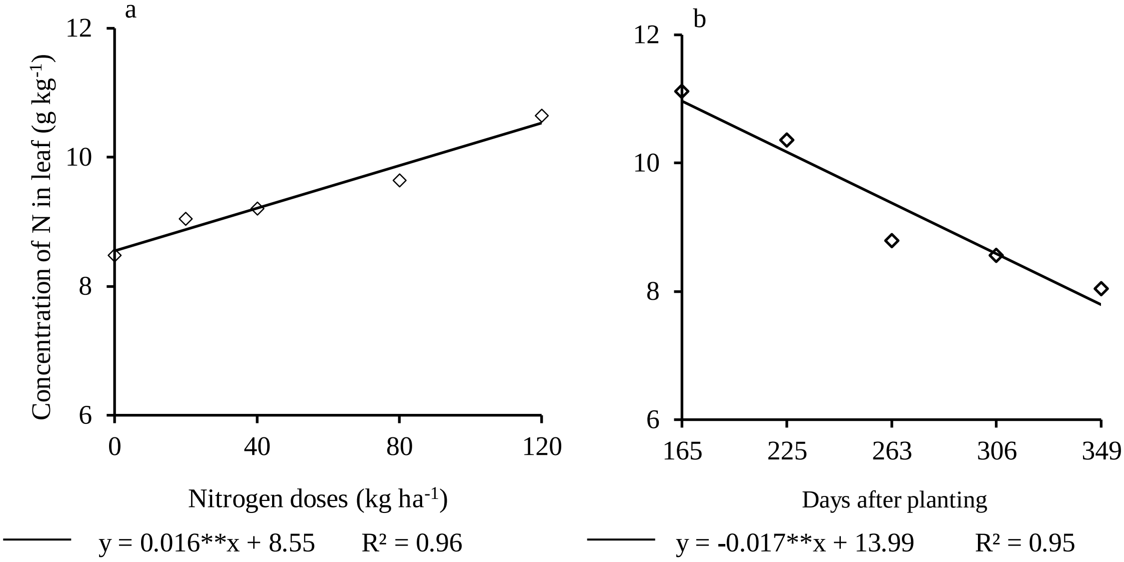
Table 4. ANOVA and mean values of nitrogen (N) concentrations in the organs of the plant (leaf, tip and culm) according to water depths (D), nitrogen (N) and days after planting (DAP)

D.V	GL	Variables		
		N (g kg^{-1})		
		Leaf	Tip$^{\alpha}$	Culm
BL	3	1.47^{ns}	1.74^{ns}	1.95^{ns}
D	3	3.33^{ns}	5.13^{ns}	1.42^{ns}
Error$_{(D)}$	9	---	---	---
N	4	14.61**	2.34^{ns}	5.80**
Erro$_{(N)}$	12	---	---	---
DAP	4	19.92**	10.80**	52.23**
Erro$_{(DAP)}$	12	---	---	---
DxN	12	1.23^{ns}	1.07^{ns}	0.82^{ns}
DxDAP	12	0.33^{ns}	1.00^{ns}	1.57^{ns}
NxDAP	16	1.28^{ns}	3.42**	1.18^{ns}
DxNxDAP	48	1.23^{ns}	1.72^{ns}	1.16^{ns}
Erro$_{(D.N.DAP)}$	264	---	---	---
General mean		9.40	13.16	4.75
CV1$_{(D)}$		10.09	6.07	14.40
CV2$_{(N)}$		20.09	9.21	23.91
CV3$_{(DAP)}$		27.55	18.51	35.45
CV4$_{(D.N.DAP)}$		15.59	6.37	17.56

^{ns} not significant, * significant at 5%, ** significant at 1% probability by F test;
$^{\alpha}$ calculated F values transformed: $(y+0.5)^{0.5}$

When evaluating the nitrogen concentration in sugarcane leaf in function of nitrogen fertilization, there was an increase in nitrogen concentration with the increase of applied nitrogen doses, adjusting to an increasing linear equation (Figure 2a). The concentration of nitrogen in the treatment without nitrogen fertilization was 8.44 g kg^{-1}. The 120 kg ha^{-1} nitrogen dose had a 10.61 g kg^{-1} concentration, providing a 25.7% increase.

Figure 2. Nitrogen concentration in sugarcane leaf (cane-plant), RB92579 variety, in function of on nitrogen (a) and days after planting (b)



Franco et al. (2010), evaluating the development of cane-plant with nitrogen fertilization (0, 40, 80 and 120 kg ha^{-1}) at planting, in a soil classified as Red Dystrophic Latosol, also found a linear increase in the nitrogen concentration in treatments with nitrogen application.

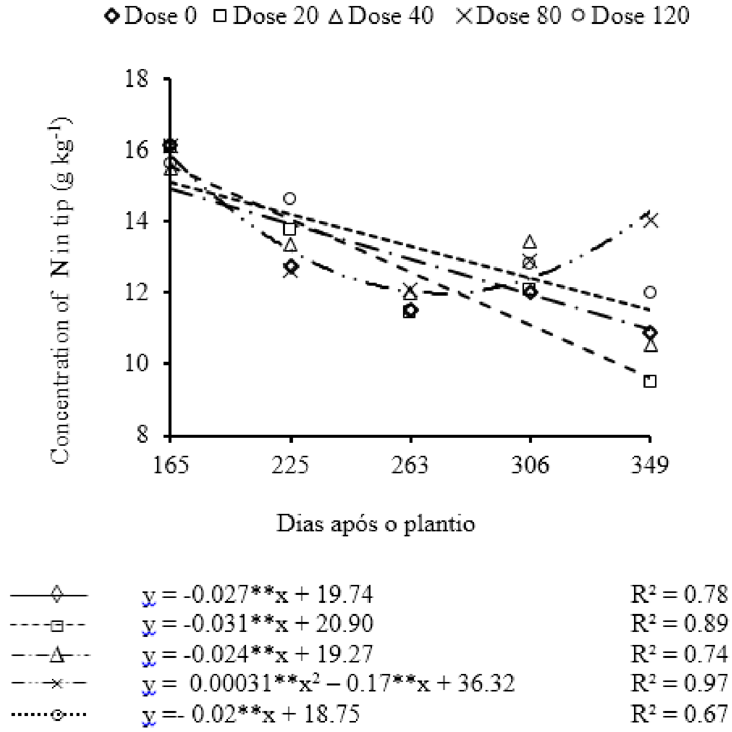
While there may be losses by leaching, volatilization, among others, fertilization using fertilizers increases the nutrients available to plants and is essential for the crop, because sugarcane crops require a considerable amount of nitrogen as a nutrient to produce a higher amount of biomass (THORBURN; MEIER; PROBERT, 2005).

Regarding the effect of days after planting on the nitrogen concentration in the leaf (Figure 2b), there was a decreasing linear effect of the regression, with a 0.017 g kg^{-1} per day reduction in the nitrogen concentration in the leaf. The highest concentration (11.10 g kg^{-1}) was observed at 165 DAP and the lowest (7.88 g kg^{-1}) at 349 DAP. A 29.0% reduction was estimated.

Oliveira et al. (2013), determining the concentration of nitrogen in sugarcane shoot at different stages of the crop cycle, also found that the nitrogen concentration in the shoot decreases over time. The highest nitrogen concentration obtained in the early stages of sugarcane plant growth was 13.2 g kg^{-1}. According to these authors, the reduction of the nitrogen concentration in the dry biomass of the plant shoot is due to its growth.

As to the concentration of nitrogen in the tip of sugarcane, there was a variation in in function of the crop cycle. However, the response varied according to the dose of nitrogen applied (Figure 3).

Figure 3. Nitrogen concentration in sugarcane tip (cane-plant), RB92579 variety, in function of days after planting and for each nitrogen doses



For 0, 20, 40 and 120 kg ha^{-1} nitrogen doses, decreasing linear equations showed a better adjustment. However, the 80 kg ha^{-1} nitrogen dose had a quadratic equation adjustment. The highest nitrogen concentrations were obtained at 165 DAP (15.28, 15.78, 15.31 and 15.45 g kg^{-1}), and the lowest at 349 DAP (10.32, 10.08, 10.89 and 11.77 g kg^{-1}) for 0, 20, 40 and 120 kg ha^{-1} nitrogen doses, respectively, with a smaller decrease (23.8%) in plants fertilized with the 120 kg ha^{-1} nitrogen dose.

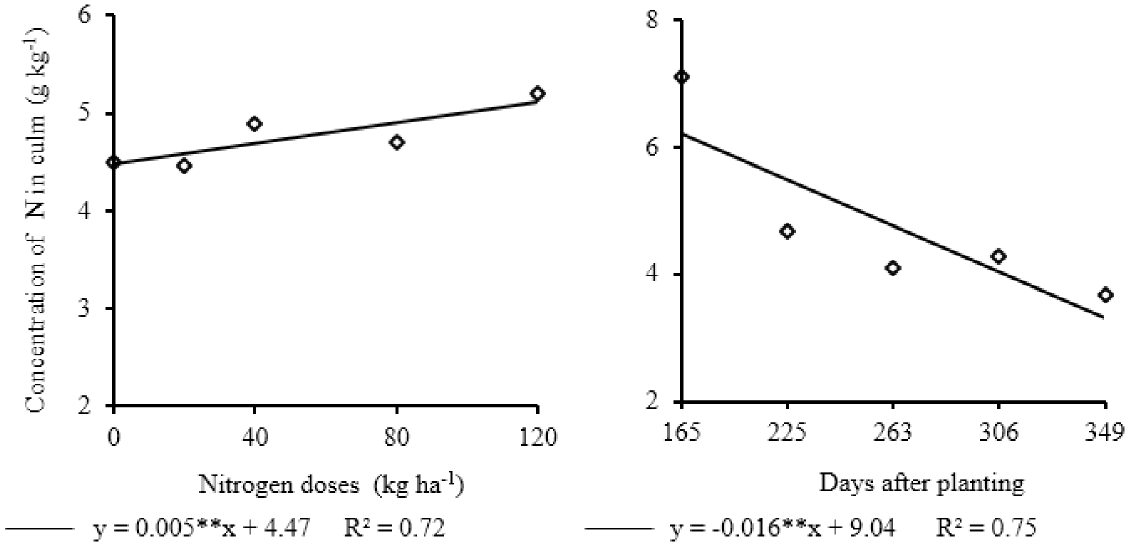
The decrease over time in the plants nitrogen concentration was due to the dilution effect, i.e., the dry biomass growth rate is higher than the nutrient absorption rate since there is a tendency by the plant to increasingly accumulate dry biomass over the crop cycle (JARRELL; BEVERLY, 1981).

Considering the 80 kg ha^{-1} nitrogen rate, it was observed that the highest concentration occurred at 165 DAP (16.43 g kg^{-1}), with a subsequent reduction up to 287 DAP (12.65 g kg^{-1}), from which an increase was observed, reaching a total of 14.30 g kg^{-1} at 349 DAP. In the evaluated times, no significant effect was observed regarding further effects of nitrogen doses during each evaluation period.

Importantly, leaves and tips are the most photosynthetically active parts. Thus, the higher concentration of nitrogen in the tips over other parts of the plant is possibly due to a higher metabolic activity and transpiration of that body, causing a greater flow of nutrients to young leaves and consequently an increase in nitrogen concentration in the tissues of this plant part.

Evaluating the nitrogen concentration in the culm, according to nitrogen dose (Figure 4a), it was found that the increasing linear equation presented the best adjustment. Thus, the highest concentration of nitrogen in the culm (5.07 g kg^{-1}) was obtained with the 120 kg ha^{-1} nitrogen dose and the lowest (4.47 g kg^{-1}) was obtained without nitrogen fertilizer, with a 13.42% increase in nitrogen concentration in the culm. Ishikawa et al. (2009), evaluating the application effect of high nitrogen doses (300 and 600 kg ha^{-1} $year^{-1}$) on nitrogen concentration in sugarcane varieties, could observe that the nitrogen concentration in the culm was significantly higher when a larger amount of nitrogen fertilizers was applied.

Figure 4. Nitrogen concentration in sugarcane culm (cane-plant), RB92579 variety, in function of nitrogen doses (a) and days after planting (b)



According to Vale et al. (2011), nutrient deficiency can limit nutrition, growth and production of sugarcane. However, in this study, no nitrogen deficiency symptoms were found in plants without nitrogen fertilization or in plants that received lower nitrogen doses. The absence of nutritional deficiency symptoms can be due to the nitrogen entering the soil from other sources such as organic matter, photochemical reactions and biological nitrogen fixation (TAIZ; ZEIGER, 2013).

Regarding nitrogen concentration in the culm in function of days after planting, a reduction was observed according to crop cycle (Figure 4b), adjusting to a decreasing linear regression equation, with a 0.016 g kg^{-1} reduction of nitrogen per day and a 46% percentage loss from 165 to 349 DAP. Oliveira et al. (2010) also observed reductions in nitrogen concentration in the culm of eleven varieties of sugarcane (cane-plant) in the period between 120 and 360 DAP.

5.2 Phosphorus in sugarcane

The concentration of phosphorus in the sugarcane leaf was influenced by the interaction between water depths, days after planting and the interaction between nitrogen doses and days after planting. However, there was no significant effect of the studied factors on the concentration of phosphorus in the tip and culm of sugarcane (Table 5).

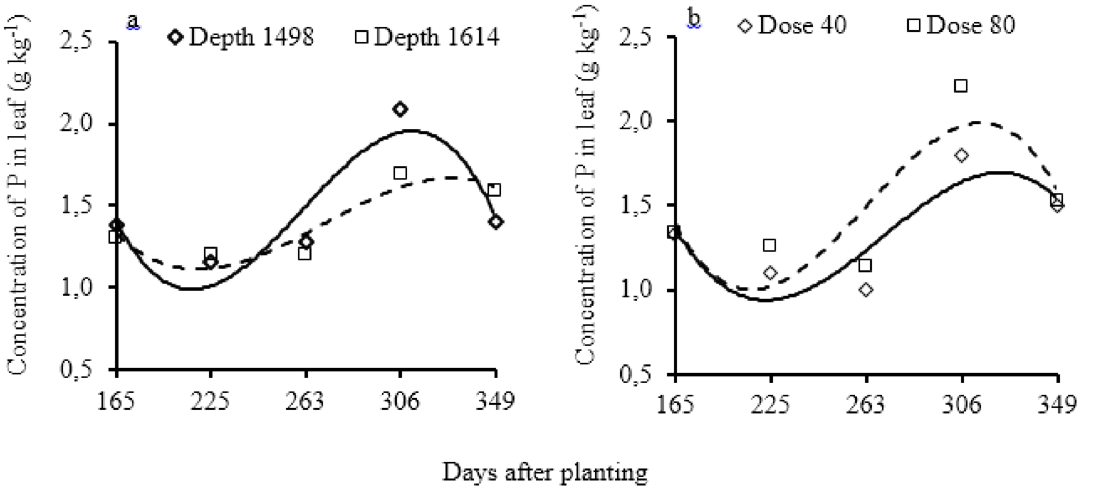
Table 5. ANOVA and mean values of phosphorus (P) concentrations in the organs of the plant (leaf, tip and culm) according to water depths (D), nitrogen (N) and days after planting (DAP).

D.V	GL	Variables		
		P (g kg^{-1})		
		Leaf	**Tip**$^{\alpha}$	**Culm**
BL	3	22.24**	37.20**	16.57**
D	3	2.32^{ns}	0.84^{ns}	0.05^{ns}
Error$_{(D)}$	9	---	---	---
N	4	1.86^{ns}	0.14^{ns}	0.31^{ns}
Erro$_{(N)}$	12	---	---	---
DAP	4	1.91^{ns}	0.55^{ns}	2.50^{ns}
Erro$_{(DAP)}$	12	---	---	---
DxN	12	0.77^{ns}	1.19^{ns}	0.83^{ns}
DxDAP	12	2.55**	0.60^{ns}	0.51^{ns}
NxDAP	16	2.87**	1.23^{ns}	1.60^{ns}
DxNxDAP	48	1.16^{ns}	0.90^{ns}	1.04^{ns}
Erro$_{(D.N.DAP)}$	264	---	---	---
General mean		1.41	2.00	1.34
CV1$_{(D)}$		6.76	6.43	9.47
CV2$_{(N)}$		10.93	10.90	14.97
CV3$_{(DAP)}$		33.78	25.07	39.15
CV4$_{(D.N.DAP)}$		10.14	7.09	10.87

^{ns} not significant, * significant at 5%, ** significant at 1% probability by F test;
$^{\alpha}$ calculated F values transformed: $(y+0.5)^{0.5}$

Evaluating the phosphorus concentration during the crop cycle and in each water depth (Figure 5a), there was a significant response to 1,498 (D_0) and 1,614 (D_1) mm depths, adjusted to a third-degree polynomial regression model. Through it, a 28.3 and 8.46% decrease of the phosphorous concentration in the leaf until 225 DAP could be verified, followed by a 84.8 and 35.8% increase until 309 and 343 DAP, and a subsequent decrease in the last evaluation time (349 DAP) related to 1,498 (D_0) and 1,614 (D_1) mm water depths, respectively.

Figure 5. Phosphorus concentration in sugarcane leaves (cane-plant), RB 92579 variety, in function of days after planting for each water depth (a) and nitrogen doses (b)



(a) —— $y = -1.61 .10^{-6^{**}}x^3+0.0012^{**}x^2-0.30^{**}x+25.18$ $R^2=0.80$

(a) - - - $y = -0.59 .10^{-6^{*}}x^3+0.00047^{*}x^2-0.12^{*}x+10.88$ $R^2=0.84$

(b) —— $y = -1.01.10^{-6^{**}}x^3+0.00081^{**}x-0.26^{**}x+17.84$ $R^2=0.70$

(b) - - - $y = -1.46.10^{-6^{**}}x^3+0.00113^{**}x-0.28^{**}x+23.10$ $R^2=0.62$

The phosphorus absorption may differ depending on plant's developmental stage. As phosphorus is a nutrient with a low mobility in soil, the small amount of roots in the early stage of plant development does not favor its absorption. However, because the root system grows in the soil, there is nutrients absorption, which initially follows its growth stages. Over time, there is a decrease in the nutrient concentration along the root surface as they are absorbed, creating a concentration gradient between the closest and the farthest region from the root (NOVAIS et al., 1999).

For 1,739 (D_2) and 1,853 (D_3) mm water depths, there was no significant effect on phosphorus concentration in the leaves, with 1.43 and 1.35 g kg^{-1} average values, respectively. The excess water applied in the soil may have caused phosphorus leaching. Regarding deployment of irrigation levels in each evaluation period, there was also no significant effect.

The phosphorus concentration in sugarcane leaf was also evaluated in response to days after planting and each nitrogen dose (Figure 5b). A significant response to 40 and 80 kg ha^{-1} nitrogen doses was observed, adjusting to a third-degree polynomial model. Nitrogen contributes to the absorption of other ions. However, it should be noted that its excess might be harmful to the plant, resulting in increased growth of shoots in relation to the root system, causing the plant to be more susceptible to water stress and nutrient deficiency, especially phosphorus and potassium (ENGELS; MARSCHNER, 1995).

Initially, there was a reduction in phosphorus concentration in sugarcane leaves until 230 and 220 DAP (0.99 and 1.08 g kg^{-1}), followed by an increase until 330 and 324 DAP (1.70 and 1.99 g kg^{-1}), and a subsequent fall at 349 DAP (1.58 and 1.65 g kg^{-1}), respectively, for 40 and 80 kg ha^{-1} N doses. A higher concentration of phosphorus (1.5 g kg^{-1}) was observed with the 80 kg ha^{-1} nitrogen dose.

The phosphorus absorption capacity by sugarcane leaves increased over time. This may have been due to root system development and possible existence of residual levels due to a heavy use of phosphate fertilizers on this crop, considering that, during the chemical characterization of the experimental area, before planting sugarcane, the soil already had an average content of 17 mg dm^{-3} (as shown in Table 1 above). For other nitrogen rates (0, 20 and 120 kg ha^{-1}), an effect of days after planting on the phosphorus concentration was observed. The phosphorus average values on the leaf were 1.35, 1.42 and 1.45 g kg^{-1}, respectively. There were also no significant effects of regression on the deployment of nitrogen doses in each evaluation period.

Phosphorus was the nutrient less absorbed by sugarcane. The values of this nutrient extracted from the soil by plants are generally low compared to nitrogen and potassium. However, this nutrient's concentration in the soil solution and the speed of its recovery are not enough to meet crop's needs, requiring its application at planting (COUTINHO et al., 2007).

5.3 Potassium in sugarcane

The potassium concentration in the organs of sugarcane (leaf, tip and culm) was influenced by days after planting. However, there were no significant effects of water depths and nitrogen doses on potassium concentration in the different sugarcane organs (Table 6). Prado and Pancelli (2008), studying the effect of nitrogen fertilization on macronutrient concentrations in the vegetative tissue (leaf) of sugarcane, also found no changes in the concentration of potassium in terms of fertilization.

Table 6. ANOVA and mean values of potassium (K) concentrations in the organs of the plant (leaf, tip and culm) according to water depths (D), nitrogen (N) and days after planting (DAP).

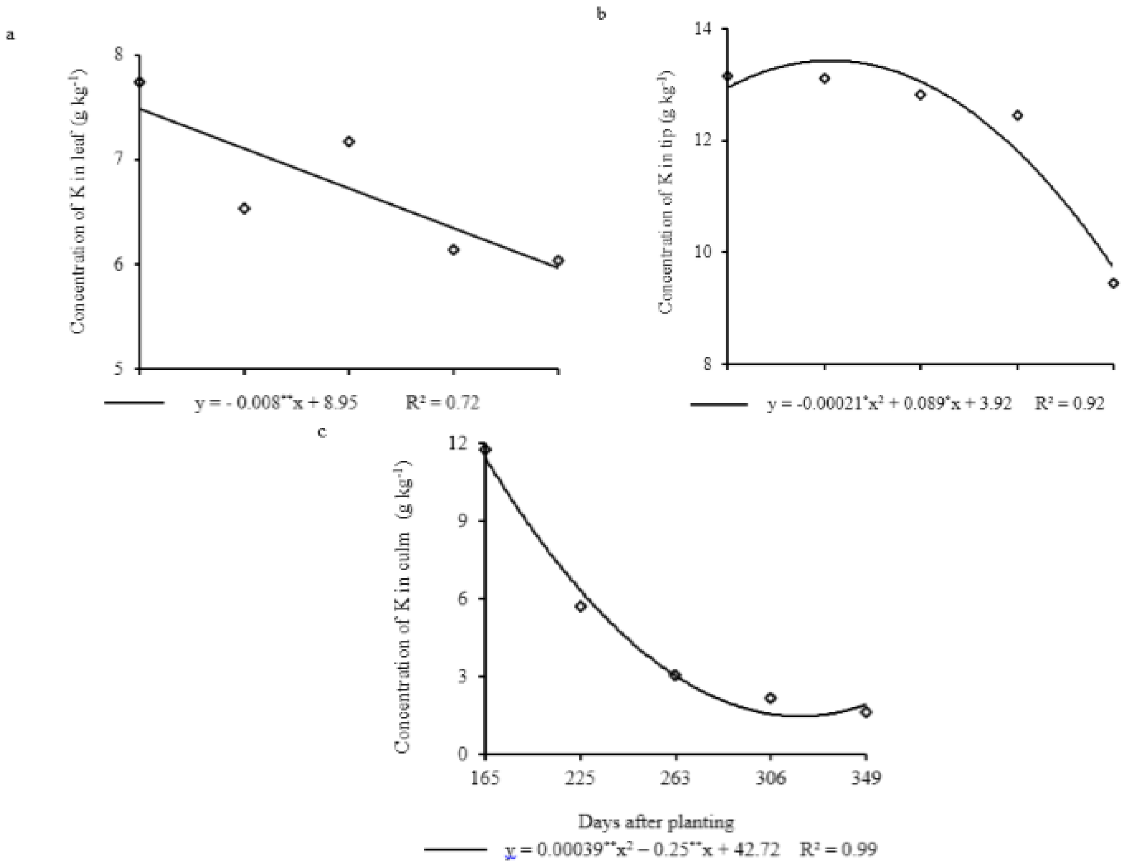
D.V	GL	Variables		
		K (g kg^{-1})		
		Leaf	Tip$^{\alpha}$	Culm
BL	3	4.47*	13.58**	4.43*
D	3	1.43^{ns}	0.40^{ns}	1.76^{ns}
Error$_{(D)}$	9	---	---	---
N	4	0.25^{ns}	0.09^{ns}	1.17^{ns}
Erro$_{(N)}$	12	---		---
DAP	4	6.53**	7.47**	151.20**
Erro$_{(DAP)}$	12	---	---	---
DxN	12	1.52^{ns}	1.08^{ns}	1.44^{ns}
DxDAP	12	1.09^{ns}	0.78^{ns}	1.03^{ns}
NxDAP	16	0.99^{ns}	0.76^{ns}	1.49^{ns}
DxNxDAP	48	0.82^{ns}	0.99^{ns}	1.17^{ns}
Erro$_{(D.N.DAP)}$	264	---	---	---
General mean		6.72	12.19	4.86
CV1$_{(D)}$		19.30	6.06	10.52
CV2$_{(N)}$		25.68	11.18	18.05
CV3$_{(DAP)}$		37.42	21.14	27.63
CV4$_{(D.N.DAP)}$		19.96	6.59	13.34

^{ns} not significant, * significant at 5%, ** significant at 1% probability by F test;
$^{\alpha}$ calculated F values transformed: $(y+0.5)^{0.5}$

Upon evaluating the potassium concentration in the leaf during the cultivation cycle, it was found that the linear regression equation presented a best adjustment (Figure 6a). Thus, the highest potassium concentration (7.63 g kg^{-1}) was obtained at 165 DAP, with a 0.008 g kg^{-1} linear reduction per day and a 19.4% reduction at 349 DAP (6.15 g kg^{-1}). The decrease in potassium concentration in leaves may have been due to the death of senescent leaves and redistribution of the nutrient among other plant organs.

For the effect of days after planting on potassium concentration in the tip (Figure 6b) and the culm (Figure 6c) of sugarcane, quadratic regression equations were adjusted. The highest concentration of potassium in tips (13.35 g kg^{-1}) was observed at 212 DAP. Then it decreased, with the lowest concentration (9.40 g kg^{-1}) being verified at 349 DAP. As for the potassium concentration in the culm, the highest (11.65 g kg^{-1}) was observed at 165 DAP, with a further reduction until 326 DAP (1.60 g kg^{-1}).

Figure 6. Potassium concentration in the leaf (A), tip (B) and culm (C) of sugarcane (cane-plant), RB92579 variety, according to the days after planting



The decrease in the concentrations of both nitrogen and potassium following the age of the plant is due to the dilution effect of these nutrients in the plant according to its growth. Thus, all factors that provide different changes in growth rates and absorption of nutrients values will entail different nutrient concentrations in the plant tissue. If there is a stoppage of plant growth and nutrients continue to be absorbed, there will be a concentration of the nutrient. If, however, the opposite occurs, i.e., a faster growth of the plant and the nutrient being absorbed to a lesser rate, the dilution occurs (MAIA et al., 2005).

Another effect that contributes to the concentration decrease of certain nutrients is nutrient translocation, which is observed for mobile nutrients such as nitrogen and potassium. In general, young leaves are richer in nitrogen, phosphorus and potassium, but poor in calcium if compared to mature leaves.

According to Oliveira et al. (2010) this decrease in nutrient concentrations in the culm can be justified, since potassium is responsible for the metabolism of hexoses and sucrose transport, by establishing a relation between the allocation of potassium and the protein synthesis, which is higher in leaves than in culms.

After nitrogen, potassium was the nutrient with the highest concentration in leaves and tips of sugarcane. The culm showed the highest concentration of nitrogen and potassium. Although not forming the structure of any organic compound, potassium plays important roles in plants such as in photosynthesis, enzyme activation, protein synthesis and transport of carbohydrates, among others. Therefore, it stimulates growth and production of plants (TAIZ; ZEIGER, 2013).

6 CONCLUSIONS

1. The concentrations of nitrogen and potassium in the leaf and culm of sugarcane and potassium in tip reduced according to the plant age.
2. The concentrations of nitrogen in the leaf and culm of sugarcane increased depending on the increase of nitrogen doses.
3. The concentration of nitrogen in the tip reduced in function of days after planting with 0, 20, 40 and 120 kg ha^{-1} nitrogen doses.
4. The order of nutrients absorption in plant organs was nitrogen > potassium > phosphorus, and the highest concentrations were observed in the tip, leaf and culm, respectively, except that potassium concentration was higher in the culm if compared to the leaf. Water depths did not affect nitrogen and potassium absorption by the plant. Only phosphorus concentration on the leaf was affected by water depths.

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