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Original Article

Morphophysiological performance of cowpea fertigated with sanitary sewage at different depths[1]

Desempenho morfofisiológico do feijão-caupi fertirrigado com esgoto sanitário em diferentes profundidades

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HIGHLIGHTS:

Surface soil compaction affects the establishment of cowpea irrigated by subsurface drip systems compared to surface irrigation.
Increasing the installation depth of the subsurface dripper affects cowpea root growth.
Water distribution is compromised by the effect of back pressure.

ABSTRACT: The application of sanitary sewage using subsurface drip irrigation contributes to mitigating the current problems of water availability and food production. The aim in this study was to evaluate cowpea receiving sanitary sewage through drippers operating at different flow rates and depths. The drippers operated at flow rates of 1.6 and 3.8 L h^{-1} and were installed at depths of 0, 5, 10, 15, 20, 25, and 30 cm. Cowpea was grown in 65 L pots filled with sandy clay soil in a greenhouse. Synthetic sanitary sewage was used and the amount applied to the pots was based on the limiting element, which in this case was nitrogen, for growing cowpea. Irrigation was managed using TDR probes. Germination and the physiological responses and morphology of cowpea roots were assessed. Capillary rise, when water was applied in subsurface, was not sufficient to evenly moisten the soil surface. The germination variables decreased as a result of the increase in drip installation depths. The distribution of water as the depth of the emitters increased was responsible for the damage to the physiological and morphological responses of cowpea roots. The flow rates of the drippers did not affect the germination of cowpea. Using the subsurface drip irrigation system was not appropriate for growing cowpea under the conditions of this study.

Key words: *Vigna unguiculata*, capillary rise, localized irrigation, germination

RESUMO: A aplicação de esgoto sanitário utilizando o gotejamento subsuperficial contribui para mitigar os problemas atuais de disponibilidade de água e produção de alimento. Objetivou-se avaliar o feijão-caupi recebendo esgoto sanitário por gotejadores operando com diferentes vazões e profundidades. Os gotejadores operaram com as vazões de 1,6 e 3,8 L h^{-1} e foram instalados nas profundidades de 0, 5, 10, 15, 20, 25 e 30 cm. O feijão-caupi foi cultivado em vasos de 65 L preenchidos com solo argiloso em casa de vegetação. Utilizou-se esgoto sanitário sintético e a quantidade aplicada nos vasos foi baseada no elemento limitante, que no caso foi o nitrogênio, para o cultivo do feijão-caupi. O manejo da irrigação foi realizado com sondas de TDR. Avaliou-se a germinação e as respostas fisiológicas e morfologia das raízes do feijão-caupi. A ascensão capilar, quando a água foi aplicada em profundidade, não foi suficiente para umedecer de maneira uniforme a superfície do solo. As variáveis de germinação apresentaram um decréscimo em função do aumento das profundidades de instalação dos gotejadores. A distribuição da água com o aumento da profundidade dos emissores foi responsável pelos prejuízos nas respostas fisiológicas e morfológicas das raízes feijão-caupi. As vazões dos gotejadores não afetaram a germinação do feijão-caupi. Utilizar o sistema de irrigação por gotejamento subsuperficial não foi apropriado para o feijão-caupi nas condições deste estudo.

Palavras-chave: *Vigna unguiculata*, ascensão capilar, irrigação localizada, germinação

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Introduction

Agricultural use of sanitary sewage (SS) is a viable alternative for the final disposal of liquid waste, making water and nutrients available to plants and recycling nutrients to the soil (Araújo et al., 2020). Choosing a crop adapted to the region of interest based on its production capacity and economic and social importance is one of the first steps when thinking about SS disposal (Alves et al., 2018).

Cowpea (*Vigna unguiculata*) is one of the most widely grown crops in arid and semi-arid regions. This legume has a short cycle and low water and soil fertility requirements (Farooq et al., 2020). To ensure greater efficiency in water use and safe application of SS, it is crucial to choose the right irrigation system. The surface drip irrigation system (SD) is recognized as the most efficient and safest way to dispose of SS, as it avoids direct contact between the SS and the aerial part of the plants, reducing the chances of environmental, operator and consumer contamination (Santos et al., 2016).

Subsurface drip irrigation (SDI) has advantages such as weed reduction and reduced water loss due to soil evaporation (Nogueira et al., 2021). Despite the known benefits of SDI, underground systems can sometimes fail to guarantee plant germination and establishment. In addition, increasing the depth of the emitter results in lower yields for some crops and soil types, due to unfavorable water distribution (Nogueira et al., 2021).

Fertigation of SS through SDI is an alternative for mitigating the current problems of water availability versus food production. The aim in this study was to evaluate cowpea receiving sanitary sewage through drippers operating at different flow rates and depths.

Material and Methods

This study was performed in a greenhouse installed in the Hydraulics Laboratory of the Departamento de Engenharia Agrícola of Universidade Federal de Viçosa (UFV), located in the municipality of Viçosa, MG, Brazil. The geographical coordinates are: 20° 46’ 18.97” S, 42° 52’ 28.19” W, Datum WGS-84, with an altitude of 651 m. The experimental period was from March 2019 to February 2020. Figure 1 shows the variations in the meteorological elements that occurred inside the greenhouse during the experimental period.

The experimental design was randomized blocks, with three replicates and treatments arranged in split plots. The main plots consisted of emitters with different flow rates and the sub-plots were made up of the different dripper installation depths. The main plots consisted of the following treatments: T1: flow rate of 1.6 L h^{-1} and T2: 3.8 L h^{-1}. The sub-plots were made up of the following drip installation depths: S0: 0; S1: 5; S2: 10; S3: 15; S4: 20; S5: 25, and S6: 30 cm.

Non-certified commercial seeds of the first generation (S1) of cowpea cultivar BRS Tumucumaque were used in

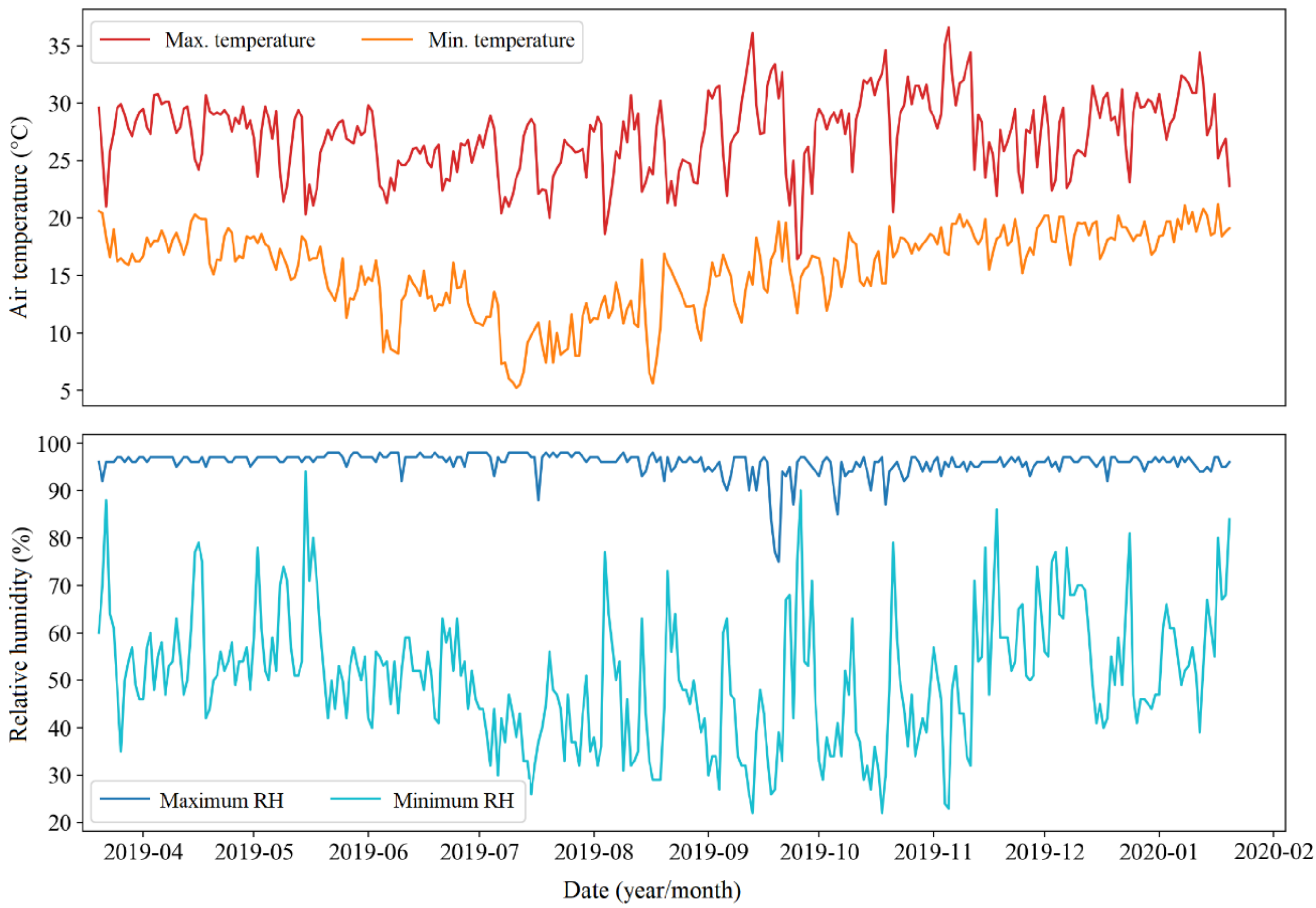

Figure 1. Maximum and minimum air temperature and maximum and minimum relative humidity of the air during the experimental period

the experiment. The drippers used were the AmnonDrip PC AS model (Pressure-compensating and anti-siphon, NaanDanJain®). The irrigation system was evaluated before the experiments began and a Christiansen's uniformity coefficient (UC) of 100% was found for the two flow rates used (Elnemr & Amer, 2020).

The experimental units consisted of pots with a volume of 65 L, with height of 60.5 cm and lower and upper diameters of 30 and 44 cm, respectively (Figure 2). The pots were filled with soil to a height of 55 cm, leaving a 5.5 cm border. The useful volume of soil was 58.9 L and the useful area at ground level was 0.1434 m².

The soil used in the experiments was collected from the Irrigation and Drainage Experimental Area of the Departamento de Engenharia Agrícola of Universidade Federal de Viçosa (UFV). The soil in the experimental area was classified as Latossolo Vermelho Amarelo Distrófico (Santos et al., 2018) or Oxisol (USDA, 1999), and the chemical and physical-hydraulic characteristics are shown in Table 1.

Fertilization of cowpea was calculated based on the chemical analysis of the soil. Initially, the soil was limed with a lime dose of 0.10 kg m^{-3} of soil (Ribeiro et al., 1999). Soil fertility correction followed the recommendations of Freire Filho et al. (2005) to meet the nutritional demand of cowpea with 6.7 g m^{-3} of N, 20 g m^{-3} of P_2O_5 and 13.3 g m^{-3} of K_2O. All the nitrogen was applied via synthetic sewage, taking into account the recommendation for the limiting element (Alves et al., 2021).

To simulate sanitary sewage, a solution of synthetic origin was used (Nopens et al., 2001). The salts and ingredients were

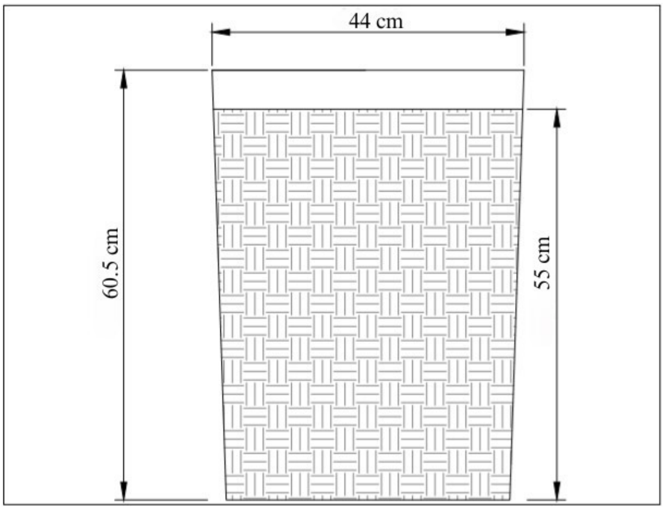

Figure 2. Sketch of the experimental units

diluted in supply water. The compounds used to prepare the synthetic sewage are shown in Table 2.

Irrigation was managed using the soil water balance. Moisture was monitored daily by inserting time domain reflectometry (TDR) probes into the sides of the pots at five depths (7.5, 15, 22.5, 30, and 37.5 cm - Souza et al., 2006), the guides being 20 cm long. The treatment with the surface drip system was used as the standard for calculating the water demand for the other treatments, thus standardizing the volume of water applied to all the plots. The entire volume of sanitary sewage applied, calculated by the limiting element, was insufficient to meet the water demand for the entire cowpea growing cycle. Therefore, good quality water was used to replace the water lost through evapotranspiration in the pots.

The first experiment was performed in order to assess the ability of drip systems installed at different depths to guarantee the emergence and establishment of cowpea. At this stage, two emergence assessment cycles were carried out between March and April 2019.

Cowpea was sown at a depth of 3.0 cm using six seeds per pot. Emerged seedlings with fully expanded cotyledons above the ground were counted daily, over a period of eight days.

Emergence percentage (E) was calculated using Eq. 1 and the emergence speed index (ESI) was calculated using Eq. 2 (Maguire, 1962). The plants were collected 15 days after sowing and their dry mass (g) was determined using the oven method at 65 ± 3 °C for 72 hours.

Table 2. Theoretical composition and respective concentrations for the production of 1.0 liter of synthetic sanitary sewage. Adapted from Nopens et al. (2001)

Salts	Quant[1]	COD	N	P	K
	(mg L^{-1})				
Urea	92	23	43	0	0
MAP	13	0	1	3	0
Sodium acetate*	132	79	0	0	0
Peptone	17	17	1	0	0
$MgSO_4$	20	0	0	0	0
KH_2PO_4	23	0	0	5	7
KCl	25	0	0	0	13
$FeSO_4$ $7H_2O$	5.8	0	0	0	0
Ingredients					
Starch	122	122	0	0	0
Milk powder	116	116	7	1	0
Yeast	52	52	6	0	0
Soybean Oil	29	29	0	0	0
Total	646	439	58	10	15

[1]Mass of salts and ingredients for producing 1 L of synthetic sanitary sewage *Hydrated sodium acetate

Table 1. Chemical and physical-hydraulic attributes of the soil before the experiments

pH H_2O	[1]OM (dag kg^{-1})	[2]P	[2]K	[3]Ca	[3]Mg	[4]SB	[5]t
		(mg dm^{-3})		(cmol$_c$ dm^{-3})			
5.80	1.88	4.60	20.00	1.01	0.50	1.56	1.56

[6]T	[7]H+Al	[8]S	[2]Cu	[2]Fe	[2]Mn	[2]Zn	[9]Prem	[10]V
(cmol$_c$ dm^{-3})		(mg dm^{-3})					(mg L^{-1})	(%)
4.20	2.64	25.30	3.00	68.20	33.10	4.70	21.60	37.10

[11]FC	[12]PWP	[13]BD	Sand	Silt	Clay	Textural classification
(m^3 m^{-3})		(g cm^{-3})	(dag kg^{-1})			
0.38	0.25	1.17	52	12	36	Sandy Clay

[1]Organic matter, determined by colorimetry; [2]Extractant: Mehlich-1; [3]Extractant: 1 M KCl; [4]SB - Sum of bases; [5]Effective CEC; [6]T: CEC at pH 7; [7]Extractant: 0.5 mol L^{-1} Calcium acetate - pH 7.0; [8]Extractant: Monocalcium phosphate in acetic acid; [9]Remaining phosphorus, determined in P equilibrium solution; [10]V - Base saturation; [11]Field capacity, [12]Permanent wilting point; and [13]Bulk density

$$E = \frac{n}{N} \times 100 \quad (1)$$

$$ESI = \sum_{i=1}^{k} \frac{n_i}{t_i} \quad (2)$$

where, E is the emergence percentage (%); n is the number of seeds that emerged; N is the total number of seeds; n_i is the number of seeds that emerged each day; t_i is the number of days after the start of the test at each count.

Physiological assessments were carried out when the plants in all treatments were in the reproductive stage (Ferraz et al., 2012), 70 days after sowing. Soil moisture was raised to field capacity one day before the evaluations, taking the volume of water calculated for the surface drip treatment as the standard.

To assess relative water content (RWC) and water saturation deficit (WSD), 20 leaf discs measuring 1 cm in diameter were collected from each plant and their fresh masses (FM) were determined. After weighing, the leaf discs from each treatment were submerged in distilled water (DW) for 24 hours. Subsequently, the leaf discs were removed from the DW and dried and weighed again to obtain the maximum or turgid mass (TM). The leaves were then dried in an oven at a temperature of around 70 °C until constant dry mass (DM) was obtained (Barrs & Weatherley, 1962). With these data, RWC and WSD were calculated using Eqs. 3 and 4, respectively.

$$RWC = \frac{FM - DM}{TM - DM} \times 100 \quad (3)$$

$$WSD = \frac{TM - FM}{TM - DM} \times 100 \quad (4)$$

where FM is the fresh mass of the leaf discs, g; TM is the maximum mass of the leaf discs after immersion in distilled water, g; DM is the dry mass of the leaf discs, g.

Stomatal conductance (gs; μmol H_2O m^{-2} s^{-1}), net photosynthesis (A; μmol CO_2 m^{-2} s^{-1}), and transpiration (E; mmol H_2O m^{-2} s^{-1}) were also assessed using a photosynthesis meter (Infrared Gas Analyzer - IRGA, brand ADC BioScientific Ltd, model LC-Pro+). The measurements were taken on the third fully expanded leaf from the apex of the plant, between 8 a.m. and 12 p.m., using artificial radiation source of 1,500 μmol m^{-2} s^{-1} and under natural conditions of air temperature and CO_2 concentration.

A portable chlorophyll meter, model CFL 1030 (Falker), was used to determine the indices of chlorophyll a, b and total. The readings were taken in the afternoon on mature leaves in the middle third.

At the end of the experiment, the soil in each treatment was divided into five layers, 0-10, 10-20, 20-30, 30-40, and 40-55 cm. The roots were collected from the different layers and washed in water to remove fragments of soil. The roots were then scanned and the images obtained were processed using WinRHIZO® software. The variables evaluated were root length (RL, cm), root volume (RV, cm^3), average root diameter (RD, mm) and, finally, the roots were dried in an oven at a temperature of around 70 °C until dry mass (DM) was obtained.

With the exception of the average root diameter, for all variables the total sum of the five layers was calculated, representing a soil column of 0-55 cm.

The ExpDes package of R software was used to carry out the statistical analyses (R Core Team, 2023). The data were subjected to analysis of variance and regression analysis for the depth factor. To select the most appropriate regression model, the coefficients of the models were subjected to the t-test, at $p \leq 0.05$, choosing only models with significant coefficients and the ability to biologically explain the variables analyzed. In order to better study the impact of the different flow rates and depths on the variables analyzed in an integrated manner, two multivariate analyses were also used: principal component analysis and k-means cluster analysis.

Results and Discussion

In the two evaluation cycles, the variables emergence, emergence speed index (ESI) and dry mass of cowpea seedlings were significantly influenced by the installation depths of the drippers. However, they were not influenced by the flow rate of the emitters. Figure 3 shows that all the variables studied in the two crop cycles decreased as a result of the increase in dripper installation depths. Linear models were fitted for the decline in emergence and dry mass in the first crop cycle. Quadratic models were fitted for ESI in the first cycle and emergence, ESI and dry mass of cowpea seedlings in the second cycle.

This study showed that subsurface drip irrigation (SDI) does not guarantee adequate establishment of cowpea plants grown in sandy clay soil (Figure 3). Regardless of the depth at which the drippers were installed, there was capillary rise of the water to the soil surface, as the cowpea seeds germinated in all treatments. However, the capillary rise in the SDI systems was not enough to evenly moisten the soil surface and thus minimize the barriers to adequate plant emergence.

This result indicates potential problems with the use of SDI systems and fertigation in sandy clay soils. These types of soils can be highly compacted, requiring mechanical intervention. If the lateral line with the drippers is installed at shallow depths (5 to 10 cm), it makes it difficult to prepare the soil, as the implement used to decompress it can damage the drippers. On the other hand, if the lateral line is installed at a greater depth, plant emergence is compromised because the water will not reach the seeds at adequate levels.

The different dripper flow rates did not affect the germination of cowpea seeds, possibly because the flow rates of the emitters did not influence the capillary rise of the water in the soil profile. There are several studies showing that increasing the flow rate of drippers promotes larger wet bulbs (Souza et al., 2018; Silva et al., 2020). Thus, it can be inferred that varying the flow rate of the drippers alters the wetting front in the horizontal and vertical downward direction, without affecting it in the vertical upward direction, corroborating Elaiuy et al. (2015) and Nazari et al. (2021).

As a result of the initial emergence experiment, in the second experiment there was a need to standardize the initial

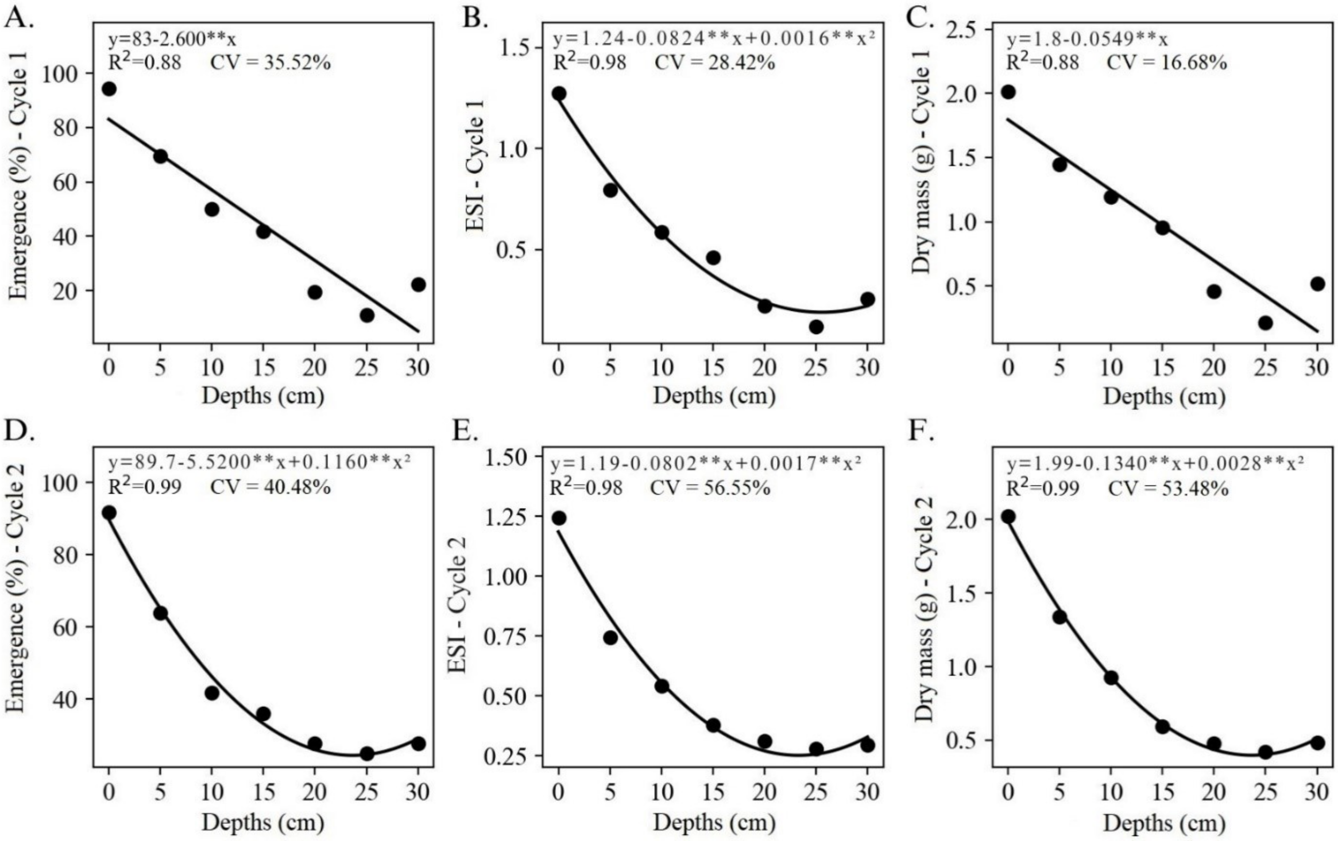

Figure 3. Emergence (A and D), emergence speed index (ESI - B and E) and dry mass (C and F) of cowpea seedlings irrigated with drippers installed at different depths in two evaluation cycles

wetting of the soil surface. In this way, it was possible to guarantee the development and completion of the cowpea cycle. Thus, for the conditions of the study, it is understood that SDI was not sufficient for the establishment of cowpea crop.

For the physiological variables studied, only stomatal conductance (gs), chlorophyll b (Chl b) and total chlorophyll (Total Chl) showed an interaction between emitter flow rate and installation depth. In the surface drip treatment, gs was higher at a flow rate of 1.6 L h^{-1} than at 3.8 L h^{-1}. The values of Chl b and Total Chl were higher at a flow rate of 1.6 L h^{-1} for the surface dripper treatments and at a depth of 5 cm. For these same variables, at installation depths of 15 and 30 cm, higher values were observed for the flow rate of 3.8 L h^{-1} (Table 3).

For the variables gs, Chl b and Total Chl, a quadratic model was fitted to explain the effect of the different depths within the flow rate of 1.6 L h^{-1}. There was an initial decline for both variables as the dripper depths increased and stabilization with a slight increase at the greater depths (Figure 4).

Considering the poor water distribution and possible water restriction caused by the SDI system compared to the surface drip system (SD), the physiological variables confirm this hypothesis. Figure 4 shows that relative water content (RWC), water saturation deficit (WSD), stomatal conductance (gs), net photosynthesis (A), transpiration (E) and total chlorophyll (Total Chl) were negatively influenced by the different dripper installation depths. Freitas et al. (2017) found a reduction in gs, A and E of cowpea grown under conditions of moderate and severe water restriction compared to the control without water restriction. The gs and photosynthesis are considered excellent indicators of the plant's response to water restriction, as reductions in these variables are a response to the water restriction caused by the treatments (Carvalho et al., 2019).

In the treatments with the drippers installed at 5 and 20 cm depth, the dry mass of the roots in layer 5 (DM L5) was greater for the flow rate of 1.6 L h^{-1} compared to the flow rate of 3.8 L h^{-1}. For the dripper installations at 0, 10 and 30 cm, root length in the first layer (RL L1) was higher

Table 3. Stomatal conductance, chlorophyll b (Chl b), and total chlorophyll (Total Chl) of cowpea fertigated with sanitary sewage applied by drippers operating at different flow rates and installation depths

Variables	Flow rate	Dripper depth (cm) 0	5	10	15	20	25	30
gs (μmol H_2O m^{-2} s^{-1})	1.6	0.99 a	0.93 a	0.69 a	0.63 a	0.49 a	0.57 a	0.52 a
	3.8	0.77 b	0.80 a	0.72 a	0.66 a	0.65 a	0.58 a	0.68 a
Chl b	1.6	20.33 a	16.98 a	14.35 a	14.03 b	12.88 a	15.48 a	13.72 b
	3.8	14.06 b	12.75 b	15.19 a	17.40 a	15.07 a	15.88 a	17.49 a
Total Chl	1.6	60.80 a	57.04 a	52.66 a	51.14 b	49.91 a	54.47 a	51.57 a
	3.8	53.51 b	48.60 b	54.11 a	57.18 a	51.72 a	54.37 a	55.77 a

Within each dripper installation depth, means followed by the same lowercase letter in the column do not differ by F test ($p \leq 0.05$)

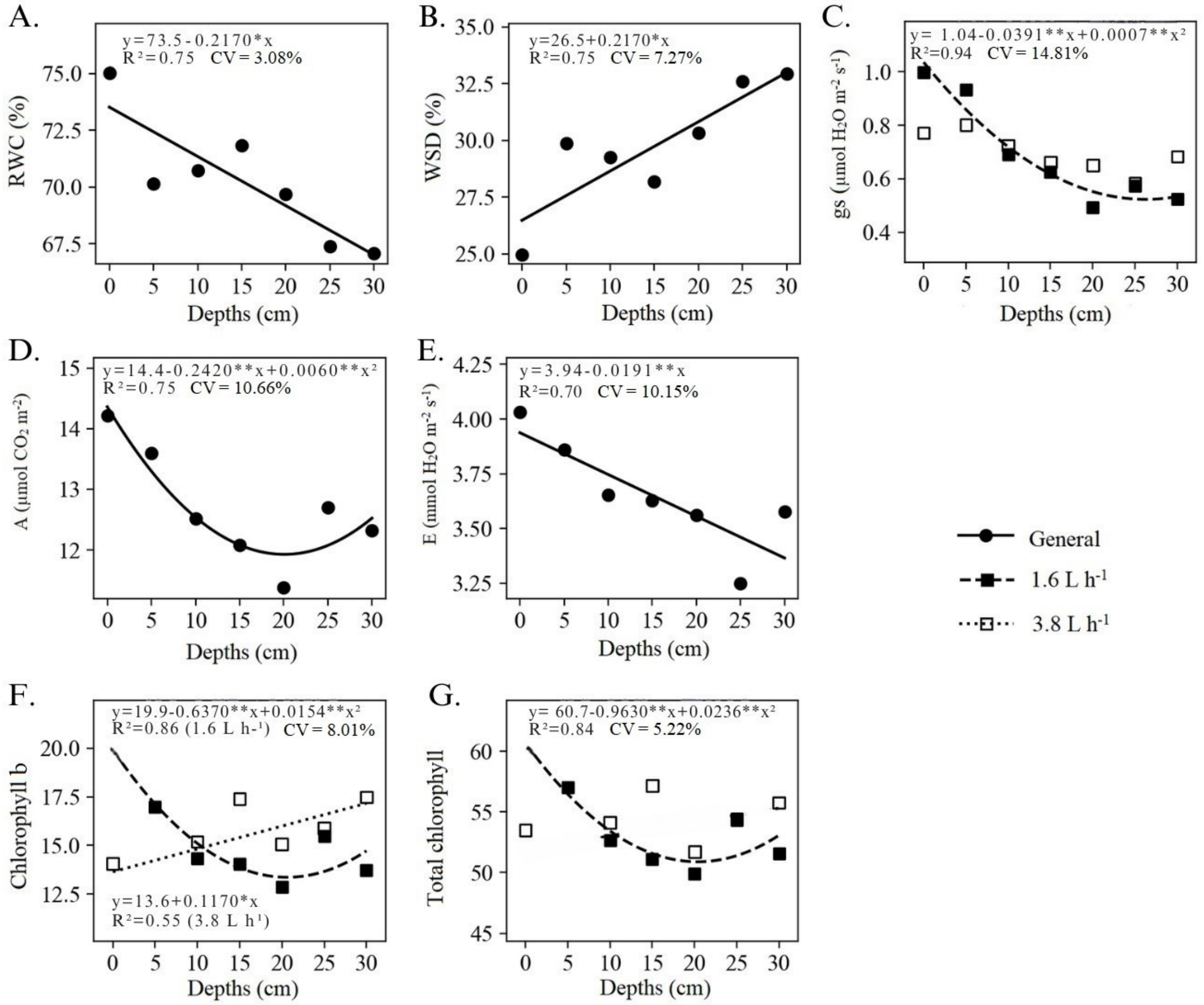

Figure 4. Relative water content (RWC - A), water saturation deficit (WSD - B), stomatal conductance (gs - C), net photosynthesis (A - D), transpiration rate (E - E), and chlorophylls indices (F and G) of cowpea fertigated with sanitary sewage applied by drippers operating at different flow rates and installation depths

for the flow rate of 1.6 L h^{-1} compared to the flow rate of 3.8 L h^{-1} (Table 4).

The regression models fitted to the root variables in the different evaluation layers are shown in Figure 5. In general, there was a reduction of roots in layers 1, 2 and 3 and in the total layer as the drip installation depths increased (Figure 5). The dry mass, length and volume of roots in the 0-10, 10-20, 20-30 and total 0-55 cm layers were negatively influenced by the greater drip installation depths (Figure 5). This was due to the lower moisture content in the upper layers. In addition, as it is a sandy clay soil (Table 1), the reduction in moisture may have increased its resistance to penetration to values that hindered the growth and development of the root system. On the other hand, the layers that received the greatest amount of sanitary sewage may have benefited from greater aggregation of the soil particles as a result of the increase in organic matter.

The distinction in soil water dynamics as a function of SD and SDI can impact soil water content and eventually influence root growth and morphology (Liu et al., 2021). If there is less water in the effective root zone (0-20 cm) and fewer roots, the plant consequently reduces transpiration

Table 4. Root dry mass in layer 5 (DM L5) and root length in the first layer (RL L1) of soil cultivated with cowpea fertigated with sanitary sewage applied by drippers operating at different flow rates and installation depths

Variables	Flow rate	Dripper depth (cm)						
		0	5	10	15	20	25	30
DM L5 (g)	1.6	2.67 a	2.83 a	1.74 a	2.23 a	3.45 a	2.56 a	3.14 a
	3.8	2.49 a	1.76 b	2.51 a	2.86 a	1.16 b	1.91 a	3.18 a
RL L1 (cm)	1.6	41549 a	3244 a	4410 a	3307 a	2520 a	2538 a	3544 a
	3.8	24440 b	3637 a	1985 b	1452 a	576 a	1393 a	766 b

Soil layers evaluated, L1 0-10; L2 10-20; L3 20-30; L4 30-40; L5 40-55, and total 0-55 cm. Within each dripper installation depth, means followed by the same lowercase letter in the column do not differ at p ≤ 0.05 according to the F test

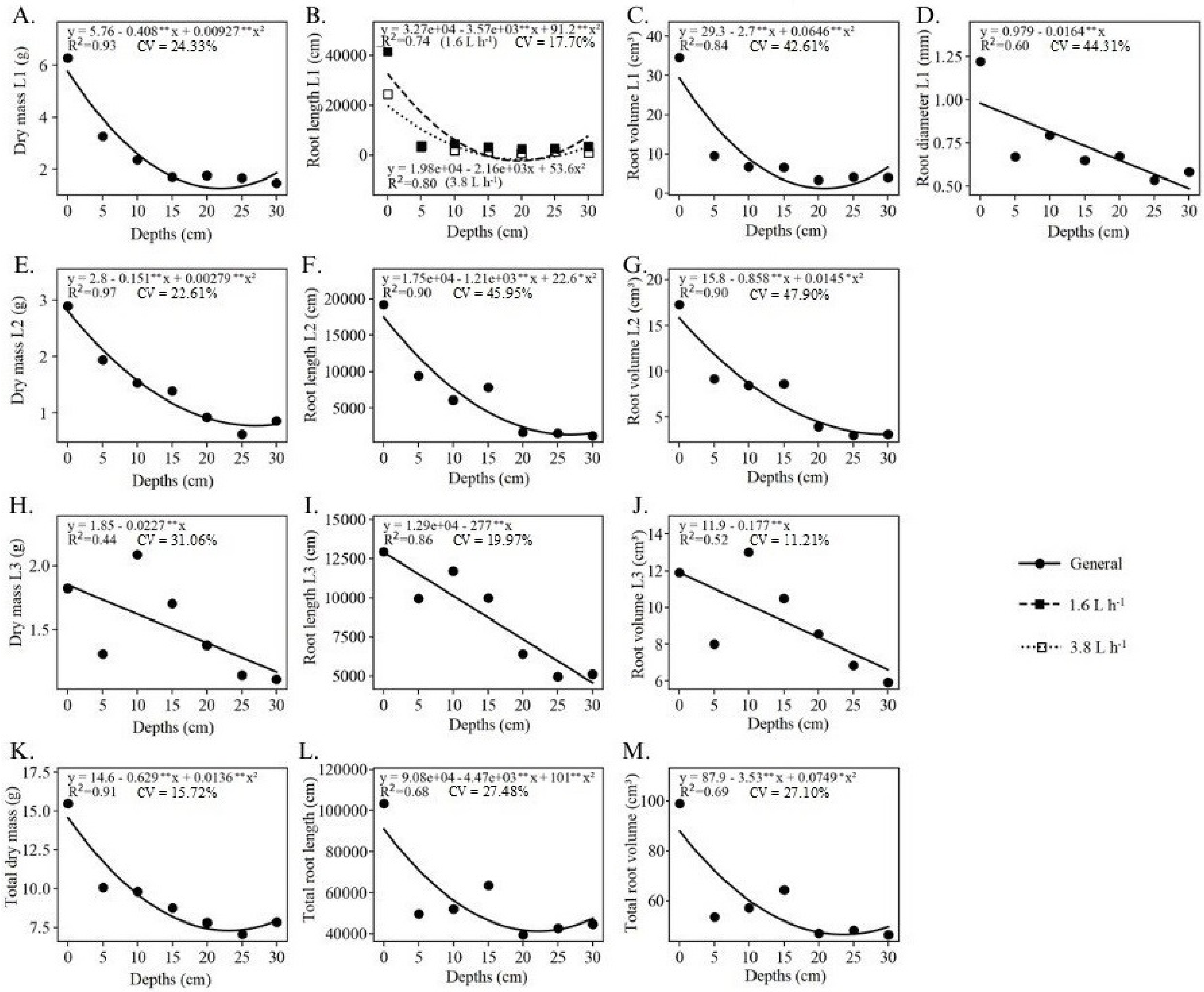

Figure 5. Dry mass (A, E, H and K), length (B, F, I and L), volume (C, G, J and M) and average diameter (D) of the roots in the soil layers L1 0-10, L2 10-20, L2 20-30, and total 0-55 cm of cowpea fertigated with sanitary sewage applied by drippers operating at different flow rates and installation depths

(Figure 4E). The reduction in transpiration influences the reduction in carbon accumulation and, consequently, biomass accumulation.

The supply of subsurface water restricted the growth of the roots in the upper soil profile and, consequently, this can affect the absorption of water and nutrients by the plants (Ma et al., 2020), as can be seen in Figure 5.

SDI tends to be more efficient in medium-textured soils and under conditions where the system is used to provide water supplementation, since, depending on the depth at which the dripper is installed, it does not guarantee an adequate stand. Generally, in very clayey soils with low hydraulic conductivity, when irrigating using SDI, there can be a back pressure between the soil and the drip line, which can reduce the flow rate of the emitter (Nogueira et al., 2021).

The emitter with a flow rate of 1.6 L h^{-1} performed better for the variables stomatal conductance, total chlorophyll, root dry mass in the 40-55 cm soil layer and root length in the 0-10 cm layer compared to the dripper with a flow rate of 3.8 L h^{-1}. Clay soil has a low water infiltration rate, so a lower flow rate emitter allows for a balanced horizontal and vertical distribution. In SDI, a higher flow rate can allow for greater back pressure and thus reduce the applied depth or create preferential paths.

When the emitter's application intensity is greater than the soil's water infiltration rate, the pressure load around the emitter becomes positive. The consequence of this is the generation of a back pressure that reduces the hydraulic gradient between the inside of the emitter and the soil, consequently reducing the emitter's flow rate. In fine-textured soils, the effect of back pressure is more pronounced, resulting in a greater reduction in emitter flow (Nogueira et al., 2021).

For the conditions of the study, the behavior of the roots was impaired with SDI (Figure 5). However, some studies have shown the opposite, where SDI performed better than SD, mainly because it supplied nutrients close to the effective zone of the root system (Selim et al., 2009). Depending on the crop and the soil, there is no difference between these two systems in terms of crop yield and development (Wu et al., 2019).

To better understand the influence of dripper installation depths and emitter flow rates on the sets of variables studied, principal component analysis (PCA), together with k-means

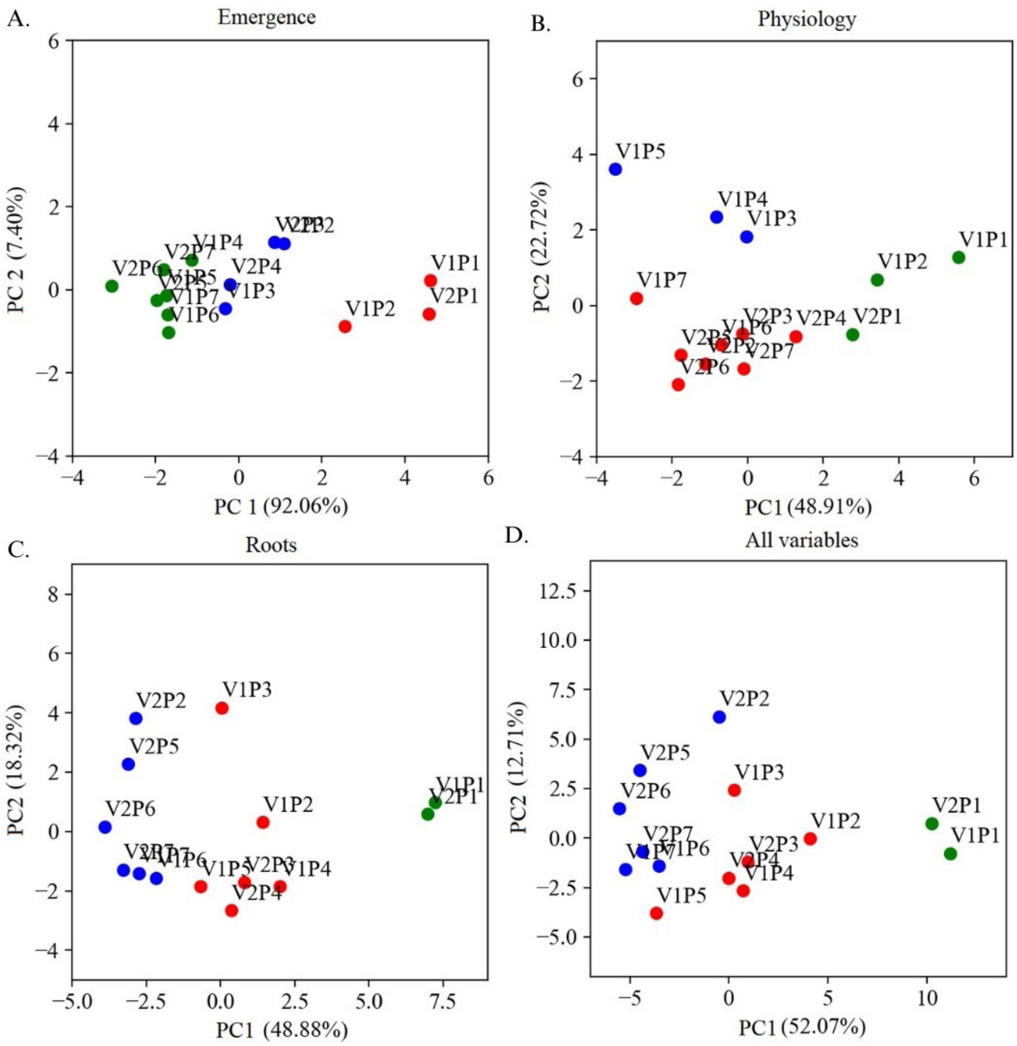

Figure 6. Principal components and cluster analysis for the different emitter flow rates (V1 and V2) and for the different drip installation depths (P1 to P7). Emergence (A), physiology (B), roots (C) and all variables (D). Points with the same color belong to the same group

cluster analysis, was carried out for each set of variables under study and for all the variables together (Figure 6).

In general, it can be seen that the points referring to the treatments with shallower depths differed from the points with greater depths. As for the flow rates, there was no well-defined pattern, corroborating the results presented earlier, which indicated a low influence of flow rate on the variables studied. Based on the grouping, it can be seen that, in general, the SD treatments were allocated to one group and the other treatments, referring to SDI, were divided into two other groups.

The principal component analysis and the clustering analysis show that, in general, the SD was distanced from the other depths of the SDI. Based on the cluster analysis, only the 5 cm installation depth was in the same group as the SD for the emergence and physiological variables. However, for the cluster analysis considering all the variables, three groups were formed, which were made up of the SD, the intermediate depths (5, 10 and 15) and the greatest dripper installation depths (20, 25 and 30 cm). These results are consistent with previous studies suggesting that the installation depth of drippers can significantly influence the distribution of water and nutrients in the soil, affecting plant emergence and physiological development. For example, Wang et al. (2021) observed that shallower depths tend to favor greater initial emergence due to better water availability in the superficial root zone. Ma et al. (2020) highlighted that intermediate and greater dripper depths can optimize the distribution of water and nutrients in crops with deeper roots, promoting more balanced growth. Therefore, our findings corroborate the existing literature, indicating that the choice of dripper installation depth should consider the specific characteristics of the crop and soil to optimize agronomic performance.

An important decision when using SDI is the depth of dripper installation. The desirable installation depth varies according to the crop, soil type, water source, climate, cultural practices and the preferences of the irrigation designer. The rooting characteristics of the crop and the redistribution of water in the soil should be the most important factors when choosing the installation depth.

Conclusions

1. The emergence of cowpea plants is compromised by increasing the installation depth of the drippers and is not affected by the different emitter flow rates.

2. Increasing the depth of the drippers in sandy clay soil negatively influenced the physiological and morphological variables of the roots of cowpea plants fertigated with sanitary sewage.

3. Cowpea responses to surface drip were more promising for the conditions of this study compared to subsurface drip.

4. In sandy clay soil, emitters with flow rates of 1.6 L h^{-1} performed better than those with 3.8 L h^{-1}.

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