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Agronomic performance of colored cotton influenced by irrigation with treated domestic sewage and potassium fertilization in semi-arid region of Brazil

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Abstract
This study evaluated the contribution of potassium (K) nutrition and application of wastewater depths to the agronomic performance of colored cotton. Treatments consisted of five irrigation depths (50, 75, 100, 125 and 150% of crop evapotranspiration - ET_C) and five K doses (0, 50, 100, 150 and 200% of the recommendation for the crop) and an absolute control irrigated with 100% ET_C water depth and fertilized with 100% N-P-K recommendation. Each treatment and the control had four replicates. Plant height, stem diameter, leaf area and shoot dry matter accumulation of cotton were evaluated at 130 days after emergence (DAE), whereas seed cotton weight was evaluated at 135 DAE. Our findings indicate that the use of treated domestic sewage for 100% ET_C replacement promotes greater gains of weight and growth in colored cotton without the need for K fertilization, evidencing the potential of wastewater for colored cotton for sustainable agriculture.

Keywords: *Gossypium hirsutum* L.; leaf area; seed cotton weight; reuse.

Desarrollo agronómico de algodón colorido influenciado por riego con aguas residuales domésticas y fertilización de potasio en la región semiárida de Brasil

Resumen
Este estudio evaluó la contribución de la nutrición con potasio (K) y la aplicación de las láminas de las aguas residuales al rendimiento agronómico del algodón colorido. Los tratamientos consistieron en cinco láminas de riego (50, 75, 100, 125 y 150% de la evapotranspiración del cultivo - ET_C) y cinco dosis de K (0, 50, 100, 150 y 200% de la recomendación del cultivo). Fue también utilizado un control absoluto de riego con lámina 100% de la ET_C y fertilizado con una recomendación de 100% N-P-K. Así como los tratamientos el control también tuvo cuatro repeticiones. La altura de la planta, el diámetro del tallo, el área de la hoja y la acumulación de materia seca del algodón en los brotes se evaluaron a los 130 días después de la emergencia (DAE), mientras que el peso del algodón semilla, se evaluó a 135 DAE. Los resultados indican que el uso de aguas residuales domésticas tratadas para compensación del 100% de ET_C promueve un mayor aumento de peso y crecimiento del algodón colorido sin la necesidad de fertilización con K, lo que evidencia el potencial de las aguas residuales para el algodón colorido para una agricultura sostenible.

Palabras clave: *Gossypium hirsutum* L; área de la hoja; peso de algodón de semilla; reutilizar.

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1. Introduction

The use of treated domestic wastewater, besides increasing water supply to agriculture, leads to saving of potable water for domestic use, nutrition of plants and nutrient cycling, improves soil fertility, reduces the environmental impacts caused by the disposal of effluents directly into water courses [5,13].

In cotton, studies on the use of treated domestic wastewater have allowed the saving of nutrients applied through mineral fertilization and led to higher growth and biomass accumulation in this species [17,15].

Potassium (K) has recognized importance in plant physiology, being considered as the main inorganic cation due to its role in enzymatic activity, maintenance of ionic balance, osmotic potential and water absorption, and stomatal regulation [14,10].

Cotton has indeterminate growth habit, requiring K concentrations that are sufficient for its growth. Thus, the absorption of this nutrient has impact on the growth and yield of this species [4].

Potassium deficiency may lead to reduction in leaf expansion and photosynthetic capacity, affecting plant growth. In addition, it has been reported as a problem in soils where cotton is cultivated because K reserve is not sufficient to meet the amounts extracted by the crop [4].

Given the above, this study aimed to investigate the agronomic performance of colored cotton under irrigation depths with treated domestic wastewater and K doses in the semi-arid region of Pernambuco, Brazil.

2. Material end methods

2.1. Location and description of the experimental area

The experiment was carried out from April 15 to August 30, 2016, under field conditions, at the Unit for Agricultural Reuse of Domestic Sewage, belonging to the Agricultural Engineering Department of the Federal Rural University of Pernambuco, situated in the municipality of Ibimirim, Pernambuco state, 334 km away from the capital, Recife. The experimental area is located between 8° 32′ 05″ S and 37° 41′ 50″ W, at mean altitude of 408 m.

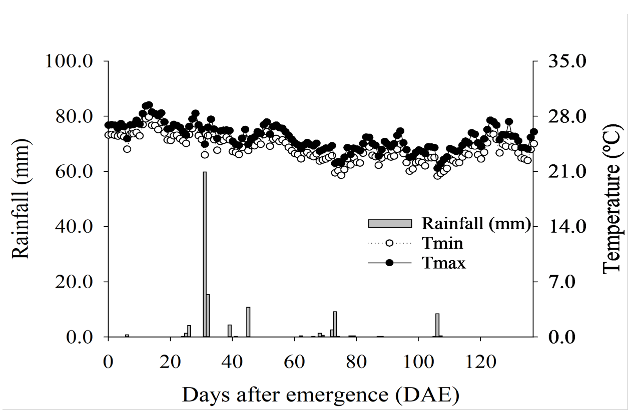

Figure 1. Rainfall (mm) and daily maximum and minimum air temperature (°C) during the cotton development cycle.
Source: The Authors.

Table 1.
Soil chemical and textural characteristics.

Attributes	Soil layer (m)	
	0-0.20	0.20-0.40
Exchange complex		
pH (H_2O)	4.60	4.30
Ca ($cmol_c$ dm^{-3})	1.25	1.40
Mg ($cmol_c$ dm^{-3})	0.75	0.70
Na ($cmol_c$ dm^{-3})	0.03	0.04
K ($cmol_c$ dm^{-3})	0.19	0.24
Al ($cmol_c$ dm^{-3})	0.15	0.40
H+Al[a] ($cmol_c$ dm^{-3})	1.56	2.14
SB[b] ($cmol_c$ dm^{-3})	2.22	2.38
CEC[c] ($cmol_c$ dm^{-3})	3.78	4.52
P (mg dm^{-3})	25	19
m[d] (%)	6	14
V[e] (%)	59	53
Textural characterization		
Sand (g kg^{-1})	760	760
Silt (g kg^{-1})	80	80
Clay (g kg^{-1})	160	160

(a) Potential acidity; (b) Sum of bases; (c) Cation exchange capacity; (d) Aluminum saturation; (e) Base saturation. Textural classification: sandy loam.
Source: The Authors.

The climate of the region is classified as BSh (very hot semi-arid) according to Köppen's classification [3], with mean annual rainfall of 454 mm. Cumulative rainfall of 122 mm and average temperature of 24.6 °C were recorded along the experimental period (Fig. 1).

The soil in the experimental area was classified as *Neossolo Quartzarênico órtico típico* (Entisol), with moderate A horizon, hyperxerophilic Caatinga phase, on a predominantly flat relief. Soil samples were collected in the 0-20 and 20-40 cm layers. The soil had a sandy loam texture with 760, 80 and 160 g kg^{-1} of sand, silt and clay, respectively, and its chemical characterization is presented in Table 1.

2.2. Experimental design and treatments

Table 2.
Physical-chemical characteristics of irrigation water.

Parameter	Water source	
	PSW	TDS
ECw (dS m^{-1})	0.3	2.1
pH	9.2	7.2
Total hardness (mg of $CaCO_3$ L^{-1})	153.3	273.4
Ca^{2+} (mg L^{-1})	54.4	74.9
Mg^{2+} (mg L^{-1})	4.3	21.0
Na^{+} (mg L^{-1})	19.0	133.1
K^{+} (mg L^{-1})	10.6	43.6
total N (mg L^{-1})	-	126
total P (mg L^{-1})	8.5	13.7
S (mg L^{-1})	4.0	5.3
Mn (mg L^{-1})	1.28	1.30
Fe (mg L^{-1})	10.3	9.2
COD[a] (mg of O_2 L^{-1})	34.0	154.0
BOD[b] (mg of O_2 L^{-1})	6.5	39.0
Dissolved O_2 (%)	85.5	46.0
Total coliforms (MPN 100 mL^{-1})	-	2.2 x 10^7
Thermotolerant coliforms (MPN 100 mL^{-1})	-	1.4 x 10^7

(a) Chemical oxygen demand; (b) Biochemical oxygen demand.
Source: The Authors.

The experimental design was randomized blocks in a (5 x 5) + 1 factorial scheme, forming 26 treatments, with four replicates, totaling 104 experimental plots. Treatments consisted of five irrigation depths (L), corresponding to 50, 75, 100, 125 and 150% of crop evapotranspiration (ET_C), using domestic wastewater treated by a UASB (Upflow Anaerobic Sludge Blanket) reactor (Table 2), and five K doses (D), corresponding to 0, 50, 100, 150 and 200% of the dose recommended for cotton, and an absolute control (AC) irrigated with public supply water (PSW) according to crop water need (100% ET_C) and fertilized with N-P-K, 100% of the recommendation, based on soil analysis and according to the fertilization recommendation for the Pernambuco State [12]. The experimental plot was 15 m^2, comprising three 5.0-m-long single rows spaced by 1.0 m, with 0.20 m distance between plants, and evaluations were carried out in the central row, disregarding 1.0 m on each end.

2.3. Irrigation management

Irrigation management was carried out according to the climate along the development of the crop. ET_C was calculated based on the daily reference evapotranspiration (ET_O) estimated by the FAO Penman-Monteith method [2], crop coefficient (K_C) proposed by [6] and location coefficient according to [1].

Irrigation depths (L) were characterized by the irrigation time (Ti) established for each treatment on a daily irrigation frequency (IF).

After crop establishment and thinning, 25 days after emergence (DAE), the irrigation depths began to be differentiated by introducing the correction factor "F" in the calculation of Ti, corresponding to 0.50, 0.75, 1.00, 1.25 and 1.50 for the irrigation depths established according to the above-mentioned treatments. At the end of the experiment, 135 DAE, the cumulative irrigation depth was 307.75, 461.62, 615.49, 769.36 and 923.24 mm for the treatments with 50, 75, 100, 125 and 150% ET_C, respectively.

A drip system was used for irrigation and the lateral lines had pressure-compensating drip tapes (Dripnet PC 16250, Netafim, Tel Aviv, Israel) with nominal diameter and flow rate of 16 mm and 2.0 L h^{-1}, respectively, and drippers spaced by 0.30 m. A horizontal axis centrifugal pump (Schneider, Rueil-Malmaison, France) of 735.5 W was used for the effluent suction.

2.4. Fertilization management

Fertilization with KCl (60% K_2O) was split: 50% of the recommended dose was applied in the planting furrow at 0.10 m depth before sowing, 25% was applied after thinning as top-dressing in a furrow 0.05 m away from the planting row at 0.10 m depth, and the remaining 25% was applied 20 days after the penultimate application, and the fertilizer was manually distributed in the furrows, totaling 0, 20, 40, 60 and 80 kg of K_2O ha^{-1} for 0, 50, 100, 150 and 200% of the recommended dose, respectively.

The same management was carried out for the absolute control, applying the formulation with 90-40-40 kg ha^{-1} of N, P_2O_2 and K_2O according to the fertilization recommendation for Pernambuco state [12]. Urea (45% N) was used as source of nitrogen, single superphosphate (20% P_2O_2) as source of phosphorus and potassium chloride (KCl, 60% K_2O) as source of potassium. Phosphorus was applied all at once, at planting. For nitrogen and potassium, 50% of the recommended dose was applied at planting and the remaining 50% was split and applied as top-dressing, 25% after thinning and 25% at 20 days after the penultimate application.

2.5. Crop management

Cotton was planted in a furrow at 0.05 m depth, by placing five seeds at each 0.20 m interval in the furrow, leaving 10 plants per linear meter after thinning. Invasive plants were manually controlled using a hoe, keeping the area free from weeds in the period from seedling emergence to 40 DAE, when the crop reached full vegetative stage, entering early flowering.

2.6. Analyzed variables

2.6.1. Morphological responses

At 130 DAE, four plants were evaluated for height (H), considered as the distance from collar to apex, measured with a tape measure; stem diameter (SD), considered as the mean of the largest and smallest diameter measurements, measured with a digital caliper at 2.0 cm from soil surface; leaf area (LA, cm^2 $plant^{-1}$), obtained by the sum of the leaf area (Y) of each leaf, measuring the midrib length (X), according to the methodology proposed by [8], using eq. (1).

$$Y = \sum(0.4322X^{2.3002}) \quad (1)$$

2.6.2. Dry matter accumulation

To determine shoot dry matter (SDM, g), leaves and stems were separately dried in a forced-air oven at 65 ºC (±1) until constant weight.

2.6.3. Leaf area ratio

Leaf area ratio (LAR, cm^2 g^{-1}) was obtained by the ratio between LA and SDM.

2.6.4. Seed cotton weight

At 135 DAE, the first harvest was carried out when 70% of the fruits were open in four plants. The second harvest was performed as the rest of the fruits opened, and seed cotton weight was estimated (SCW, g $plant^{-1}$).

2.7. Statistical analysis

The data were subjected to analysis of variance. When there was significant effect of the interaction, the means were fitted with multiple regression models (response surfaces) considering the irrigation depths (L) and doses (D) as independent variables. The statistical package SAS 9.0 for Windows (SAS Institute, Inc., Cary, NC, USA, 2001) was applied, using the procedures PROC GLM for variance analysis, PROC REG for regression analysis and PROC RSREG for response surface analysis [22].

3. Results and discussion

The interaction between irrigation depths with treated domestic wastewater (L) and K doses (D) had significant effect at $p < 0.05$ on plant height (H) and at $p < 0.01$ on leaf area (LA), shoot dry matter (SDM), leaf area ratio (LAR) and seed cotton weight (SCW). Stem diameter was only affected by the factor irrigation depth (L) (Tables 3 and 4).

3.1. Morphological responses

Maximum height of colored cotton (H = 83.84 cm) was obtained when the irrigation depth with treated domestic wastewater increased to 146% ET_C, combined with 80% of the K_2O dose recommended for the crop (Fig. 2a). The absolute control (AC), under the studied conditions, obtained mean height of 69.3 cm.

Higher irrigation depths favored greater water availability in the soil, which under these conditions allowed greater stomatal opening and consequently higher photosynthetic assimilation, contributing to greater plant height. Conversely, irrigation deficit leads to lower growth in height [11].

Evaluating three irrigation regimes, namely: saturation, regular and deficit, i.e., 120, 100 and 80% field capacity, [21] found significant differences for the studied conditions, observing greater plant height at saturation, followed by the regular regime and then deficit irrigation.

[15], evaluating the growth of cotton fertigated with wastewaters in the semi-arid region of Minas Gerais, found that the use of these waters causes higher plant growth compared with the control treatment, irrigated with public-supply water and under mineral fertilization. These authors attribute this effect to the greater supply of nitrogen and phosphorus to the plants, leading to higher growth.

Table 3.
Summary of analysis of variance for cotton height (H), stem diameter (SD), leaf area (LA).

Source of variation	DF	Mean Square		
		H	SD	LA
Block	3	66.0826*	3.4605*	87022^{NS}
ID (L)	4	559.2520**	7.0310**	889217**
PD (D)	4	597.5087**	0.9949^{NS}	399933**
L x D	16	31.3363*	1.5499^{NS}	87938**
Residual	72	16.8162	1.1319	37633
CV (%)		5.51	10.66	15.82

(**), (*) and (NS) significant at 0.01 and 0.05 probability levels and not significant, respectively.
Source: The Authors.

Table 4.
Summary of analysis of variance for shoot dry matter (SDM), leaf area ratio (LAR) and seed cotton weight (SCW).

Source of variation	DF	Mean Square		
		SDM	LAR	SCW
Block	3	45.6011^{NS}	57.7299^{NS}	0.0454^{NS}
ID (L)	4	453.8360**	97.2223*	164.0034**
PD (D)	4	110.5630**	121.7802**	105.0256**
L x D	16	136.1866**	88.1396**	23.6289**
Residual	72	21.4882	28.4761	0.8287
CV (%)		12.65	15.52	2.77

(**), (*) and (NS) significant at 0.01 and 0.05 probability levels and not significant, respectively.
Source: The Authors.

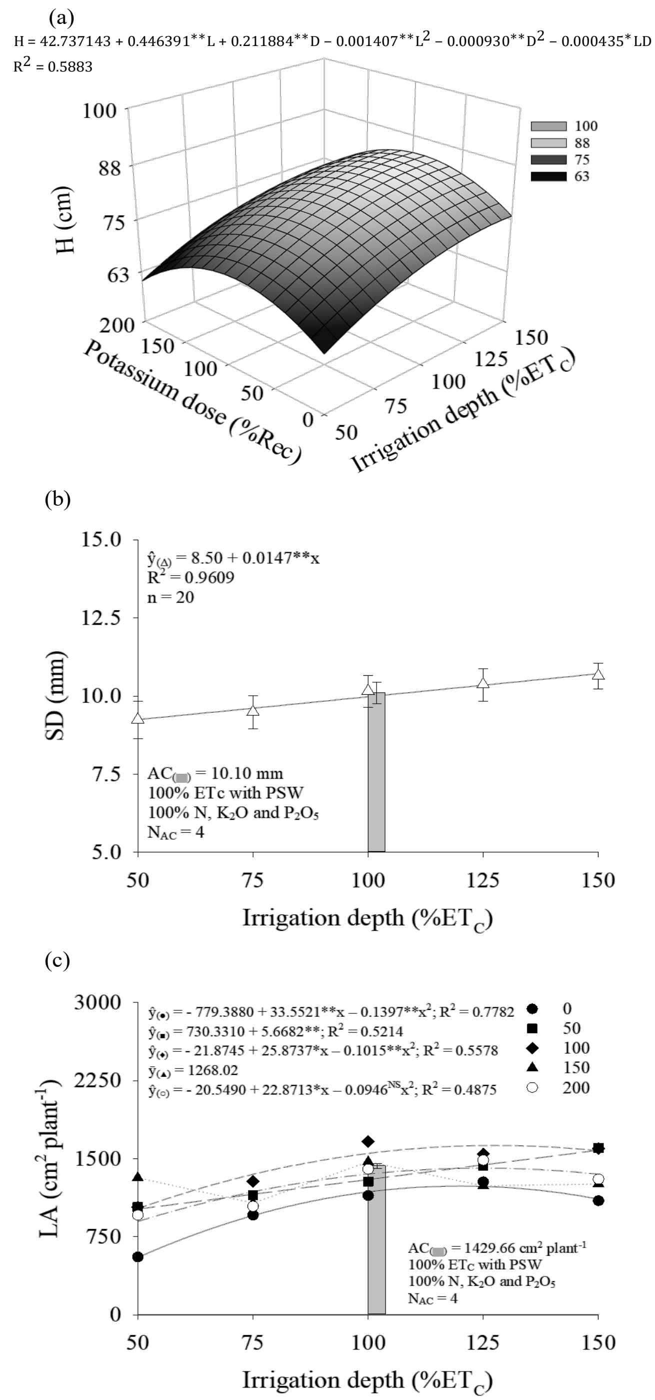

Figure 2. Plant height (A), stem diameter (B) and leaf area (C) of colored cotton, cv. 'BRS Rubi', as a function of the applied treatments. **, * and NS significant at 0.01 and 0.05 probability levels and not significant, respectively. Vertical bar indicates the value of the absolute control.
Source: The Authors.

Plant growth data were described by a quadratic model as a function of K application in the soil. The maximum dose causing maximum height was inferior to the 100% recommended for the crop, which can be attributed to the K concentration available in the treated domestic wastewater.

Cotton growth in height was probably influenced by the K present in the wastewater because K supply modulates various physiological processes in plants, and the main one is the regulation of cell osmotic balance, which allows cell turgor and consequently cell expansion, leading to plant growth [20,9].

SD was only influenced by irrigation depths with treated domestic wastewater and its maximum value (10.71 mm) was obtained with 150% ET_C irrigation depth, based on the regression equation obtained. For the absolute control, the mean value of SD was 10.10 mm (Fig. 2b).

The 100% ET_C irrigation depth led to the same SD as that in the absolute control, which may indicate that the amount of nutrients present in the treated domestic wastewater was sufficient to meet the requirement of the crop along its development, without the need for K nutrition, causing the plant to maintain the same stem diameter.

Maximum LA was obtained with the combination of L = 127% ETC and D = 100% of the dose recommended for the crop, equal to 1627 cm^2, and was obtained by the eq. (2):

$$\hat{y}_{D=100\%} = -21.8745 + 258737^{*}x - 0.1015^{**}x^2; \quad R^2 = 0.5578 \qquad (2)$$

Irrigation depths and K doses above these percentages reduce leaf expansion. The absolute control showed leaf area of 1429 cm^2 (Fig. 2c).

Foliar maintenance in cotton plants is associated with adequate K supply because this nutrient has important function in cell osmotic balance. Thus, plants that received the percentages which caused higher LA had higher number of leaves with greater expansion. However, K demand can vary depending on the phenological stage of cotton.

The increase in LA caused by the increment in the levels of the studied factors, up to the maximum combination discussed previously, results from the accumulation of photoassimilates during photosynthesis [19], leading to higher dry matter accumulation in the plants, as indicated in Fig. 3.

3.2. Accumulation of dry mass

SDM increased linearly as a function of the replacement using treated domestic wastewater (L) and quadratically as a function of K fertilization (D). Among the studied levels of each factor, the combination between 150% ET_C irrigation depth and 50% of the dose recommended for the crop caused highest SDM accumulation, 46.39 g $plant^{-1}$ (Fig. 3). The absolute control showed SDM of 34.8 g.

The increase in SDM caused by the factor irrigation depth (L) may result from the accumulation of nutrients present in the treated domestic wastewater such as N, P and K (mean concentrations of 126.0, 13.7 and 43.6 mg L^{-1}, respectively) and of photoassimilates during photosynthesis [17,19].

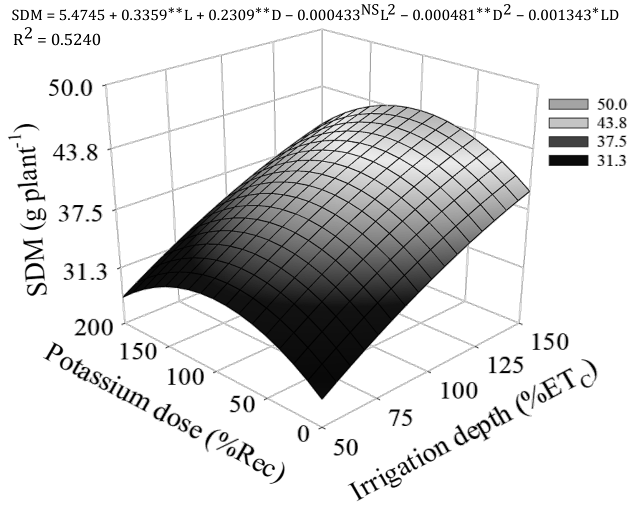

Figure 3. Shoot dry matter of colored cotton, cv. 'BRS Rubi', as a function of the applied treatments. **, * and NS significant at 0.01 and 0.05 probability levels and not significant, respectively. Vertical bar indicates the value of the absolute control.
Source: The Authors.

As observed, greater water availability increases stomatal opening, favoring the entry of CO_2 in the mesophyll, thus enhancing photosynthesis [18].

Considering 100% ET_C replacement with treated domestic wastewater, SDM was equal to 34.73 g, which is similar to the value accumulated by the AC. This result indicates that only irrigation with 100% ET_C caused an accumulation of nutrients with no need for mineral supplementation under the studied conditions. Similar results have also been found by [17] and [15], who observed that irrigation with wastewaters can replace mineral fertilization, because they provide sufficient amounts of nutrients for plants.

In relation to K doses, the quadratic effect observed, combined with the irrigation depths, can be associated with the intensification of the osmotic effect caused by the fertilizer used (KCl) along with the salts present in the wastewater, at concentrations of 74.9, 21.0, 133.1 and 43.6 mg L^{-1} for calcium, magnesium, sodium and potassium, respectively, with electrical conductivity of 2.1 dS m^{-1}.

3.3. Leaf area ratio

LAR expresses the photosynthetic capacity of the plant and its maximum value (42.0 cm^2 g^{-1}) was obtained with 200% of the K dose recommended for the crop and 125% ETc irrigation using treated domestic wastewater (Fig. 4). However, percentages higher than those negatively affect LAR. The absolute control showed LAR of 41.0 cm^2 g^{-1}.

Greater K supply in the soil resulted in higher leaf area ratio, which can be associated with the modulation of this nutrient in the osmotic regulation, leading to greater water influx into the cells with consequent increase in leaf turgor and expansion [20,9]. Thus, it increases this quotient since LAR represents the ratio between the assimilatory tissue of the plant (LA) and the shoot dry matter resulting from photosynthesis (SDM).

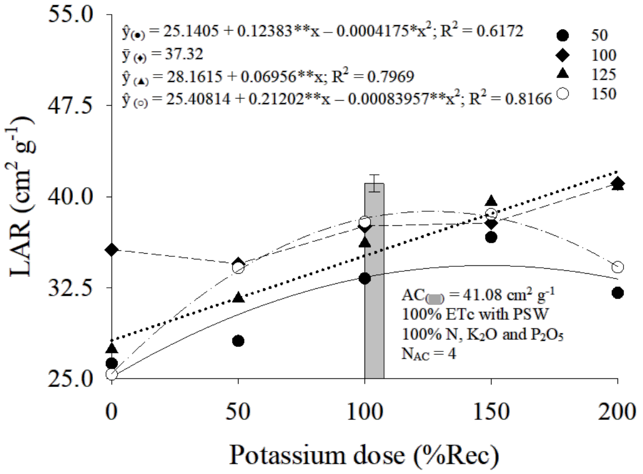

Figure 4. Follow-up test of the interaction for leaf area ratio (LAR) of colored cotton, cv. 'BRS Rubi', as a function of irrigation depths with treated domestic wastewater (L) and potassium doses (D). **, * and NS significant at 0.01 and 0.05 probability levels and not significant, respectively. Vertical bar indicates the value of the absolute control.
Source: The Authors.

3.4. *Seed cotton weight*

Based on the multiple regression equation, maximum physical yield of seed cotton estimated by the SCW was obtained with the combination between L = 150% ETc and D = 100% under the studied conditions, 38.15 g plant^{-1} (Fig. 5). The absolute control produced 28.87 g plant^{-1}.

The results of the present study corroborate those of [23], who observed increase in cotton yield as water replacement increased, and are also consistent with those found by [7], who observed quadratic fit of cotton yield with higher K supply in the soil and in the leaf.

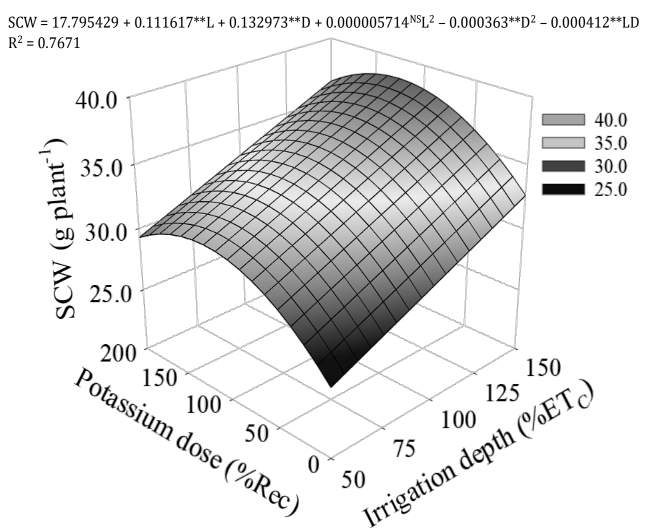

Figure 5. Response surface for seed cotton weight (SCW) of colored cotton, cv. 'BRS Rubi', as a function of irrigation depths (L) and potassium doses (D). **, * and NS significant at 0.01 and 0.05 probability levels and not significant, respectively.
Source: The Authors.

When the crop received only the irrigation necessary to replace 100% ET_C using treated domestic wastewater, SCW was equal to 29.0 g plant^{-1}, similar to the value obtained in the absolute control. Thus, it can be noted that irrigation with treated domestic wastewater alone, with no need for K nutrition, leads to satisfactory yield with consequent saving of water and nutrients applied in mineral fertilization.

4. Conclusions

Our findings indicate that the use of treated domestic sewage to replace a depth of 100% ET_C promotes greater gains in yield and growth of colored cotton, with 100% saving of drinking water and potassium via mineral fertilization, being a sustainable alternative source of water for the semi-arid region.

Acknowledgements

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