Impact of Irrigation on the Yield, Total Cost, and Its Influence on Hydraulic Conductivity in a Soil Under Vinasse Application

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Abstract

This study had the objective to evaluate the effect of irrigation and fertigation (N) in the crop yield and its impact on the total cost, in addition to its influence on the conductivity hydraulic capacity and logarithmic hydraulic conductivity in an Oxisol under vinasse application cultivated with sugarcane (second year), in state of Goiás, Brazil. The experimental design comprised randomized blocks in a 5 × 2 factorial scheme, with four replications. Treatments consisted of five levels of water replacement (100, 75, 50, 25 and 0%), with and without fertirrigation (N). The planting of sugarcane, cultivar RB85-5453, was performed in a double row (W-shaped), 8 m long, with 1.80 m spacing between the double rows, the distance between the crops in the double row was 0.40 m, with a total area of 52.8 m^2 in each paddock. For treatments with water, replacement (WR) a drip tube was placed in the ground at a depth of 0.20 m among the furrows of the double row. The drip tube (DRIPNET PC 16150) comprised a thin wall, 1.0 bar pressure, nominal discharge 1.0 L h^{-1}, and 0.50 m spacing between drippers. Nitrogen was applied by fertirrigation at a dose of 100 Kg ha^{-1}, at 30-day intervals, with 10 applications throughout the development of the sugarcane culture. Potassium fertilization was fully realized at planting. The total cost with irrigation did not increase significantly with fertirrigation (< 3%) in an Oxisol under vinasse application.

Keywords: *Saccharum officinarum* L., yield, expenses, fertilization, vinasse

1. Introduction

The sugar and ethanol industry is of great importance to the Brazilian economy, contributing effectively to the growth of the domestic market, through the production to several important products, the sugar and ethanol industry has occupied a prominent place in Brazilian agribusiness, therefore the irrigation and fertigation have become essential practices for increasing the crop yield with great economic importance, such as sugarcane (Dias Neto 2000; Dantas Neto et al. 2006; Santos 2014).

The use of fertilizers via irrigation (fertigation) reduces losses without increasing production costs, moreover, irrigation alone greatly affects the stalk, sugar, and alcohol yield variables, but fertigation usually intensifies these increases (Roberts, 2008; Da Silva et al., 2014).

The saturated hydraulic conductivity (Ksat) is a measure for the maximum water transmission capacity of a saturated porous medium (Mallants et al., 1997). It has been widely used as a constant in hydrological transport models to assess the risk of chemical leaching, to characterize water infiltration, and to model surface runoff. However, many samples are necessary to characterize the spatial and temporal variability of Ksat in natural soils (Amer et al., 2009).

Consequently, measurement of Ksat is expensive and labor intensive (Ahuja et al., 1989). Therefore, it is usually easier to estimate Ksat from easy-to-measure basic soil properties such as porosity (ϕ) or particle diameter, the latter being used in many recent studies (Rosas et al., 2013 and Salarashayeri and Siosemarde, 2012).

Despite a considerable spatial and temporal variability, most publications reported averaged comparisons between diferente tillage practices and did not account for spatio-temporal dynamics (Schwen et al., 2011; Strudley et al., 2008).

Recently, a series of studies addressed both the temporal and management-induced changes in soil hydraulic properties (Alletto and Coquet, 2009; Bormann and Klaassen, 2008; Schwen et al., 2011). These studies helped to improve our understanding of the dynamic impacts of soil management on physical and hydraulic soil properties.

In this context, the objective to evaluate the effect of irrigation and fertigation (N) in the crop yield and its impact on the total cost, in addition to its influence on the conductivity hydraulic capacity and logarithmic hydraulic conductivity in an Oxisol under vinasse application cultivated with sugarcane (second year), in state of Goiás, Brazil.

2. Method

The experiment was performed in the experimental area of the Federal Institute Goiano, campus Rio Verde GO Brazil, in the municipality of Rio Verde, Goiás (GO), Brazil, 17°48'28"S and 50°53'57"W, mean altitude 720 m, slightly rolling ground relief (slope 6%), Oxisol with mean texture 458, 150 and 391 g kg^{-1} sand, silt and clay, respectively, and chemical characteristics as shown in Table 1.

Table 1. Chemical characterization of soil in the experimental area

Layer	pH	OM	P	K	Ca	Mg	Al	H+Al	S	CTC	V
m	-	g dm^{-3}	mg dm^{-3}	---------------mmol dm^{-3}---------------							%
0.0-0.2	5.4	22.28	4.87	3.23	20.5	7	0	34.61	0.40	65.51	46.74
0.2-0.4	5.5	20.17	2.79	2.55	17.3	6	0	25.50	0.22	51.47	49.62

pH in distilled water. P and K – extractor Mehlich^{-1}. O.M – Organic matter. V – Saturation by bases.

The experimental design comprised randomized blocks in a 5 × 2 factorial scheme, with four replications. Treatments consisted of five levels of water replacement (100, 75, 50, 25 and 0%) and two doses of nitrogen (0 and 100 kg N ha^{-1}).

The planting of sugarcane, cultivar RB855453, was performed in a double row (W-shaped), 8 m long, with 1.80 m spacing between the double rows. The distance between the crops in the double row was 0.40 m, with a total area of 35.2 m^2 in each paddock. For treatments with water, replacement (WR) a drip tube was placed in the ground at a depth of 0.20 m among the furrows of the double row. The drip tube (DRIPNET PC 16150) comprised a thin wall, 1.0 bar pressure, nominal discharge 1.0 L h^{-1}, and 0.50 m spacing between drippers. On planting, all furrows of the plots were fertilized with 30 kg N ha^{-1} (urea), 120 kg P_2O_5 ha^{-1} (single superphosphate) and 80 kg K_2O ha^{-1} (potassium chloride). Nitrogen was applied by fertirrigation at a dose of 100 Kg ha^{-1}, at 30-day intervals, with 10 applications throughout the development of the sugarcane culture (Table 2). Potassium fertilization was fully realized at planting. Nitrogen was spread only in the treatment with 0% water replacement.

The fertigation with vinasse was carried out 90 days after planting (Sousa and Lobato, 2004). Chemical characteristics of vinasse: 0.31 kg m^{-3} of N, 0.12 kg m^{-3} of P_2O_5, 1.64 kg m^{-3} of K_2O, 0.52 kg m^{-3} of CaO, 0.35 kg m^{-3} of MgO, 1.45 kg m^{-3} of SO_4, 19.60 of organic matter, 6.00 kg m^{-3} of Cu, 2.00 kg m^{-3} of Zn, 3.50 kg m^{-3} of Mn, 7.50 kg m^{-3} of Fe.

Water demand was calculated by a 0.1 kPa puncture digital tensiometer. Tensiometric sensors were placed at a depth of 0.20, 0.40, 0.60 and 0.80 m, at a distance of 0.15, 0.30, 0.45 and 0.60 m from the drip tube, with daily readings of water tension in the soil. The soil's physical and water characteristics were determined by the water retention curve in the soil, with an available water capacity (AWC) of 100 mm. Soil was kept at field capacity in treatments with 100% WR. By the end of the experiment, the water supplemented to the soil was calculated to determine the volume of water provided (Table 2).

Table 2. Water volume received at each water replacement level

WR (%)	WA (mm)	R (mm)	TVW (mm)
0	0	1812	1812
25	110	1812	1922
50	220	1812	2032
75	330	1812	2142
100	440	1812	2252

WR – water replacement; WA – water applied during the experiment; R – rainfall; TVW– Total volume of water received.

Total evaporation-transpiration and precipitation reached 1700 and 1812 mm, respectively in the treatment without water replacement.

The parameters of the equations that represent the model for the soil was accomplished through the RETC program version 6.02. Type of model (Retention curve model: Van Genuchten, m=1-1/n) and conductivity model: Mualem.

$$\theta = \theta r + \frac{(\theta s - \theta r)}{\left[1 + (\alpha \times |\psi_m|)^n\right]^m} \tag{1}$$

$$S_e = \frac{e - e,}{\theta s - \theta r} \qquad 0 \le \text{Se} \le 1 \tag{2}$$

$$\text{K(Se)} = Ks\, \text{S}_e^1 \left(\frac{\int_0^{Se} \frac{1}{h(x)} dx}{\int_0^1 \frac{1}{h(x)} dx} \right)^2 \tag{3}$$

$$\text{D}(\theta) = \text{K} \frac{\partial \text{h}}{\partial \theta} \tag{4}$$

$$\text{C} \frac{\partial h}{\partial t} = \frac{\partial}{\partial z} (\text{K} \frac{\partial \text{h}}{\partial z} - \text{K}) \tag{5}$$

where:

θ - water contents, $cm^3\ cm^{-3}$;

θ_r - the residual water contents, $cm^3\ cm^{-3}$;

θ_s - the saturated water contents, $cm^3\ cm^{-3}$;

m, n e α - empirical parameter. With m = 1-1/n;

h - is the soil water pressure head (with dimension cm);

t - is time (days);

z - is soil depth (cm);

Se - effective water content;

K - is the hydraulic conductivity (cm $days^{-1}$);

Ks - is the saturated hydraulic conductivity (cm $days^{-1}$);

D(θ) - soil water diffusivity function ($cm^2\ days^{-1}$)

C - is the soil water capacity (cm^{-l}).

The production cost was calculated using the total production operational cost structure used by the Brazilian Institute of Agricultural Economy, proposed by Matsunaga et al. (1976).

Results were analyzed by ANOVA. In significant cases, regressions of linear and quadratic were performed for water replacement levels. Nitrogen application means were compared using Tukey test at significance degree $\alpha = 0.05$.

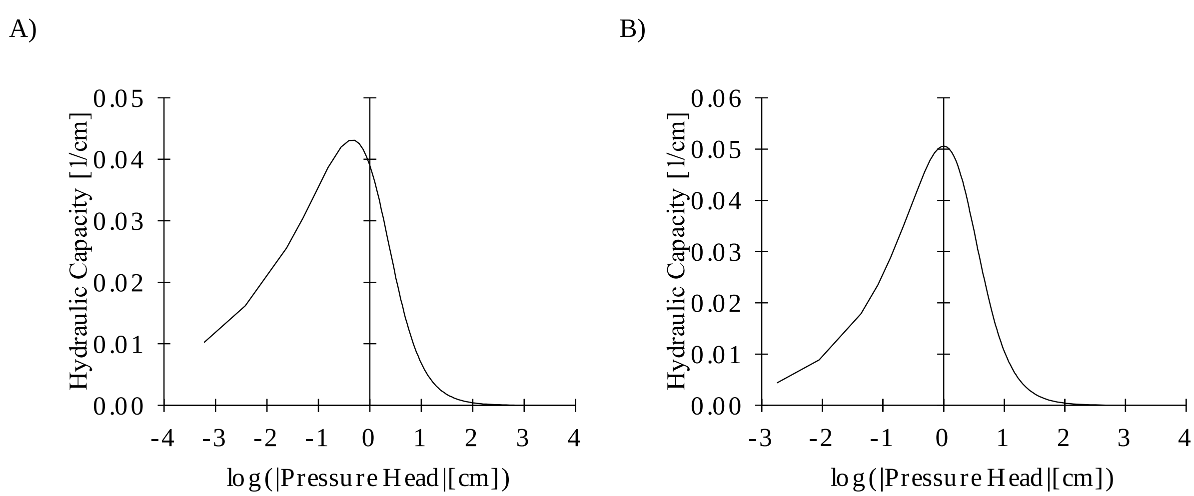
3. Results and Discussion

The yields were 77.68; 111.54; 118.03; 153.39; 154.23 ton ha^{-1} and 77.02; 90.72; 104.63; 141.34; 145.21 ton ha^{-1}, for a water replacement of 0, 25, 50, 75 and 100% with and without application of N, respectively. Compared with the control (without fertigation), the sugarcane productivity (plant and ratoon crops) increased by 30.80% and 31.83% when treated with the maximum dose of N, respectively; the increase in sugarcane productivity can be the same in plant and ratoon crops that shows the benefit of fertigation (Cunha et al., 2020). The Total Recoverable Sugar (TRS) were 140.48; 138.44; 135.60; 133.12; 135.90 kg ton^{-1} and 134.92; 139.70; 141.59; 138.45; 142.23 kg ton^{-1}, for a water replacement of (0, 25, 50, 75 and 100%) with and without N application, respectively.

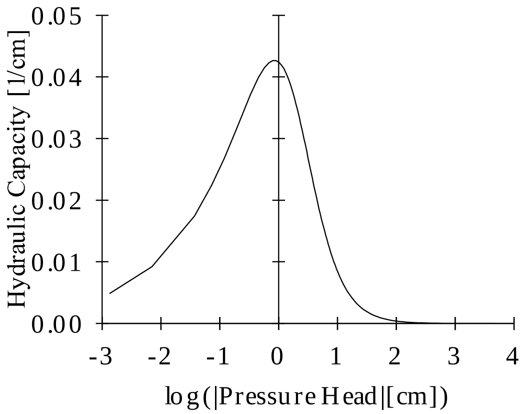
The highest total cost is verified for the first year in irrigated sugarcane with 100% of the water replacement and fertirrigation with N, with amounts of R$ 13,355.68, with the lowest total cost verified for the second year in dry cultivation without the addition of N after planting, with values of R$ 3,247.25. The difference in the total cost between the areas with and without irrigation did not exceed 50% of the total cost observed in the first year of sugarcane cultivation. The total cost with irrigation did not increase significantly with fertirrigation (< 3%).

Nutrient availability in the soil is one of the major factors that limits the mean productivity of sugarcane, although fertilization is used to increase the soil nutrient availability, it can have a significant impact on the production costs of sugarcane, accounting for up to 25% of these costs (Trivelin, 2000; Esperancini et al., 2015; Cunha et al., 2020).

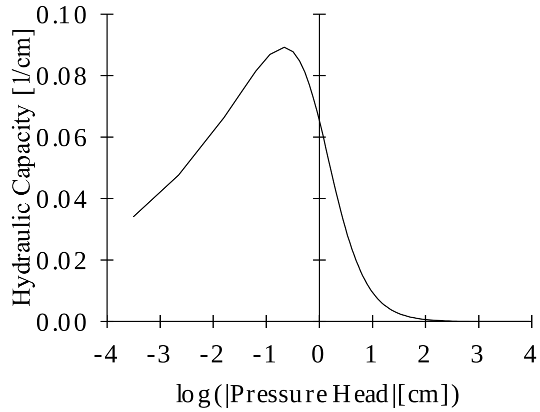
The hydraulic capacity (HC) maximum it was 0.043, 0.0426, 0.05, 0.083 and 0.073 cm^{-1} in the logarithmic pressure head (LPH) of -0.296, -0.102, -0.356, -1.081 and -0.945 cm for water replacement 0, 25, 50, 75 and 100% with fertirrigation and HC maximum it was 0.051, 0.089, 0.159, 0.095 and 0.135 cm^{-1} in the LPH of 0.015, -0.66, -1.27, -1.13 and -1.24 cm for water replacement 0, 25, 50, 75 and 100%, without fertirrigation, respectively (Figure 1).



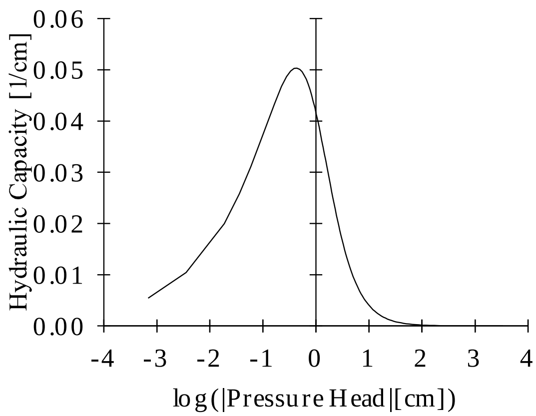
C)


Hydraulic Capacity [1/cm]
0.05
0.04
0.03
0.02
0.01
0.00
-3 -2 -1 0 1 2 3 4
log(|Pressure Head|[cm])

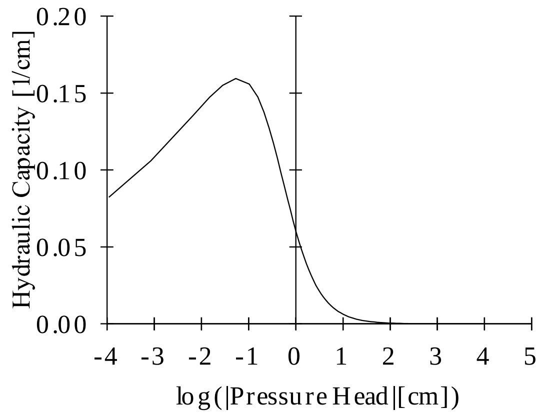
D)


Hydraulic Capacity [1/cm]
0.10
0.08
0.06
0.04
0.02
0.00
-4 -3 -2 -1 0 1 2 3 4
log(|Pressure Head|[cm])

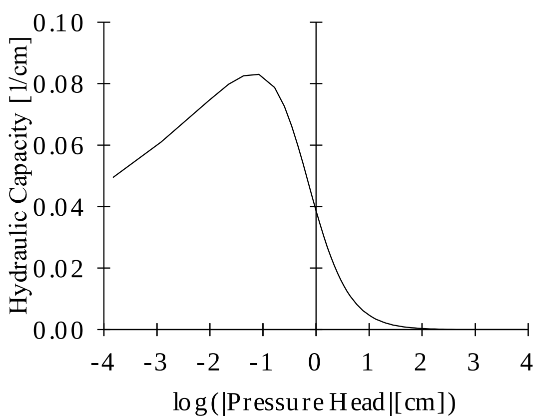
E)


Hydraulic Capacity [1/cm]
0.06
0.05
0.04
0.03
0.02
0.01
0.00
-4 -3 -2 -1 0 1 2 3 4
log(|Pressure Head|[cm])

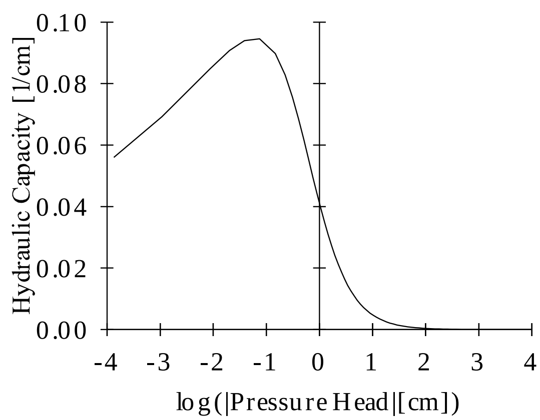
F)


Hydraulic Capacity [1/cm]
0.20
0.15
0.10
0.05
0.00
-4 -3 -2 -1 0 1 2 3 4 5
log(|Pressure Head|[cm])

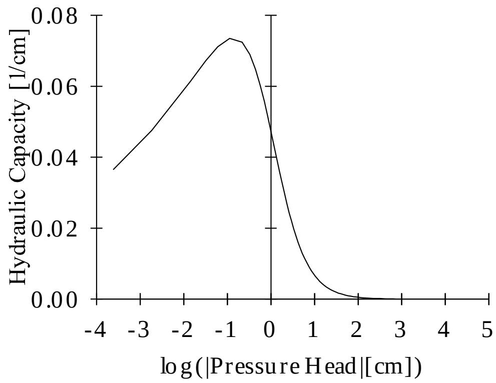
G)


Hydraulic Capacity [1/cm]
0.10
0.08
0.06
0.04
0.02
0.00
-4 -3 -2 -1 0 1 2 3 4
log(|Pressure Head|[cm])

H)


Hydraulic Capacity [1/cm]
0.10
0.08
0.06
0.04
0.02
0.00
-4 -3 -2 -1 0 1 2 3 4
log(|Pressure Head|[cm])

I)



J)

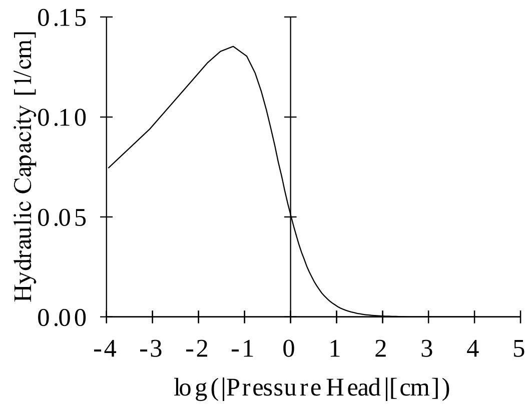


Figure 1. Hydraulic capacity in function of logarithmic pressure head at a depth of 40 cm for the water replacement of 0 (A), 25 (C), 50 (E), 75 (G) and 100% (I) with fertirrigation and of 0 (B), 25 (D), 50 (F), 75 (H) and 100% (J) without fertirrigation

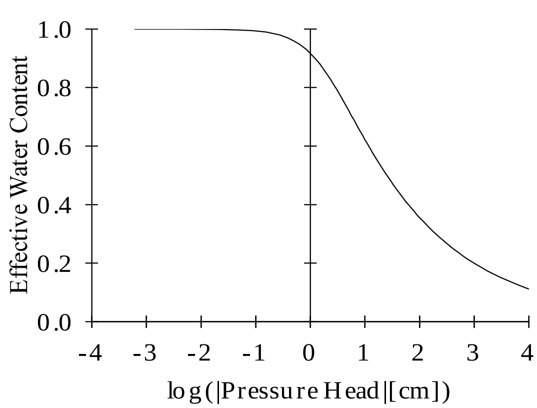
Boas et al. (2011) observed that the average total costs were inversely proportional to the yield, and in all soil water tension treatments was verified a scale effect on the economical result, therefore the irrigation on crop, using the soil water tension as reference for the cultures is a viable economical technique.

The minimum LPH it was -3.22, -2.87, -3.16, -3.83 and -3.62 cm for water replacement 0, 25, 50, 75 and 100%, with fertirrigation and -2.75, -3.51, -3.96, -3.87 and -3.96 cm for water replacement 0, 25, 50, 75 and 100%, without fertirrigation, respectively. The maximum LPH it was 4, 3.68, 3.52, 3.94 and 4.04 cm for water replacement 0, 25, 50, 75 e 100%, with fertirrigation and 3.5, 3.94, 4.04, 3.98 and 4.05 cm for water replacement 0, 25, 50, 75 and 100 without fertirrigation, respectively.

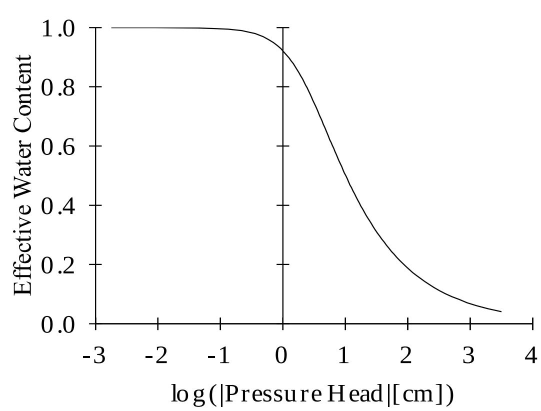
The results indicated thatexpenses with fixedcosts related to the lateral lines of the irrigation system were usually bigger, and the sensitivity analysis shows that the profitability of irrigation for the cultures wasassociated with annual fixed cost of the irrigation system, soil physical properties (as hydraulic capacity) and the culture selling price (Cunha et al., 2015; Martins et al., 2016).

The effective water content (EWC) initial (equal the 1) it was verified in the logarithmic pressure head (LPH) of -3.22, -2.87, -3.16, -3.83 and -3.62 cm in the water replacement 0, 25, 50, 75 and 100% with fertirrigation and LPH of -2.75, -3.51, -3.96, -3.87 and -3.96 cm for water replacement 0, 25, 50, 75 and 100% without fertirrigation, respectively (Figure 2).

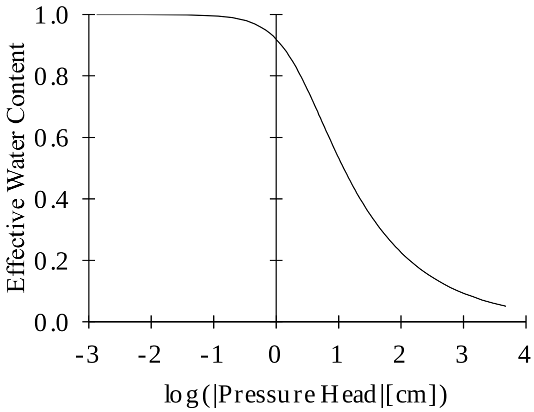
A)



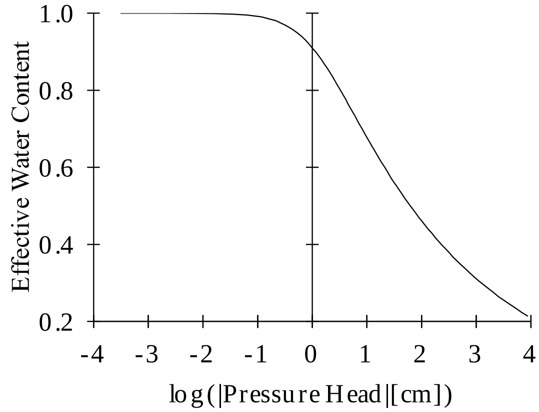
B)



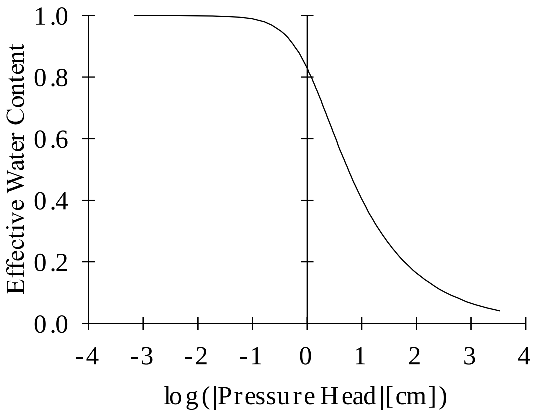
C)


Effective Water Content
1.0
0.8
0.6
0.4
0.2
0.0
-3 -2 -1 0 1 2 3 4
log(|Pressure Head|[cm])

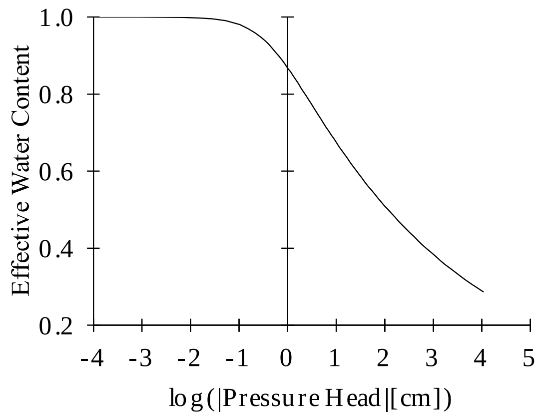
D)


Effective Water Content
1.0
0.8
0.6
0.4
0.2
-4 -3 -2 -1 0 1 2 3 4
log(|Pressure Head|[cm])

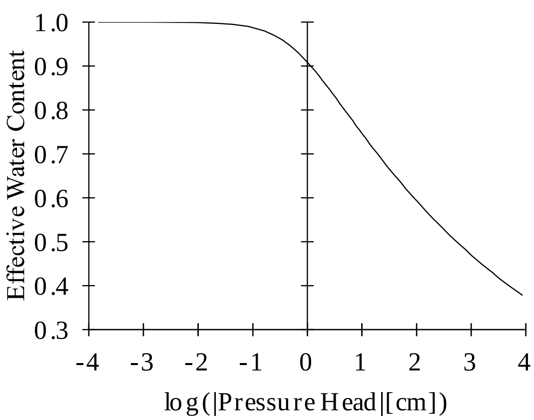
E)


Effective Water Content
1.0
0.8
0.6
0.4
0.2
0.0
-4 -3 -2 -1 0 1 2 3 4
log(|Pressure Head|[cm])

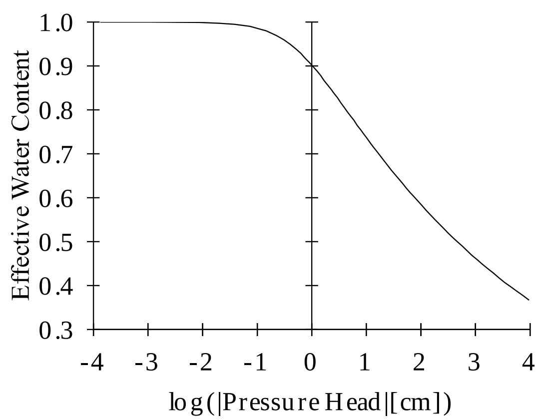
F)


Effective Water Content
1.0
0.8
0.6
0.4
0.2
-4 -3 -2 -1 0 1 2 3 4 5
log(|Pressure Head|[cm])

G)


Effective Water Content
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
-4 -3 -2 -1 0 1 2 3 4
log(|Pressure Head|[cm])

H)


Effective Water Content
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
-4 -3 -2 -1 0 1 2 3 4
log(|Pressure Head|[cm])

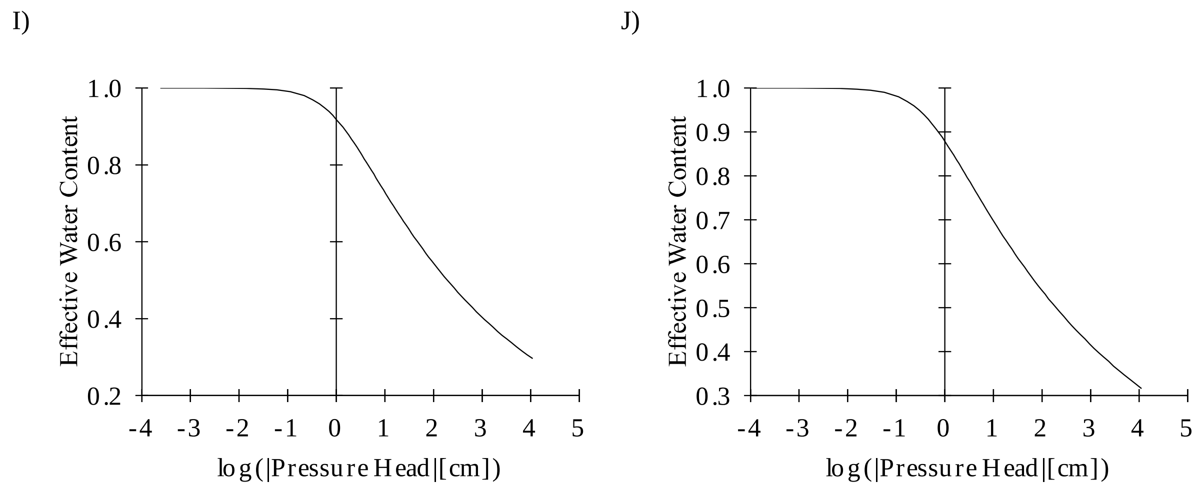


Figure 2. Effective water content in function of logarithmic pressure head at a depth of 40 cm for the water replacement of 0 (A), 25 (C), 50 (E), 75 (G) and 100% (I) with fertirrigation and of 0 (B), 25 (D), 50 (F), 75 (H) and 100% (J) without fertirrigation

Soil management affect soil physical and water properties, including parameters such as hydraulic conductivity of saturated and unsaturated soil, influencing its retention capacity and water availability, consequently affecting the yield of the crops, which may lead to losses or reduction in the profits of the agricultural activity (SILVA et al., 2012).

The LPH it was negative until the EWC of 0.908, 0.918, 0.827, 0.908 and 0.918 in the water replacement 0, 25, 50, 75 and 100% with fertirrigation and until the EWC of 0.918, 0.908, 0.867, 0.898 and 0.878 in the water replacement 0, 25, 50, 75 and 100% without fertirrigation, respectively.

In soils with low water content, the available water is insufficient to supply the water needs of the plant, leading to wilting, consequently, crop productivity and profitability are affected due to the substantial negative impact on plant growth and development (Lawlor and Cornic, 2002; Silva, 2005).

The EWC it was approximately zero in the LPH of 4, 3.68, 3.52, 3.94 and 4.04 cm in the water replacement 0, 25, 50, 75 and 100% with fertirrigation and LPH of 3.5, 3.94, 4.04, 3.98 and 4.05 cm in the water replacement 0, 25, 50, 75 and 100% without fertirrigation, respectively. Silva et al. (2014), state that inadequate management causes compaction, reduced hydraulic conductivity of the soil and consequently reduced nutrient absorption and changes in infiltration and redistribution of water, causing severe losses in crop yield and increases in total cost.

The EWC presented reduction of 50% in the logarithmic pressure head of 1.402, 1.08, 0.75, 2.73 and 2.28 cm in the water replacement 0, 25, 50, 75 and 100% with fertirrigation and LPH of 1.01, 1.79, 2.07, 2.67 and 2.29 cm in the water replacement 0, 25, 50, 75 e 100% without fertirrigation, respectively. The irrigation, fertirrigation and vinasse application can cause significant alterations in the physical and chemical properties of the soil, the magnitude of these structural modifications caused by management depends on the occurrence and frequency of operations of superficial and subsurface agricultural practices in the soil and, the compacting effect produced by the transit of agricultural machinery, which are directly related to rising production costs (Mesquita and Moraes, 2004).

It is concluded that the maximum hydraulic capacity was 0.05 and 0.07 cm^{-1} in a logarithmic pressure head of 0.015 and -0.9 cm, for the water replacement of 0 and 100% with fertigation, for these treatments the mean yields were 77.68 and 154.23 ton ha^{-1}, and the mean TRS were 140.48 and 135.90 kg ton^{-1}, respectively.

The logarithmic pressure head when near zero demonstrated an effective water content of 0.9 cm^3 cm^{-3} in the water replacement 75% so much for with fertigation how much for without fertigation, for these treatments the mean yields were 153.39 and 141.34 ton ha^{-1}, and the mean TRS were 133.12 and 138.45 kg ton^{-1}, respectively.

4. Conclusion

The mean yields were 122.97 and 111.78 ton ha^{-1}, for irrigated crop, with and without application of N, respectively. The mean TRS were 136.71 and 139.38 kg ton^{-1}, for irrigated crop, with and without N application, respectively.

Irrigation influences the hydraulic capacity and logarithmic hydraulic conductivity an Oxisol under vinasse application, increasing crop yield by approximately 50%.

Under the conditions studied, the sugarcane production system using the fertigation technique is economically viable.

Acknowledgements

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