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Superabsorbent polymers and sanitary sewage change water availability during the cowpea emergence phase

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ABSTRACT: Superabsorbent polymers (SAP) enhance water retention and facilitate seed emergence, though studies predominantly use high-quality water, neglecting SAP performance with alternative sources like sanitary sewage. Addressing the imperative to reduce fresh water demand, especially in water-scarce regions, SAP and sanitary sewage emerge as potential agricultural alternatives, partially fulfilling crop water and nutritional needs. This study assessed the impact of SAP and synthetic sanitary sewage (SSS) on substrate attributes and cowpea emergence in a randomized factorial design (8 x 2), incorporating varying SAP doses (0–0.14%) and hydration sources (SSS and distilled water). Cowpea was cultivated in polystyrene trays under controlled conditions. While SAP and SSS augmented water retention, total dissolved solids, pH, and electrical conductivity (ECse) also increased. Increased ECse negatively affected cowpea germination, emergence speed index (ESI), and time to 50% emergence. In conclusion, applying SAP near cowpea seeds impeded emergence, warranting the exploration of alternative strategies. Despite the rise in ECse, SSS demonstrated benefits for germination, establishing itself as a viable water source for cowpea emergence. This study underscores the necessity for further research into SAP applications and recognizes synthetic sanitary sewage as a promising, water-conserving source for sustainable cowpea growth.
Keywords: available water; germination; hydrogel; sowing; wastewater.

Polímeros superabsorventes e esgoto sanitário alteram a disponibilidade hídrica na fase de emergência do feijão-caupi

RESUMO: Os polímeros superabsorventes (SAP) aumentam a retenção hídrica e emergência das sementes, embora estudos utilizem predominantemente água de boa qualidade, negligenciando o desempenho do SAP com fontes alternativas como o esgoto sanitário. Respondendo ao imperativo de reduzir o consumo de água doce, especialmente em regiões com escassez hídrica, SAP e esgoto sanitário surgem como potenciais alternativas agrícolas. Neste estudo avaliou-se SAP e esgoto sanitário sintético (SSS) nos atributos do substrato e na emergência do feijão-caupi em delineamento fatorial casualizado (8x2), incorporando diferentes doses de SAP (0–0,14%) e fontes hídricas (SSS e água destilada). Cultivou-se feijão-caupi em bandejas de poliestireno sob condições controladas. SAP e SSS aumentaram a retenção hídrica, total de sólidos dissolvidos, pH e condutividade elétrica (ECse). O aumento da ECse reduziu a germinação do feijão-caupi, velocidade de emergência e tempo para emergência de 50% das sementes. Conclui-se que o SAP aplicado próximo das sementes prejudica a emergência do feijão-caupi, justificando a exploração de estratégias alternativas. SSS demonstrou benefícios para a germinação, estabelecendo-se como fonte hídrica viável para emergência do feijão-caupi. Este estudo destaca a necessidade de maiores investigações sobre aplicações de SAP e reconhece SSS como fonte hídrica para o crescimento sustentável do feijão-caupi.
Palavras-chave: água disponível; germinação; hidrogel; semeadura; águas residuárias.

1. INTRODUCTION

It is estimated that by 2025, more than 60% of the world's population will undergo a restriction on access to water (FAO, 2020) due to either quantity or quality. This problem directly affects the agricultural sector, in which there is a need to produce more food for the growing population while creating no conflict over water use. Thus, irrigated agriculture is subject to challenges because it has a greater demand for water resources, accounting for 70% of freshwater use (FAO, 2016).

It is interesting to seek strategies that reduce the demand for fresh water. One way to reduce water consumption is to increase the use of rainwater. Water availability in the soil must also be increased to allow greater water storage after a rainfall event. Water availability is a function of the effective rooting depth and water content equivalent to the permanent wilting point and field capacity. The plant uses the water retained between field capacity and the permanent wilting point; the available water differs between these characteristics. Brazilian soils have available water between

0.51 and 2.30 mm cm^{-1} (EMBRAPA, 2022). The lower the clay content, the lower the soil's water retention. As a result, using superabsorbent polymers (SAP) is a promising alternative to increase soil water retention capacity and, consequently, the water available for plants (PEREIRA et al., 2018).

SAPs are made from polymers and can absorb up to 300% of their weight in water, making them available to the plant in a controlled manner over a more extended period (SATRIANI et al., 2018). SAPs can be classified according to the origin of the material, which can be synthetic or natural (BEHERA; MAHANWAR, 2020). Synthetic SAPs are petrochemically based (such as polyacrylic acid, methacrylic acid, vinyl acetate, and polyethylene glycol). Natural SAPs are based on polysaccharides (such as cellulose, starch, alginate, and agarose) and polypeptides (such as gelatin and collagen) (BERRADI et al., 2023). According to Behera and Mahanwar (2020), synthetic SAPs are replacing natural SAPs due to their high absorption capacity, availability of a wide variety of raw materials, and excellent durability. Due to their hydrophilic, non-toxic and biodegradable properties, they are the most desirable products for various applications, such as agriculture. Moreover, according to Maraveas (2020), synthetic SAPs are priced at a quarter of the cost compared to natural SAPs.

In the initial stage of cultivation, soon after transplantation or sowing, the root system is shallow and the plant explores a small layer of soil. Thus, the water stored in the soil is very small, which can quickly be depleted by evapotranspiration. Thus, frequent replacements of water must happen to avoid water deficit. With low water availability in the soil, frequent irrigation with small water depths is necessary (CRUZ et al., 2020; EMBRAPA, 2022). However, mechanized irrigation systems, designed with minimal water depths exceeding the crop's water demand, and subsurface drip systems, which need greater water depths to reach the bulb defined in the project, will waste large volumes of water per irrigation event (BERNARDO et al., 2019). Thus, using SAP to increase soil water retention will increase the irrigation interval and reduce water waste in crops irrigated by the systems above.

In addition to reducing water demand, it is also necessary to seek strategies that minimize the pollution of water bodies. The use of sanitary sewage in agriculture is a promising alternative to final disposal and makes it possible to reduce freshwater consumption, reduce pollution of water bodies, preserve water resources, provide water and nutrients for plants, and recycle nutrients for the soil (ELGALLAL et al., 2016).

Sanitary sewage has a high load of microorganisms that are harmful to human health and cause contamination of soil, water and plants. Therefore, before being applied in agriculture, sanitary sewage must be treated. However, studies prove minimal contaminants in sanitary sewage after treatment (BAETTKER et al., 2021; FRANÇA et al., 2021). However, research shows that this minimal load of contaminants has not harmed the performance of agricultural crops (AL-SUHAIBANI et al., 2021; KHAN et al., 2022; RAGONEZI et al., 2022; SOUZA et al., 2022). Regarding the effects of this minimum load of contaminants on the plant and the air, one way to solve these problems would be to apply domestic sewage in-depth, using subsurface drip irrigation. In this way, the aerial part of the crop will not receive the application of sewage and will not be spread in the air by the wind.

The researcher will be exposed to these microorganisms in scientific research, as sanitary sewage is routinely handled. Natural sewage also shows temporal and spatial variability of its constituents, making it difficult to control them in scientific research. Thus, an alternative is to work with synthetic sanitary sewage (SSS), which has the advantage of not contaminating the environment and has the same concentrations of its constituents over time. SSS has been used in different studies to replace natural sewage (BAETTKER et al., 2021; MANDEL et al., 2019; PEREIRA et al., 2018).

By associating the application of SAP with sanitary sewage, it is possible to achieve greater crop production and, in a sustainable way, to enhance water use efficiency. However, care must be taken in applying new techniques in agriculture. Applying SAP and sanitary sewage positively affects soil physical and chemical attributes and crop development (JASIM et al., 2016; SANTOS et al., 2015). However, these techniques can cause soil salinization (CARVALHO et al., 2019; LEUTHER et al., 2019) and water restriction in the early stages of germination and seedling emergence. It is worth pointing out that it is in these stages that the plant stand is established, impacting the yield and profitability of commercial crops.

Among commercial crops, cowpea (*Vigna unguiculata*) stands out among those most cultivated in arid and semi-arid regions. This legume crop, native to Africa, is one of the main sources of plant protein, playing an important role in human food and in the generation of employment and income. It is a short-cycle crop with low water and soil fertility requirements (FAROOQ et al., 2020).

Some isolated studies show that SAP and fertigation with sanitary sewage benefit the agronomic characteristics of cowpeas. Davoodi et al. (2020) found that applying SAP was essential to increase the water content and ensure higher yields of cowpeas. In the control treatment (without SAP application), water deficit reduced grain yield, number of pods per plant, number of seeds per pod and protein yield. Marashi and Mombani (2020) also found that, under water deficit conditions, SAP promoted higher photosynthetic rates, protein percentage and cowpea yield. Research also shows domestic sewage contains enough nutrients to replace mineral fertilizers in cowpea production. Thus, previous studies have shown that fertilization with domestic effluents positively affects cowpeas' agronomic characteristics (FEITOSA et al., 2019; FERREIRA et al., 2019). However, it should be noted that in these studies, the application of domestic effluent began after seed germination. Thus, studies are needed to evaluate the effect of SAP and SSS on cowpea germination.

Given the above, it is essential to study alternative and more sustainable agricultural production techniques, such as applying SAP and sanitary sewage to meet some of cowpea's water and nutritional needs. This study aimed to evaluate whether superabsorbent polymer and synthetic sanitary sewage interfere with the physical and chemical attributes of the substrate and in the emergence characteristics of cowpea cultivar ‘BRS Tumucumaque.’

2. MATERIAL AND METHODS

2.1. Area and experimental design

The experiment was conducted in a growth chamber of the Institute of Biotechnology Applied to Agriculture (BIOAGRO) at the Federal University of Viçosa (UFV), located in the municipality of Viçosa, MG, Brazil, whose geographical coordinates are 20°45'32" S and 42°52'08" W, DATUM WGS-84, with an altitude of 670 m. The study was carried out from January to March 2019. Commercial, uncertified, first-generation (S1) seeds of cowpea, cultivar 'BRS Tumucumaque', were used in the experiment.

The experimental design was completely randomized, in a factorial arrangement (8 x 2), consisting of the combination of eight doses of SAP and two sources of hydration, with four replicates, totaling 64 experimental units. The doses were 0, 0.02, 0.04, 0.06, 0.08, 0.10, 0.12 and 0.14% SAP in the dry substrate. These doses are equivalent to 0 kg ha^{-1}, 0.9 kg ha^{-1}, 1.8 kg ha^{-1}, 2.7 kg ha^{-1}, 3.6 kg ha^{-1}, 4.5 kg ha^{-1}, 5.4 kg ha^{-1} and 6.3 kg ha^{-1} of SAP, respectively. The manufacturer did not have a SAP dose recommendation for cowpeas. Thus, two pre-tests were carried out in which doses equal to or greater than 0.20% did not allow seed germination. Thus, it was decided to fractionate SAP doses up to 0.14%. The water sources were SSS and DW. Each experimental unit consisted of a polystyrene tray with one seed per cell.

The SAP used was the commercial product Agrogel®. These polymers are of high quality and purity, specially developed for agriculture, and comprise the line of Hydroplan-EB (HyB) polymers (HYDROPLAN, 2020). SAP is made of a copolymer of acrylamide and potassium acrylate and has a neutral pH and a particle size of less than 1 mm.

A solution of synthetic origin was used to simulate sanitary sewage (NOPENS et al., 2001). The compounds used to prepare the SSS are shown in Table 1. The salts and ingredients were added to 10 L buckets and filled with public-supply water. Then, using a mechanical stirrer, the solution was mixed for 15 minutes until the solutes were completely dissolved.

Table 1. Theoretical composition and respective concentrations for the production of 1 liter of synthetic sanitary sewage. Source: Adapted from Nopens et al. (2001).
Tabela 1. Composição teórica e respectivas concentrações para a produção de 1 litro de esgoto sanitário sintético. Fonte: Adaptado de Nopens et al. (2001).

Salts	Quantity[1]	COD	N	P_2O_5	K_2O
	mg L^{-1}				
Urea	92	23	43	0	0
MAP	13	0	1	3	0
Sodium acetate[2]	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
Powdered milk	116	116	7	1	0
Yeast	52	52	6	0	0
Soy oil	29	29	0	0	0
Total	646	439	58	10	15

[1]Mass of salts and ingredients for the production of 1 L of synthetic sanitary sewage. [2]Hydrated sodium acetate; COD - Chemical oxygen demand; MAP - mono-ammonium phosphate.

2.2. Evaluation of substrate water retention curve

The sand + superabsorbent polymer mixture was sampled to determine the water retained at different matric potentials (-10, -30, -100, -300, -500, and -1,500 kPa). These analyses were carried out at the Water and Soil Laboratory of the Agricultural Engineering Department of UFV. The amount of water retained at different matric potentials was determined in Richards' pressure plate apparatus (RICHARDS, 1949). The amount of water available in the substrate (sand) for the plant was calculated by the difference between the waters retained at field capacity (-10 kPa) and at the permanent wilting point (-1,500 kPa) (BERNARDO et al., 2019).

The substrate water retention curve was determined using Van Genuchten's equation with SWRC 3.0 software (Dourado Neto et al., 2000) for all SAP doses and water sources.

2.3. Evaluation of substrate chemical attributes

The same sample sent to the Water and Soil Laboratory to determine the substrate water retention curves were analyzed for the substrate's pH, ECse, and total dissolved solids (TDS) in the 1:2.5 (substrate: water) proportion. The procedures were performed according to Ayers and Westcot (1985). The solutions were stirred and remained at rest for one hour; soon after, the measurements were taken using the MP Series device from Hach®. The instrument was calibrated in the laboratory before performing each round of sampling. All collected water samples were placed and stored in cooler boxes, with ice added to maintain the temperature below four °C for sample preservation until they arrived safely at the laboratory.

2.4. Emergence and initial development of seedlings

The experiment was conducted in an air-conditioned growth room at 25±0.5 ºC and photoperiod/dark period of 12/12 hours. Washed sand sterilized in an oven at 200 ºC for two hours was used as substrate. The substrate was moistened with a volume of water corresponding to 60% of its retention capacity (BRASIL, 2009).

The trays used in the study were polystyrene, 67 cm long, 34 cm wide, and 5.2 cm in total height. The trays had 200 cells in the 10-unit x 20-unit configuration. The cells had a quadrangular upper area with a width and length of 2.7 cm (area of 7.29 cm^2). The proper height of the cells was 4.4 cm, and the bottom was tapered. The total volume of each cell was 16 cm^3.

In each tray, 4.5 kg of dry sand was added, and based on the proportion of SAP per substrate, the doses to be applied were determined. The SAP was homogenized to the substrate, and subsequently, distilled water (DW) and SSS were calculated and applied to fill 200 cells with the mixture. Thus, each cell was filled with 22.5 g of dry sand, and in the treatment of 0.14%, for example, 31.5 μg of SAP was applied.

Cowpea was sown at a depth of 3 cm and the spacing between seeds was 3.4 cm. Irrigation was performed with sprayers whenever the need to moisten the substrate was noted. The water requirement was obtained by the difference between the mass of the previously known wet tray and the tray's mass at the irrigation time. Emerged seedlings were counted daily, considering those with the cotyledons fully expanded above the substrate for eight days.

Emergence percentage (E) (Equation 1), emergence speed index (ESI) (Equation 2) (MAGUIRE, 1962), the time required for the occurrence of 50% emerged seedlings (T50) (FAROOQ et al., 2005), and height of cowpea seedlings (FAROOQ et al., 2005) were evaluated.

$$\mathrm{E} = \frac{\mathrm{n}}{\mathrm{N}} \times 100 \qquad (01)$$

$$\mathrm{ESI} = \sum_{i=1}^{k} \frac{n_i}{t_i} \qquad (02)$$

where: E = emergence percentage, in %; n = number of emerged seeds; N = total number of seeds; ESI = emergence speed index; n_i = number of seeds that emerged each day; t_i = number of days after the test started in each count.

2.5. Relative water content

The relative water content (RWC) and water saturation deficit (WSD) of cowpea seedlings were calculated following recommendations from Taiz and Zeiger (2013). For this, in each experimental unit, four cowpea seedlings representing the mean of each replicate were selected to evaluate the RWC and WSD parameters. In each seedling, only one primary leaf was collected. A disc of 1 cm diameter was removed from this leaf, and the fresh mass (FM) was determined. After weighing, the leaf discs of each experimental unit were immersed in distilled water for 24 hours. Subsequently, the leaf discs were removed from the distilled water, dried, and weighed again to obtain the maximum or turgid mass (MM). Then, these leaves were dried in an oven at around 70 °C until a constant dry mass (DM) was obtained.

The above data was used to calculate the RWC and WSD according to Equations 3 and 4, respectively, according to the calculation procedures recommended by Taiz and Zeiger (2013).

$$\mathrm{RWC} = \frac{\mathrm{FM}-}{\mathrm{MM}-\mathrm{DM}} \times 100 \qquad (03)$$

$$\mathrm{WSD} = \frac{\mathrm{MM}-\mathrm{FM}}{\mathrm{MM}-\mathrm{D}} \times 100 \qquad (04)$$

where: RWC = relative water content, in %; FM = fresh mass of leaf discs, in g; DM = dry mass of leaf discs, in g; MM = mass of leaf discs after immersion in distilled water, in g; WSD = water saturation deficit, in %.

2.6. Statistical analyses

Data normality was tested using the Shapiro-Wilk test at a 5% probability level. The Shapiro-Wilk test assesses deviations between observed and expected values in a normal distribution, and rejecting the null hypothesis indicates that the data do not follow a normal distribution. After meeting the assumptions of normality, the data were subjected to analysis of variance (ANOVA) using the F test at a 5% probability level. In ANOVA, the single effects and the effects of the interaction between SAP and water source (WS) factors were checked. When SAP*WS was significant, interaction slicing was performed.

The quantitative factor (SAP) was analyzed through regression, which tested linear and quadratic models. Model selection was based on the significance of the regression coefficients, using the t-test at a 5% probability level, on the coefficient of determination (R^2) and the biological phenomenon.

For qualitative factor (WS), the means comparison test was used. Means were compared using Tukey's test at a 5% probability level.

The statistical analyses were performed using the Experimental Designs package of R software (R DEVELOPMENT CORE TEAM, 2020).

3. RESULTS

3.1. Water retention in the substrate

The curves of water retention in the substrate containing different doses of SAP and receiving different water sources, consisting of DW and SSS, are presented in Figure 1. The fits of the models were significant at a 5% level. It can be observed that the behaviors of the substrate water retention curves varied for each SAP dose and the different water sources; however, no trend was verified in response to the factors imposed. Therefore, the effects of treatments were evaluated by the analysis of variance for field capacity (FC), equivalent to the matric potential of -10 kPa, permanent wilting point (PWP) at -1,500 kPa, and available water in the substrate (AWS) (Table 2).

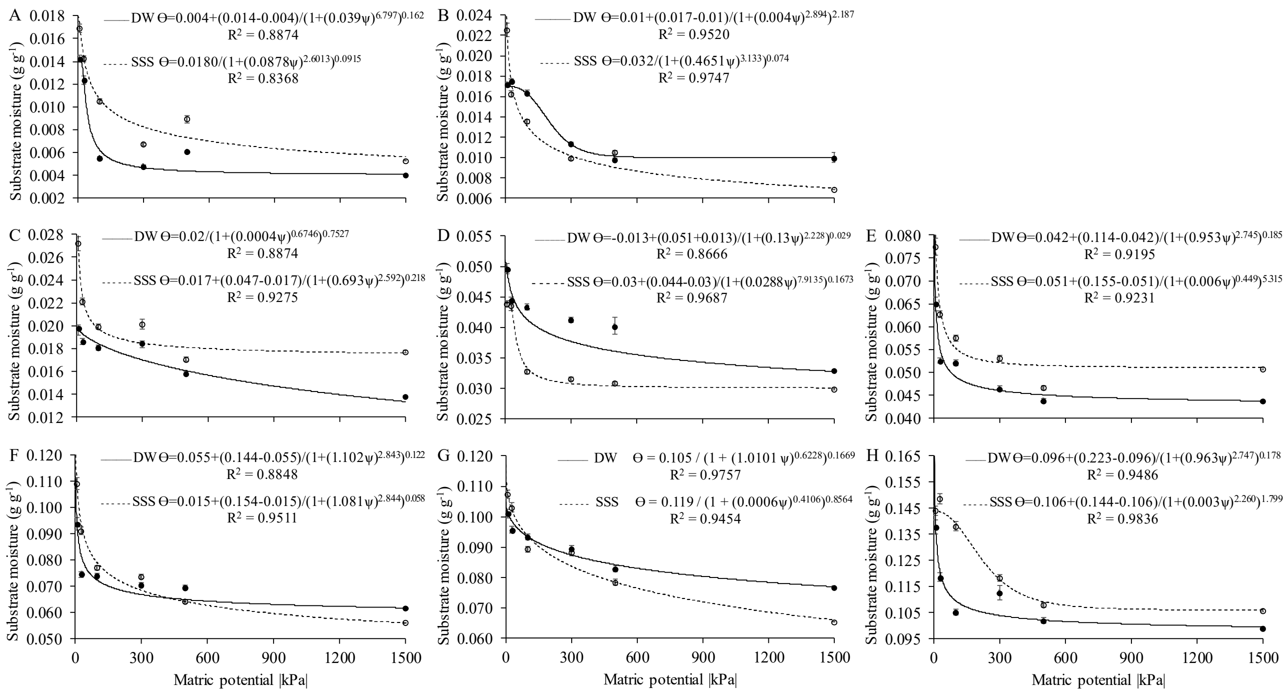


Figure 1. Curves of water retention in substrates containing 0 (A), 0.02 (B), 0.04 (C), 0.06 (D), 0.08 (E), 0.10 (F), 0.12 (G) and 0.14% (H) of superabsorbent polymers (SAP) for different water sources of distilled water (DW) and synthetic sanitary sewage (SSS).
Figura 1. Curvas de retenção de água nos substratos contendo 0 (A); 0,02 (B); 0,04 (C); 0,06 (D); 0,08 (E); 0,10 (F); 0,12 (G) e 0,14% (H) de polímeros superabsorventes (SAP) para diferentes fontes hídricas de água destilada (DW) e esgoto sanitário sintético (SSS).

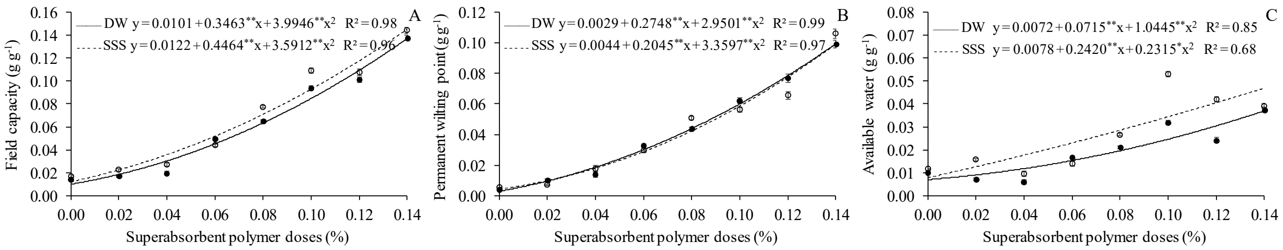
The interactions between SAP and WS were significant for all the physical-hydraulic attributes studied (Table 2). A summary of the analyses of variance is presented in the tables below, where mean squares followed by significance are provided. Thus, verifying the studied factors' single effects and interaction effects is possible.

Figure 2 shows the behaviors of different physical-hydraulic attributes of the substrate as a function of different SAP doses and water sources. Regardless of the water source used in substrate hydration, the physical-hydric attributes evaluated in the present study increased in response to the increasing doses of SAP.

Table 2. Field capacity (FC), permanent wilting point (PWP), and available water in the substrate (AWS) containing different doses of superabsorbent polymers (SAP) and hydrated with water sources (WS) of distilled water (DW) or synthetic sanitary sewage (SSS).
Tabela 2. Capacidade de campo (FC), ponto de murcha permanente (PWP) e água disponível no substrato (AWS) com diferentes doses de polímeros superabsorventes (SAP) e hidratado com fontes hídricas (WS) de água destilada (DW) ou esgoto sanitário sintético (SSS).

SAP doses	FC (g g^{-1})		PWP (g g^{-1})		AWS (g g^{-1})	
(%)	DW	SSS	DW	SSS	DW	SSS
0.00	0.0141 b	0.0170 a	0.0041 a	0.0055 a	0.0100 b	0.0115 a
0.02	0.0171 b	0.0225 a	0.0100 a	0.0069 b	0.0071 b	0.0155 a
0.04	0.0197 b	0.0271 a	0.0136 b	0.0177 a	0.0061 b	0.0095 a
0.06	0.0496 a	0.0440 b	0.0348 a	0.0300 b	0.0148 a	0.0140 a
0.08	0.0649 b	0.0776 a	0.0438 b	0.0510 a	0.0211 b	0.0266 a
0.10	0.0938 b	0.1090 a	0.0619 a	0.0561 b	0.0319 b	0.0529 a
0.12	0.1012 b	0.1076 a	0.0769 a	0.0662 b	0.0243 b	0.0414 a
0.14	0.1379 b	0.1441 a	0.0994 b	0.1060 a	0.0384 a	0.0381 a
SAP	8.71E-3**		4.67E-3**		7.41E-4**	
WS	3.20E-4**		8.59E-6**		3.90E-4**	
SAP*WS	3.96E-5**		4.14E-5**		6.57E-5**	
CV (%)	0.21		1.59		2.98	

Within each variable analyzed, means followed by the same lowercase letter in the row indicate no difference between water sources for each dose of the superabsorbent polymer by Tukey test at 0.05 significance level.



** and * significant at 1 and 5% by the F test, respectively.

Figure 2. Field capacity (FC) (A), permanent wilting point (PWP) (B), and available water in the substrate (AWS) (C) in different superabsorbent polymers (SAP) doses and hydrated with distilled water (DW) or synthetic sanitary sewage (SSS).
Figura 2. Capacidade de campo (FC) (A); ponto de murcha permanente (PWP) (B) e água disponível no substrato (AWS) (C) em diferentes doses de polímeros superabsorventes (SAP) e hidratado com água destilada (DW) ou esgoto sanitário sintético (SSS).

3.2. Electrical conductivity, TDS, and pH of the substrate

The interactions between SAP and water sources were significant for all chemical attributes evaluated (Table 3). Figure 3 shows the effects of different SAP doses on the chemical attributes of the substrate. Regardless of the water source used for substrate hydration, the increase in SAP doses promoted increments in electrical conductivity (ECse) values, total dissolved solids (TDS), and pH.

3.3. Emergence and initial development of seedlings

Table 4 summarizes the variance analysis for emergence, ESI, and time required to emerge 50% of cowpea seeds. The water sources caused a single effect on emergence. Table 4 also shows that SSS promoted more remarkable cowpea emergence than the substrate hydrated with DW. Figure 4 shows some parameters related to cowpea emergence as a function of different SAP doses applied to the substrates. The increasing doses of SAP promoted reductions in the emergence and ESI of cowpeas, regardless of the water source applied in seed hydration (Figures 4A and B).

Figure 5 shows images of trays with cowpea seedlings eight days after sowing for all treatments imposed. In this figure, it is possible to verify the reduction of seedlings as the SAP doses increased.

3.4. Shoot length and relative water content of seedlings

Table 5 shows the values of shoot length, relative water content, and water saturation deficit of cowpea seedlings under different combinations of water sources and SAP doses. The water sources caused a single effect on the shoot length of cowpea seedlings. At SAP doses of 0.00 and 0.04%, hydration with SSS led to higher shoot length values, and at SAP doses of 0.02, 0.06, and 0.08%, hydration with DW resulted in higher shoot length of cowpea seedlings.

The interactions between SAP and water sources were significant for the RWC and WSD of cowpea seedlings (Table 5). Regardless of the SAP dose, hydration with DW promoted higher RWC and lower WSD than hydration with SSS.

Figure 6 shows the behavior of the shoot length values of cowpea seedlings as a function of SAP doses for the two water sources evaluated. It is observed that the increase in SAP doses promoted a linear reduction in the height of seedlings hydrated with distilled water and synthetic sanitary sewage. Such reduction can also be seen in Figure 7, which shows images of cowpea seedlings in the different treatments eight days after sowing.

Table 3. Electrical conductivity (CEes), total dissolved solids (TDS), and pH of the substrate with different doses of superabsorbent polymers (SAP) and hydrated with water sources (WS) consisting of distilled water (DW) or synthetic sanitary sewage (SSS).
Tabela 3. Condutividade elétrica (CEes), sólidos dissolvidos totais (TDS) e pH do substrato com diferentes doses de polímeros superabsorventes (SAP) e hidratados com fontes hídricas (WS) constituídas de água destilada (DW) ou esgoto sanitário sintético (SSS).

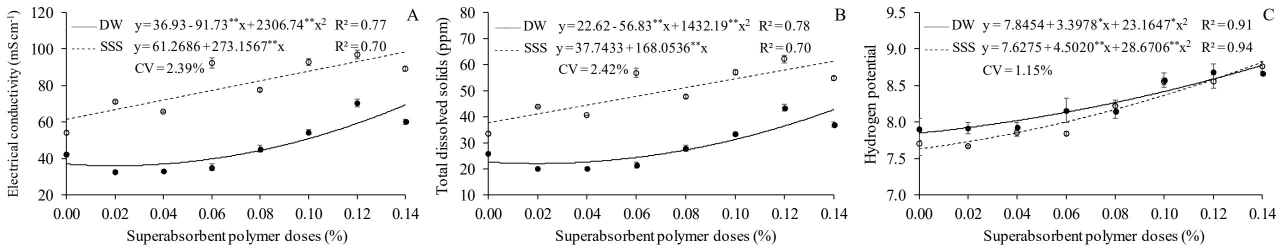
SAP doses	EC_{se} (µS cm^{-1})		TDS (ppm)		pH	
(%)	DW	SSS	DW	SSS	DW	SSS
0.00	42.13 b	54.22 a	25.88 b	33.39 a	7.90 a	7.70 b
0.02	32.73 b	70.93 a	19.99 b	43.71 a	7.91 a	7.67 b
0.04	33.13 b	65.70 a	20.25 b	40.47 a	7.92 a	7.85 a
0.06	35.11 b	92.38 a	21.48 b	56.88 a	8.16 a	7.84 b
0.08	45.16 b	77.39 a	27.78 b	47.67 a	8.14 a	8.22 a
0.10	54.43 b	92.62 a	33.52 b	57.03 a	8.57 a	8.55 a
0.12	70.42 b	100.90 a	43.40 b	62.13 a	8.69 a	8.56 a
0.14	60.14 b	88.98 a	37.05 b	54.79 a	8.66 a	8.76 a
SAP	1.10E+3**		4.22E+2**		8.87E-1**	
WS	1.37E+4**		5.21E+3**		1.30E-1**	
SAP*WS	2.36E+2**		9.01E+1**		3.04E-2**	
CV (%)	2.39		2.42		1.15	

Within each analyzed variable, means followed by the same lowercase letter in the row indicate no difference between the water sources for each dose of the superabsorbent polymer by Tukey test at 0.05 significance level.

Table 4. Emergence, emergence speed index (ESI), and time for the emergence of 50% of the seeds (T50) of cowpea grown on substrates that received superabsorbent polymers (SAP) and that were hydrated with distilled water (DW) or synthetic sanitary sewage (SSS).
Tabela 4. Emergência, índice de velocidade de emergência (ESI) e tempo para a emergência de 50% das sementes (T50) do feijão-caupi cultivado em substratos que receberam polímeros superabsorventes (SAP) e que foram hidratados com água destilada (DW) ou esgoto sanitário sintético (SSS).

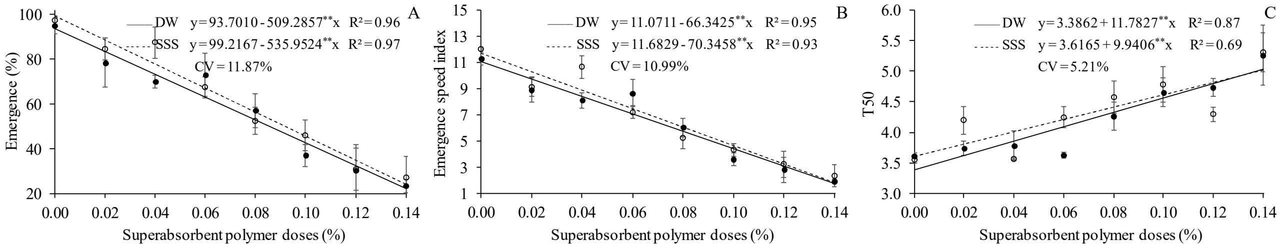
SAP doses	Emergence (%)		ESI		T50	
(%)	DW	SSS	DW	SSS	DW	SSS
0.00	58.1 b	61.7 a	11.26 a	12.03 a	3.62 a	3.55 a
0.02			8.92 a	9.08 a	3.74 b	4.20 a
0.04			8.09 b	10.65 a	3.79 a	3.56 a
0.06			8.66 a	7.21 b	3.63 b	4.25 a
0.08			6.04 a	5.23 a	4.26 a	4.57 a
0.10			3.62 a	4.32 a	4.66 a	4.78 a
0.12			2.82 a	3.23 a	4.73 a	4.29 b
0.14			1.99 a	2.31 a	5.27 a	5.30 a
SAP	5.33E+3**		9.27E+1**		2.67E+0**	
WS	2.10E+2*		1.75E+0^{ns}		1.64E-1^{ns}	
SAP*WS	1.11E+2^{ns}		2.79E+0**		2.48E-1**	
CV (%)	11.87		10.98		5.23	

Within each analyzed variable, means followed by the same lowercase letter in the row indicate no difference between the water sources for each dose of the superabsorbent polymer by Tukey test at 0.05 significance level.



** and * significant at 1 and 5% by the F test, respectively.

Figure 3. Electrical conductivity (CEes) (A), total dissolved solids (TDS) (B), and pH (C) of the substrate as a function of superabsorbent polymers (SAP) doses and hydrated with distilled water (DW) or synthetic sanitary sewage (SSS).
Figura 3. Condutividade elétrica (CEes) (A), sólidos dissolvidos totais (TDS) (B) e pH (C) do substrato em função de diferentes doses de polímeros superabsorventes (SAP) e hidratados com água destilada (DW) ou esgoto sanitário sintético (SSS).



** and * significant at 1 and 5% by the F test, respectively.

Figure 4. Emergence (A), emergence speed index (ESI) (B), and time required for the emergence of 50% of the seeds (T50) (C) of cowpea cultivated with different doses of superabsorbent polymers (SAP) and hydrated with distilled water (DW) or synthetic sanitary sewage (SSS).
Figura 4. Emergência (A), índice de velocidade de emergência (ESI) (B) e tempo requerido para a emergência de 50% das sementes (T50) (C) do feijão-caupi, cultivado com diferentes doses de polímeros superabsorventes (SAP) e hidratados com água destilada (DW) ou esgoto sanitário sintético (SSS).

Table 5. Shoot length (SL), relative water content (RWC), and water saturation deficit (WSD) of cowpea seedlings cultivated in substrates that received superabsorbent polymers (SAP) and that were hydrated with distilled water (DW) or synthetic sanitary sewage (SSS).
Tabela 5. Comprimento da parte aérea (SL), teor relativo de água (RWC) e déficit de saturação hídrica (WSD) de plântulas do feijão-caupi cultivado em substratos que receberam polímeros superabsorventes (SAP) e que foram hidratados com água destilada (DW) ou esgoto sanitário sintético (SSS).

SAP dose (%)	SL (cm)		RWC (%)		WSD (%)	
	DW	SSS	DW	SSS	DW	SSS
0.00	11.33 b	14.38 a	79.79 a	76.87 b	20.21 b	23.13 a
0.02	9.50 a	7.25 b	73.69 a	72.33 b	26.31 b	27.67 a
0.04	10.50 b	12.50 a	80.80 a	71.51 b	19.20 b	28.49 a
0.06	10.38 a	6.63 b	80.40 a	80.14 b	19.60 b	19.86 a
0.08	8.17 a	6.38 b	80.54 a	74.21 b	19.46 b	25.79 a
0.10	6.63 a	6.13 a	80.54 a	71.90 b	19.46 b	28.10 a
0.12	5.75 a	6.38 a	80.85 a	76.43 b	19.15 b	23.57 a
0.14	4.75 a	5.75 a	79.56 a	72.99 b	20.44 b	27.01 a
SAP	5.72E+1**		1.89E+1*		1.89E+1**	
WS	6.60E+0*		1.98E+2**		1.98E+2**	
SAP*WS	1.05E+1**		1.09E+1ns		1.09E+1ns	
CV (%)	12.04		3.78		3.78	

Within each analyzed variable, means followed by the same lowercase letter in the row indicate no difference between the water sources for each dose of the superabsorbent polymer by Tukey test at 0.05 significance level.

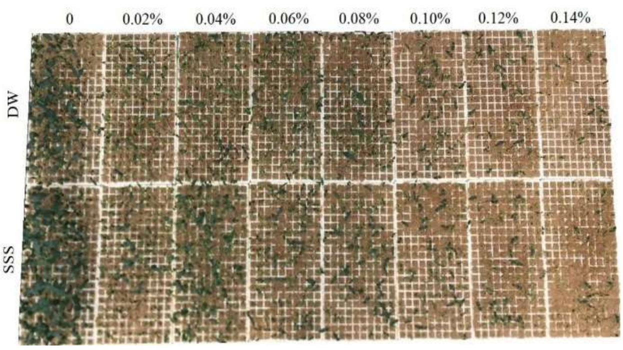
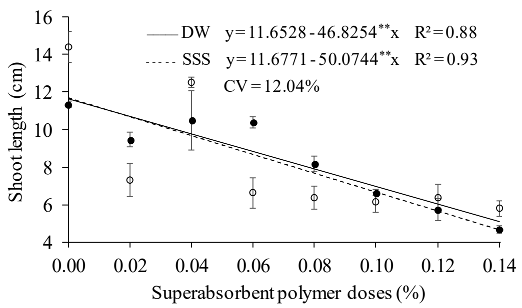


Figure 5. Emergence of cowpea seedlings at eight days after sowing in substrates that received different doses of superabsorbent polymers (SAP) and that were hydrated with distilled water (DW) or synthetic sanitary sewage (SSS).
Figura 5. Emergência das plântulas de feijão-caupi aos 8 dias após a semeadura, cultivado em substrato que receberam diferentes doses de polímeros superabsorventes (SAP) e hidratados com água destilada (DW) ou esgoto sanitário sintético (SSS).

4. DISCUSSION

Table 2 shows that SSS promoted higher FC values except for the treatment in which the substrate received an SAP dose of 0.06%. SSS contains nutrients (salts) in its composition (Table 1), reducing the osmotic potential and increasing water retention. The application of treated sanitary sewage significantly increases the water content retained in the upper soil layer compared to the application of water (LOY et al., 2018; TUNC; SAHIN, 2015). On the other hand, the water contained in the substrate will have a lower total potential (matric potential + osmotic potential). Thus, despite increased water retained at FC, a fraction of it will not be available to the plant. This amount of available water will depend on the ability of the crop to tolerate salinity (DIAS; BLANCO, 2010). Thus, it is clear that even by increasing the amount of water retained, water restriction can be increased due to reduced water potential.



** and * significant at 1 and 5% by the F test, respectively

Figure 6. Shoot length of cowpea seedlings as a function of different doses of superabsorbent polymers.
Figura 6. Comprimento da parte aérea de plântulas de feijão-caupi em função de diferentes doses de polímeros superabsorventes.

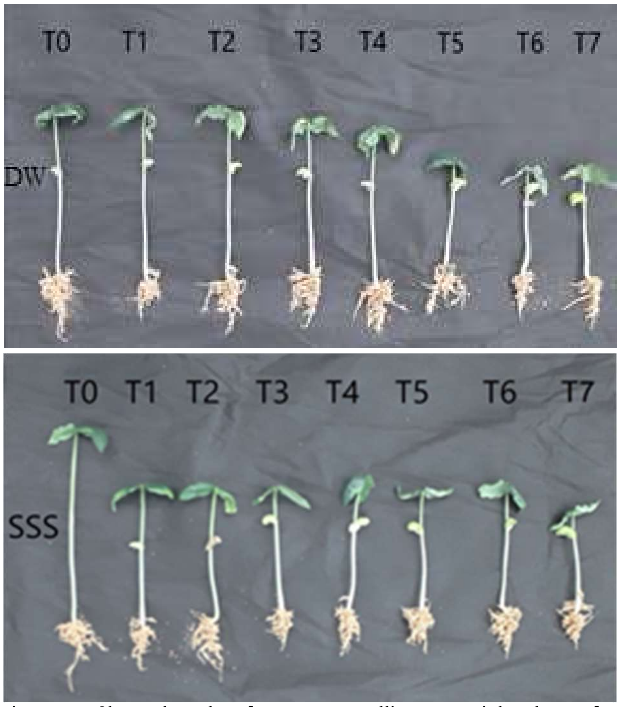


Figure 7. Shoot length of cowpea seedlings, at eight days after sowing, in substrate hydrated with distilled water (DW) or synthetic sanitary sewage (SSS) and under different doses of superabsorbent polymers: T0 = 0; T1 = 0.02; T2 = 0.04; T3 = 0.06; T4 = 0.08; T5 = 0.10; T6 = 0.12 and T7 = 0.14%.
Figura 7. Comprimento da parte aérea das plântulas de feijão-caupi, aos 8 dias após a semeadura, em substratos hidratados com água destilada (DW) ou esgoto sanitário sintético (SSS) e com doses de polímeros superabsorventes: T0 = 0; T1 = 0,02; T2 = 0,04; T3 = 0,06; T4 = 0,08; T5 = 0,10; T6 = 0,12 e T7 = 0,14%.

The highest FC values in treatments hydrated with SSS also enabled higher values of AWS (Table 2). On average, SSS promoted a 43.1% increase in AWS compared to the other water sources. In the present study, AWS was the difference between the FC (-10 kPa) and PWP (-1,500 kPa), which did not show a predominance of higher values for the same water source of substrate hydration. This may have occurred because the osmotic potential has a lower relative contribution in situations of lower matric potentials (DIAS; BLANCO, 2010), as with PWP.

Regardless of the water source used in substrate hydration, the physical-hydric attributes evaluated in the present study increased in response to the increasing doses of SAP (Figure 2). This behavior can be justified by the capacity of SAP to absorb water by more than 100 times its mass, releasing it in a controlled manner (NAVROSKI et al., 2015). The mechanism of water absorption by the SAP occurs through the first contact of the water molecules with the polymer matrix, which hydrates the polar hydrophilic groups. This process is called primary water binding and results in the beginning of polymer expansion. Then, free water enters the gel structure by osmosis, filling the space between the polymer chains and the empty pores of the SAP. According to Mendonça et al. (2015), SAPs act as soil conditioners, improving structural properties (increase in water retention), but also have other advantages, such as increases in permeability and infiltration rates, in addition to reducing water erosion and contributing to the efficient use of water.

At first, as long as the soil has good aeration porosity, agricultural management enabling increased FC is considered advantageous. However, with the application of SAP, the PWP was also increased (Figure 2B), showing that SAP firmly retains part of the water, so SAP needs to degrade to release strongly retained water. Parvathy et al. (2014) verified the capacity of SAP to release the absorbed water slowly into the environment, partially releasing the retained moisture over 30 days.

Applying SAP in the substrate favored the increase of available water (Figure 2C). A similar result was observed by Pereira et al. (2018). AWS represents the total availability of water in the substrate. To find the actual availability of water for crops, it is necessary to multiply it by an availability factor (f), which ranges from 0.3 to 0.4 for legumes (BERNARDO et al., 2019). According to the regression equations, SAP doses of 0.0555% and 0.0313% are sufficient to double the value of available water in the substrate hydrated with distilled water and synthetic sanitary sewage, respectively. In practical terms, this means that the irrigation interval can also be doubled, resulting in greater flexibility in irrigation management and increasing water security. The highest dose of SAP applied (0.14%) increased the available water in the substrates hydrated with DW and SSS by 6.3 and 6.7 times, respectively.

Using SAP as a soil conditioner made it possible to improve soil water retention and most of cowpea's morphological and production properties (PEREIRA et al., 2018). Mazen et al. (2015) observed maize improvement (*Zea mays*) development by applying different SAPs mixed to the soil in the proportions of 0, 0.05, 0.10, 0.20, and 0.40%. The authors concluded that the different types of SAP can improve water availability in the soil.

Regardless of the SAP dose, SSS promoted an increase in the ECse and TDS of the substrate (Table 3). This is justified by salts and other elements used to prepare the SSS (Table 1). The highest ECse value of the substrate hydrated with SSS was 100.90 $\mu S\ cm^{-1}$, equivalent to 0.10 $dS\ m^{-1}$. This value is lower than the reference values for the bean crop, whose limit is 1.0 $dS\ m^{-1}$, according to Ayers and Westcot (1985).

Regarding the pH, Table 3 shows that the SSS, compared to DW, promoted lower values in the treatments in which the substrates received lower doses of SAP. Possibly, the salts dissolved in the SSS have a primary character.

According to the regression equations in Figure 3A, the treatment that received DW and SAP dose of 0% had ECse of 36.93 $\mu S\ cm^{-1}$, while for the SAP dose of 0.14%, the value was 69.30 $\mu S\ cm^{-1}$, that is, an increase of 87.65% in ECse. For the treatment with SSS, the SAP doses of 0 and 0.14% promoted ECse of 61.27 and 99.51 $\mu S\ cm^{-1}$, respectively, an increase of 62.41% in ECse. The increase in ECse as a function of SAP doses can be attributed to the release of K from the chemical composition of the hydrogel itself, as it is composed of potassium acrylate. In other situations, the increase in ECse may also be due to the retention of water and nutrients because of the lower leaching, which causes the increase of salt content in the substrate. The increase in ECse contributes to the reduction of the osmotic potential, reducing the total water potential in the substrate. The result of this is an increase in water restriction for cowpeas. Different studies have also reported increased ECse as a function of SAP doses (CARVALHO et al., 2019; NAVROSKI et al., 2015; MENDONÇA et al., 2013).

The increase in pH with the addition of SAP is due to its alkaline nature. An increase in pH as a function of SAP doses has also been reported by Navroski et al. (2015). The increase in pH can harm germination, and the influence of pH during this stage has received little attention. According to Wagner

Júnior et al. (2007), pH values greater than 8.0 have been reported as inhibitors of the germination process. In addition, the increase in pH reduces the availability of nutrients, such as phosphorus. It may hamper the initial stage of a cultivation cycle since this element is essential for cell division.

Table 4 shows that SSS promoted a higher emergence percentage of cowpeas regarding the treatment in which the substrate was hydrated with DW. SSS can provide water and nutrients for plants (JASIM et al., 2016), such as ammoniacal nitrogen and nitrates, potassium, phosphorus, magnesium, and micronutrients. Some of these nutrients in the SSS possibly promoted positive effects on cowpea emergence. Among the nutrients, nitrates act positively on germination as signal molecules. Studies conducted by Miladinov et al. (2020) showed that potassium nitrate, in addition to the positive impact on germination, promoted a reduction in lipid peroxidation activity and also an increase in the activity of antioxidants, which are essential to overcome abiotic stress. In addition, nutrients such as phosphorus contribute to cell division, promoting beneficial effects on the initial development of plants (BILLAH et al., 2020; LIU, 2021; OKORO et al., 2020).

The interactions between SAP and water sources were significant for ESI and T50 of cowpeas (Table 4). For most SAP doses, substrate hydration did not cause differences in ESI and T50, except for the SAP doses of 0.04 and 0.06% for ESI and SAP doses of 0.02, 0.06 and 0.12% for T50. There was no clear trend regarding the optimal hydration method, even at SAP doses, with differences between hydration sources. This occurred possibly because the beneficial effects promoted by the water sources were nullified.

Despite the higher water retention in substrates hydrated with SSS (Table 2), using DW promotes rapid water absorption by the SAP. This is because DW does not contain dissolved salts in its constitution, facilitating the retention of water by the SAP. Akhter et al. (2004) verified that water absorption by SAP was faster with DW and reached its maximum values at 4, 7, and 12 hours in DW, tap water, and saline water, respectively. The authors observed that water absorption by SAP decreased with increasing water salinity, and the maximum absorption occurred in distilled water (505 g g^{-1}), followed by tap water (212 g g^{-1}) and saline water (140 g g^{-1}) during the first hydration cycle.

The increasing doses of SAP promoted reductions in cowpea emergence percentage and ESI, regardless of the water source applied in seed hydration (Figures 4A and B). SAPs are essential in increasing water retention in the substrate (Figure 2C); however, when applied close to the seeds, even at low concentrations (0.02%), they can negatively affect cowpea germination.

Applying SAP in the substrate increased the ECse (Figure 3A) and the water retention capacity (Figure 2A); consequently, the osmotic potential was reduced. This hampered the absorption of water by the seeds and negatively influenced all emergence variables of cowpeas (Figure 4). Imbibition of water by the seed is essential for the resumption of metabolism and the beginning of cellular events. As it occurs in the soil, the movement of water to the seed results from a gradient from high to low energy levels; that is, the water potential in the seed cell is equal to the sum of the osmotic, pressure, and matric potentials ($\psi cell = \psi o + \psi p + \psi m$).

Some studies have shown benefits to the germination of different species by applying SAP (SU et al., 2017; CASSOL et al., 2020; ZHANG et al., 2020; JANG et al., 2021). Yonezawa et al. (2017) verified a 20% increase in okra (*Abelmoschus esculentus*) germination with a SAP dose of 0.3%. Thus, it is possible to understand that the concept of available water differs for seeds and for developing cowpea plants. For common bean (*Phaseolus vulgaris*), Forti et al. (2009) verified problems in seed germination under water availability conditions of -40 kPa, compared to the optimum conditions.

The increasing doses of SAP promoted an increase in the T50 of cowpeas, regardless of the water source applied in seed hydration (Figure 4C). This is disadvantageous in germination because a longer time is required to emerge 50% of the seeds.

Figure 5 shows a reduction in seedlings as SAP doses increased, highlighting germination problems. Seedling emergence, when reduced and uneven, can lead to delays in development, problems with weed control, non-uniformity of the crop at various phenological stages, and interference in product quality and plant characteristics related to harvest efficiency.

The interactions between SAP and water sources were significant for the RWC and WSD of cowpea seedlings (Table 5). Regardless of the SAP dose, hydration with DW promoted higher RWC and lower WSD than hydration with SSS. The SSS is composed of salts that promote the increase of salinity near the roots, and this may have influenced the lower relative water content and higher saturation deficit compared to DW. However, applying nutrients under salinity conditions can alleviate its harmful effects (RAHMAN et al., 2017). Hence, the height of the seedlings was not negatively influenced due to the balance of elements present in the SSS.

The increase in SAP doses negatively affected all emergence variables, especially the competition between the seed and SAP for water. This is because SAP retains water and makes it available slowly, promoting an initial water restriction, which results in slower germination and lower seedling height. Seeds require free water for rapid absorption, germination, emergence, and adequate hypocotyl elongation (BEWLEY et al., 2013).

The reduction in seedling height as a function of increased SAP doses was observed in cucumber (*Cucumis sativus*) seeds (ALVES; TEIXEIRA, 2012). Rahman et al. (2017) found that shoot and root lengths decreased significantly with increased ECse levels. Therefore, it is necessary to know an adequate dose of SAP for each species and to determine an appropriate time of application, at which the positive effects of SAP application are maximized and the unfavorable adverse effects arising from this practice are minimized.

Arid and semi-arid regions face problems with water availability in both quantity and quality. Thus, adopting techniques that enable more adequate water management for these regions is a constant challenge. The present study observed that SSS is a viable alternative to water sources for the emergence of cowpeas. However, because synthetic sanitary sewage was used in the present research, studies using original sewage must be carried out. Thus, observing the effect of microorganisms from sanitary sewage on cowpea's germination and initial development will be possible.

It was also observed that SAP increases water retention in the substrate, but its application close to the seeds and the increasing doses negatively influenced cowpea emergence. Thus, studies to evaluate the effects of SAP on cowpea roots and the product's activity period are necessary. Field studies are necessary to evaluate the ideal spatial and temporal distance for SAP application concerning seed if cowpea roots are unaffected.

5. CONCLUSIONS

The superabsorbent polymer and synthetic sanitary sewage affect the substrate's physical and chemical attributes and the emergence characteristics of cowpeas.

There were increases in the values of field capacity, permanent wilting point, and available water in the substrate due to increasing doses of superabsorbent polymers in substrates hydrated with distilled water or synthetic sanitary sewage.

There were increases in electrical conductivity, total dissolved solids, and pH in response to increasing doses of superabsorbent polymers in the substrate hydrated with the different water sources.

Using sanitary sewage in the cowpea's emergence increases the substrate's electrical conductivity and total dissolved solids compared to distilled water.

Superabsorbent polymers in contact with seeds affect cowpeas during the emergence phase, regardless of hydration with distilled water or sanitary sewage.

The use of sanitary sewage enables a more significant remarkable emergence of cowpea compared to distilled water for the conditions of the present study.

With the increase in the doses of superabsorbent polymers, there is a reduction in the height of cowpea seedlings cultivated in substrates hydrated with distilled water or sanitary sewage, negatively impacting plant growth until the appearance of primary leaves.

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