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Technical feasibility of the use of sludge from the water treatment plant in lettuce production

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Abstract – The sludge generated in water treatment plants (WTP sludge), despite having physicochemical characteristics with agricultural potential, is a solid waste discarded in landfills. This research aimed to: 1) evaluate the technical feasibility of WTP sludge in substitution of commercial substrates in the production of lettuce seedlings; 2) to evaluate the yield commercial, in the municipality of Arapiraca, semiarid region of the state of Alagoas - Brazil. The research was carried out in two stages: 1) seedling production in greenhouse in 4 x 4 x 5 factorial arrangement, with four sludge doses (0, 20, 40 and 60%), four commercial substrates (Pindstrup®, Vida Verde®, Bioplant 434® and Bioplant 401®) and five cultivars (Veneranda, Camila, Elba, 'Vitória Verdinha' and Diva); 2) seedlings produced at field level were used in 3 x 3 x 5 factorial arrangement, in which Pindstrup treatments and 60% sludge dose were excluded, as they did not promote seedling emergence. In the 1st experiment, it was observed linear reduction of seedling quality index with the addition of sludge. In the 2nd experiment, the average yield was 5.4 Mg ha^{-1}, in which 20% sludge dose promoted the highest values, being recommended for lettuce production in the semiarid region of Alagoas.

Keywords: *Lactuca sativa* L. Seedling quality index. Urban solid waste. WTP sludge.

Viabilidade técnica do uso de lodo da estação de tratamento de água na produção de alface

Resumo – O lodo gerado nas estações de tratamento de água (lodo de ETA), apesar de apresentar características físico-químicas com potencialidade agrícola, é um resíduo sólido descartado em aterros sanitários. Esta pesquisa objetivou: 1) avaliar a viabilidade técnica do lodo de ETA em substituição a substratos comerciais na produção de mudas de alface; 2) avaliar a produtividade comercial, em Arapiraca, região semiárida de Alagoas - Brasil. A pesquisa foi realizada em dois estágios: 1) produção de mudas em casa de vegetação, no arranjo fatorial 4 x 4 x 5, com quatro níveis de lodo (0, 20, 40 e 60%), quatro substratos comerciais (Pindstrup®, Vida Verde®, Bioplant 434® e Bioplant 401®) e cinco cultivares (Veneranda, Camila, Elba, Vitória Verdinha e Diva); 2) utilizou-se as mudas produzidas, em nível de campo, no esquema fatorial 3 x 3 x 5, em que foram excluídos os tratamentos Pindstrup e a dose de 60% de lodo, por não promoverem emergência. No 1º experimento, observou-se redução linear no índice de qualidade da muda com o acréscimo de lodo. No 2º experimento, a produtividade média foi de 5,4 Mg ha^{-1}, em que a dose de 20% de lodo promove os maiores valores, sendo recomendado para produção de alface na região semiárida de Alagoas.

Palavras-chave: *Lactuca sativa* L. Índice de qualidade da muda. Resíduo sólido urbano. Lodo de ETA.

Viabilidad técnica del uso de lodos de la planta de tratamiento de agua en la producción de lechuga

Resumen – Los lodos generados en las plantas de tratamiento de agua (lodos de PTA), a pesar de tener características fisicoquímicas con potencial agrícola, son un residuo sólido que se desecha en rellenos sanitarios. Esta investigación tuvo como objetivos: 1) evaluar la factibilidad técnica de los lodos de PTA como sustituto de los sustratos comerciales en la producción de plántulas de lechuga; 2) evaluar la productividad comercial, en Arapiraca, región semiárida de Alagoas - Brasil. La investigación se realizó en dos etapas: 1) producción de plántulas en invernadero, en factorial arranjo 4 x 4 x 5, con cuatro niveles de lodos (0, 20, 40 y 60%), cuatro sustratos comerciales (Pindstrup®, Vida Verde®, Bioplant 434® y Bioplant 401®) y cinco cultivares (Veneranda, Camila, Elba, Vitória Verdinha y Diva); 2) las plántulas producidas, a nivel de campo, se utilizaron en un esquema factorial 3 x 3 x 5, en el que se excluyeron los tratamientos Pindstrup y la dosis de lodo al 60%, por no promover la emergencia. En el 1er experimento se observó que el índice de calidad de las plántulas presentó una media de 0,22, con una reducción lineal con la adición de lodos, con excepción de los cultivares Veneranda y Elba en el sustrato Bioplant 434. En el 2do experimento la productividad promedio fue de 5,4 Mg ha^{-1}, en la que la dosis del 20% de lodo promueve los valores más altos, siendo recomendada para la producción de lechuga en la semi- región árida de Alagoas.

Palabras clave: *Lactuca sativa* L. Índice de calidad de plântulas. Residuos sólidos urbanos. Lodos de PTA.

Introduction

In Brazil, 79.6 million megagrams (Mg) of urban solid waste (USW) were generated in 2020. The organic fraction is the main component (45.3%), followed by recyclables (39.2%) (MMA 2022). Based on the consumption and disposal patterns of the population, it is possible to project a 50% increase in USW generation in Brazil by 2050, compared to 2019 (ABRELPE 2020).

The main causes of the increase in the waste volume and disposal complexity are urban and industrial development. One of the problems faced today is the search for the reduction of waste generation, its reuse and proper disposal, according to current legislation that regulates activities with polluting potential (Moreira et al. 2017).

Water treatment, carried out in Water Treatment Plants (WTP), aiming at its potability for human consumption, generates large amounts of sludge (WTP sludge), which are discarded in landfills. This solid waste consists of clay, silt and fine sand, as well as organic material and minerals, often from the silting of rivers (Gonçalves et al. 2017). According to NBR 10004/2004, WTP sludge is classified as class IIA, non-inert, with biodegradability, combustibility or water solubility properties.

Due to its physicochemical characteristics and high annual production, WTP sludge has been used as input in the construction industry (Ruviaro et al. 2021) and agriculture, as a soil conditioner, when incorporated, improving its physicochemical characteristics (Franco et al. 2022), and in the production of substrates, with promising results (Rocha et al. 2015; Cunha et al. 2020; Brito et al. 2021). The substrate plays a fundamental role, as it must have adequate physicochemical characteristics that allow aeration, retention and availability of water and nutrients, in addition to being free of pathogens, allowing rapid seedling germination, emergence and support (Schafer and Lerner 2022). This initiative, in addition to reducing costs, transforms disposable materials into a value-added co-product (Teodoro and Pereira 2021), preserves natural resources, making it an ecologically correct activity, as it mitigates environmental damage, in addition to increasing the useful life of landfills.

Among cultivated vegetables, lettuce (*Lactuca sativa* L.) is the most produced leafy species in Brazil, due to its nutritional composition (low calorie, phenolic compounds, fiber, minerals, vitamins A and C), beneficial to human health (Trentini and Holo 2019). According to IBGE (2020), lettuce is grown in 108,382 establishments, with national production of 671,509 Mg, with the Southeastern (64.0%), Southern (16.2%) and Northeastern (10.4%) regions being the largest producers.

In the production of seedlings of lettuce, despite the existence of different trademarks of substrates on available in the consumer market, it is observed that some cultivars are adapted to specific substrates (Trentini and Holo 2019; Silva et al. 2020; Moraes et al. 2021). Therefore, it is necessary to identify the adequate amount of WTP sludge that, together with other inputs, produces quality seedlings. It is also necessary to identify cultivars with specific adaptation to the substrate that allows expressing the maximum genetic potential, according to yield.

This study aimed to: 1) evaluate the technical feasibility of WTP sludge as substitute for commercial substrates in the production of seedlings of lettuce cultivars; 2) to evaluate the quality of seedlings produced in the field, in Arapiraca, semiarid region of Alagoas - Brazil.

Material and Methods

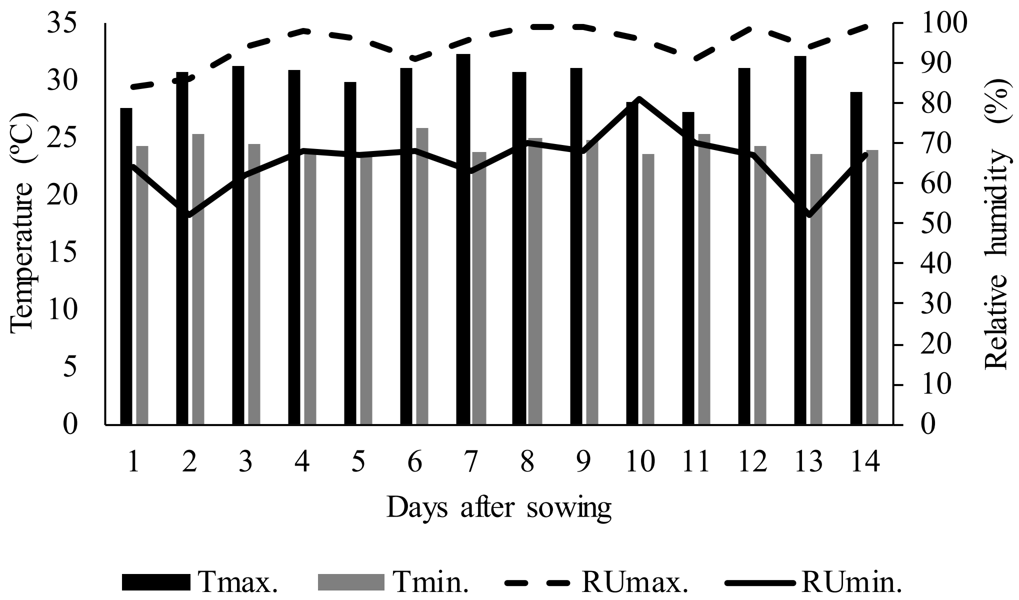
Site

The study was carried out in 2021 on commercial properties of Arapiraca/AL. The climate in the region is of 'BSh' type (hot semiarid), according to the Köppen classification (Climate-Date 2022). The study was carried out into two experimental stages: 1st) in greenhouse, aiming to evaluate seedling quality; 2) in the field, aiming to evaluate lettuce production components.

Greenhouse experiment

The study was carried out in a commercial nursery for commercial production of seedlings, chapel model, covered with low density polyethylene film, located in the district of Flexeiras, Arapiraca/AL, under the following geographical coordinates -9.799041 S and -36.604969 W, and 229 m a.s.l. (altitude), between February and March 2021. Using a digital thermo-hygrometer, model FEPRO-MUT60OS, variations in the temperature and relative humidity inside the greenhouse were monitored during 14 days after sowing (Figure 1).

Figure 1. Temperature (T) and relative humidity (RU) variation in the greenhouse.



From the 15th day, seedlings undergone the adaptation process, outside the greenhouse (full sun). The average, minimum and maximum temperatures, relative humidity and rainfall during this period (10 days) were 22.7 and 34.8°C, 67.7% and 45.8 mm, respectively.

The experiment was installed in a completely randomized design, 4 x 4 x 5 factorial arrangement, with four WTP sludge doses (0, 20, 40 and 60% to replace commercial substrates), four commercial substrates for vegetables (Pindstrup®, Vida Verde®, Bioplant 434® and Bioplant 401®) and five lettuce cultivars (Veneranda, Camila, Elba, 'Vitória Verdinha' and Diva), with four replicates. The plot consisted of 10 seedlings, considering the eight central ones as a useful area.

The technical information provided by the manufacturer was: Pindstrup, composed of *Sphagnum* peat, pH 5.9, limestone, macro and micronutrients, electrical conductivity 0.3 dS m^{-1}, water holding capacity of 400%; Vida Verde, composed of rice and pine husk, coconut fiber, pH 5.8, super simple, potassium nitrate, 14-16-18 (NPK) formulation, Yoorin Master 1 (17% P2O5, 18% Ca, 7.0% Mg, 0.1% B, 0.05% Cu, 0.3% Mn, 10% Si and 0.55% Zn), electrical conductivity 0.5 dS m^{-1}, water holding capacity of 150 %; Bioplant 434, *Sphagnum* peat, vermiculite, coconut fiber, rice husk, pH 6.5, limestone, 11-52-00 formulas, electrical conductivity 0.8 dS m^{-1}, 100% water holding capacity; Bioplant 401, varies only, in relation to Bioplant 434, regarding the 14-16-18 formula.

Lettuce cultivars were selected based on the acceptability of producers and consumers and had the following characteristics: Veneranda, loose leaf type, cut leaf edges and green color; Camilla, loose leaf type, large, light green leaves; Elba, loose leaf type, large pale green leaves; 'Vitória Verdinha', smooth type, without head formation, intense green color; Diva, iceberg type, compact head, intense green color.

The crude water of the São Francisco river is treated for human consumption in the water treatment plant, managed by company 'Agreste Saneamento S/A' that, in 2021, were generated 1,690 Mg of sludge in the Arapiraca/AL unit. In January 2021, WTP sludge was collected and, in the laboratory, after being dehydrated in an oven at 65ºC for 72h, was ground in a disc mill (Botini®). A WTP sludge sample was analyzed according to the NBR 10004:2004 standard, in which the concentrations of organic and inorganic toxic wastes and residues are absent or below maximum permitted levels, without risk to human health.

From a sample composed of WTP sludge, formed by 10 simple samples, chemical analyses were carried out, obtaining the following results: pH (water) of 6.1; P (Mehlich) of 1.0 mg dm^{-3}; K and Na (Mehlich), Ca, Mg and Al (1N KCl), H (calcium acetate pH 7.0) of 0.25, 0.25, 4.0, 2.9, 2.7 and 0.0 cmolc dm^{-3}, respectively. The total organic matter content was 13.1%. The Fe, Cu, Zn and Mn (Mehlich) contents were 376.0, 0.90, 1.80 and 302.1 mg dm^{-3}, respectively. The physical analysis showed that the sludge is classified as clayey loam, with the following constitution: coarse sand, fine sand, silt and clay of 214, 114, 364 and 328 g kg^{-1}, respectively.

Seedlings were produced in 200-cell trays with volume of 18 cm^3 each, manually placing one pelleted seed per cell. For all treatments, Carolina Soil® commercial substrate was used to cover seeds, as it has higher vermiculite content, greater moisture retention and allows the same emergence condition for all treatments. Irrigation was performed by microsprinkler using Gyronet LR Netafim system, flow rate of 70 L h^{-1}, with application of a 1.6 mm day^{-1} for approximately 40 minutes. Management practices are those adopted by company 'Semear Agropecuária S/A'.

At eight days after planting (DAP), the emergence percentage was evaluated and, at 25 DAP, from eight seedlings in the useful area of the plot, the average seedling height (SH; mm) was evaluated, measured from stem to apex, with the aid of a ruler; stem diameter (SD; mm), measured at the seedling stem with the aid of a caliper; shoot mass (SM; g), measured with the aid of digital analytical scale; root mass (RM; g), obtained after separating the root from the substrate, in running water; total mass (TM; g), obtained by the sum of the shoot and root mass. Data were used to calculate the seedling quality index (SQI), proposed by Dickson et al. (1960), according to Equation 1:

$$SQI = \frac{TM}{\frac{SH}{SD} + \frac{SM}{RM}} \qquad (1)$$

Field experiment

From seedlings produced in the 1st experiment, a survey was conducted on a family property located in the district of Batingas, Arapiraca/AL, geographical coordinates -9°79'90.4" S and -36°60'49.6"

W, 247 m a.s.l. (altitude), between March and April 2021. During the experimental period, average, minimum and maximum temperatures were 21.7 and 29.8ºC, respectively.

The experiment was carried out in a randomized block design, 3 x 3 x 5 factorial arrangement, corresponding to seedlings from three WTP sludge doses (0, 20 and 40% - WTP was not applied in the soil in this stage), three commercial substrates (Vida Verde®, Bioplant 434® and Bioplant 401®) and five lettuce cultivars, with three blocks (one block received shade in the late afternoon, the other two blocks, full sun, free from shade). The 60% sludge dose and the Pindstrup® commercial substrate were excluded, as they did not promote seedling emergence. The experimental plot consisted of nine plants, five of which were considered useful area (LÚCIO et al. 2016).

In the experimental area, 15 simple soil samples were collected at depth of 0 – 20 cm, and a composite sample (500g) was collected for chemical analyses, presenting the following results: pH (water), 7.3; P (Mehlich), 120 mg dm^{-3}; K and Na (Mehlich), Ca, Mg and Al (1N KCl), H (calcium acetate pH 7.0), 0.32, 0.87, 3.6, 3.0, 0.0, 0, 3 cmolc dm^{-3}, respectively. The total organic matter content was 1.37%. Fe, Cu, Zn and Mn contents (Mehlich) were 120.8, 0.45, 21.24 and 57.77 mg dm^{-3}, respectively. The fertilization used consisted of 80 kg ha^{-1} of tanned bovine manure + 60 kg ha^{-1} of tanned goat manure + 10 kg ha^{-1} of 16-00-20 NPK formula + 10 kg ha^{-1} of castor bean cake, using 30 g $plant^{-1}$ in the base fertilization.

Soil preparation, from turning and homogenization, was manually performed. Beds had width of 1.0 m, adopting spacing of 0.30 x 0.30 m between plants and between rows. At 15 DAP, manual weeding was performed. Due to the rainfall regularity during the experimental period, totaling 94 mm, irrigation was not performed.

At 35 DAP, at harvest time, the following biometric variables were evaluated: plant height, leaf width and length, all with the aid of a ruler (cm), and commercial yield (shoots without roots; Mg ha^{-1}), with the aid of a digital scale, in which damaged leaves were discarded.

Statistical analyses

Initially, the assumptions of the analysis of variance (ANOVA) were tested, applying the Tukey, Durbin-Watson, Bartlett and Shapiro-Wilk tests for non-additivity, residual independence, homoscedasticity and error normality, respectively for all variables. Then, ANOVA was performed, applying the Scott-Knott test ($p < 0.05$) in the grouping of means. The *ExpDes* package, version 1.2.2 (Ferreira et al. 2014) of the R software (R Core Team 2022) was used.

Results and Discussion

Greenhouse experiment

Seedling emergence

The inclusion of sludge replacing the Pindstrup substrate, as well as 60% sludge dose associated with any of the substrates, did not promote seedling emergence. Cunha et al. (2020) identified similar results with the species *Handroanthus impetiginosus* (Mart. ex DC) Mattos with the addition of 60% WTP sludge on substrate. It is possible that the sludge, which has 80.6% of fine particles and high organic matter content in its composition (13.1%), when associated with the substrate, which promotes high water retention, has reduced aeration, compromising germination and emergence. Silva et al. (2019) observed that the adequate water holding level of the substrate is essential for the metabolic processes triggered by germination to promote seedling establishment. Therefore, Pindstrup treatments and 60% WTP sludge dose were excluded from statistical analyses on field experiment.

Seedling Quality Index (SQI)

Significant triple interaction ($p < 0.01$) was observed for the seedling quality index, indicating that the initial growth of cultivars was influenced by the composition of the different substrates (Table 2). According to Silva et al. (2020), there is no Dickson index reference value for lettuce, which was developed for forestry species. Therefore, considering the general average (Table 2), it could be inferred, for this study, that treatments that reduced SQI below 0.22 do not produce quality seedlings. In general, 0 and 20% sludge doses exceeded this minimum limit (Table 3).

Table 2. Summary of ANOVA (F-Test) for seedling quality index (SQI).

Source of variation	Seedling quality index
Cultivar	23.7**
Substrate	34.6**
Sludge	202.1**
Cultivar x Substrate	10.2**
Substrate x Sludge	47.6**
Cultivar x Sludge	7.8**
Cultivar x Substrate x Sludge	12.4**
CV (%)	16.8
Mean	0.22

**: significant at 1% by the F test. CV: coefficient of variation.

Bioplant 434 substrate promoted SQI above the general average, mainly with 0% sludge (Table 3). With 40% sludge, Diva cultivar showed significant reduction of 55% in SQI. However, Veneranda and Elba cultivars, using the same substrate, did not show significant reduction ($p > 0.05$). The aluminum concentration in the sludge (2.7 cmolc dm^{-3}) is classified as high (> 1.0 cmolc dm^{-3}), according to Prezotti and Martins (2013), which may indicate the tolerance/susceptibility of cultivars to Al.

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Table 3. Sludge x Substrate x Cultivar interaction for seedling quality index (SQI).

Substrate	Cultivar	WTP sludge dose (%)			Mean
		0	20	40	
Vida Verde*	Veneranda	0.20 BaX	0.19 DbX	0.14 BbY	0.18
	Camila	0.38 AaX	0.35 BaX	0.13 BaY	0.29
	Elba	0.32 AaX	0.25 CaY	0.17 AaZ	0.25
	'Vitória Verdinha'	0.19 BbY	0.33 BaX	0.03 CbZ	0.18
	Diva	0.23 BbY	0.40 AaX	0.18 AaY	0.27
Bioplant 434*	Veneranda	0.24 CaX	0.17 CbY	0.24 AaX	0.22
	Camila	0.34 BaX	0.21 BbY	0.19 BaY	0.25
	Elba	0.23 CbX	0.17 CbX	0.19 BaX	0.20
	'Vitória Verdinha'	0.36 BaX	0.17 CbY	0.22 AaY	0.25
	Diva	0.43 AaX	0.28 AbY	0.15 CaZ	0.35
Bioplant 401*	Veneranda	0.25 AaX	0.25 BaX	0.06 AcY	0.19
	Camila	0.16 BbY	0.21 BbX	0.05 AbZ	0.14
	Elba	0.18 BbY	0.31 AaX	0.10 AbZ	0.20
	'Vitória Verdinha'	0.20 BbY	0.31 AaX	0.04 AbZ	0.18
	Diva	0.28 AbX	0.32 AbX	0.09 AbY	0.23
Mean		0.28	0.26	0.13	

Means with the same letter belong to the same grouping by the Scott-Knott test ($p > 0.05$): capital letters (A, B), in the column, compare cultivars in each substrate and in each sludge dose; lowercase letters (a, b), in the column, compare the performance of each cultivar 'between' substrates in each sludge dose; X, Y and Z, in the row, promote the grouping of cultivars between sludge doses in each substrate.

Among cultivars, when using Vida Verde substrate at 0% sludge dose, Camila and Elba cultivars presented the highest SQI ($p < 0.05$); in Bioplant 434 substrate, the Diva cultivar stood out; in Bioplant 401, Veneranda and Diva cultivars showed seedlings with higher SQI (Table 3). With 20% sludge dose, the Diva cultivar performed the highest SQI in Vida Verde and Bioplant 434 substrates; in Bioplant 401, there was no significant difference among Elba, 'Vitória Verdinha' and Diva cultivars. At 40% sludge dose + Bioplant 434, Veneranda and 'Vitória Verdinha' cultivars stood out. This information expresses the significant interaction and adaptability of cultivars to specific environments (substrate + sludge), as observed by Moraes et al. (2021), in which the Great Lake cultivar presented the best performance in the S8 substrate (33% sugarcane bagasse + 33% pig waste + 33% bovine waste), and the Simpson cultivar in the S6 substrate (33% Plantmax® + 33% sugarcane bagasse + 33% pig waste).

In general, the sludge increment promoted linear reduction in SQI, except for the Veneranda cultivar, with average of 0.24, cultivated in the Bioplant 434 substrate (Table 3). These results are important in the seedling production planning phase, in which the producer will be able to choose the best substrate composition, using the seedling quality and lower cost binomial.

Field assessments

The characteristics related to plant size such as height, length and width, provide important information for marketing planning, considering that the main way of packaging plants for transport occurs by plastic or wooden boxes (Resende et al. 2017). For characteristics plant height, leaf length and yield, triple interaction ($p < 0.05$) was observed, indicating that the composition of substrates influenced the perform of cultivars in the field. There was no interaction for leaf width, and significant differences were observed between sludge doses and cultivars, in isolation (Table 4).

Table 4. Summary of ANOVA (F Test) for the analyzed variables.

Source of variation	Height (cm)	Leaves		Yield (Mg ha^{-1})
		Length (cm)	Width (cm)	
Sludge	25.4**	14.0**	3.3*	21.3**
Substrate	4.5**	16.6**	1.0 ns	2.3 ns
Cultivar	6.5**	18.7**	18.9**	6.7**
Sludge x Substrate	2.5*	3.1**	1.1 ns	0.9 ns
Sludge x Cultivar	0.7 ns	1.0 ns	0.6 ns	1.6 ns
Substrate x Cultivar	0.8 ns	0.7 ns	0.5 ns	1.3 ns
Sludge x Substrate x Cultivar	2.1**	1.8*	0.8 ns	1.9**
CV (%)	8.4	8.0	11.1	20.6
Mean	17.9	16.3	13.1b	5.4

**, *, ns: significant at 1%, 5% and non-significant at 5% probability, respectively by the F test. CV: coefficient of variation.

The coefficient of variation ranged from 8.0% for leaf length, indicating great experimental precision, to 20.6% for yield, indicating that there was variation between plants, probably due to rainfall intensity. When considering the green mass of plants, there is greater variability within the experimental unit, due to the variation in the water content in each plant, directly influencing the unit weight and yield (LÚCIO et al. 2011).

Plant height

In general, the linear reduction observed in SQI, with the increase of sludge content in substrates (Table 4), was exceeded in Veneranda, Camila, Elba (Vida Verde) and 'Vitória Verdinha' cultivars (Bioplant 401) (Table 5). The 20% sludge dose reduced plant height only of the Diva cultivar using the Bioplant 401 substrate. All cultivars can be produced with any substrate at 40% sludge dose, except for Elba cultivar, which presented the smallest height (16 cm) using the Bioplant 434 substrate. This cultivar had average value of 24.4 cm at 35 DAP, cultivated in the conventional system in Mossoró/RN, semiarid region (Souza et al. 2018), evidencing the genotype variation as a function of the production environment.

Table 5. Triple Substrate x Cultivar x Sludge dose interaction for plant height (cm).

Substrate	Cultivar	WTP sludge dose			Mean
		0	20	40	
Vida Verde*	Veneranda	18.2 AaX	18.5 BaX	15.3 BaY	17.3
	Camila	16.8 AaX	16.7 CbX	15.6 BaX	16.4
	Elba	17.7 AbX	19.3 BbX	18.8 AaX	18.6
	'Vitória Verdinha'	18.3 AaY	21.2 AaX	16.3 BaY	18.6
	Diva	19.2 AaX	19.3 BaX	16.3 BaY	18.3
Bioplant 434*	Veneranda	17.5 BaX	18.0 BaX	18.0 AaX	17.8
	Camila	18.3 BaX	20.3 AaX	16.0 BaY	18.2
	Elba	21.3 AaX	21.5 AaX	16.0 BbY	19.6
	'Vitória Verdinha'	19.3 BaX	19.0 BbX	16.8 BaY	18.4
	Diva	18.0 BaY	20.3 AaX	16.3 BaY	18.2
Bioplant 401*	Veneranda	18.0 AaX	16.8 AaX	167 BaX	17.2
	Camila	16.3 BaX	17.7 AbX	15.8 BaX	16.6
	Elba	19.0 AbX	18.3 AbX	190 AaX	18.8
	'Vitória Verdinha'	17.5 AaX	18.5 AbX	16.8 BaX	17.6
	Diva	19.0 AaX	17.2 AbY	160 BaY	17.4
Mean		18.3	18.8	16.6	

Means with the same letter belong to the same grouping by the Scott-Knott test ($p > 0.05$): capital letters (A, B), in the column, compare cultivars in each substrate and each sludge dose; lowercase letters (a, b), in the column, compare the performance of each cultivar 'between' substrates in each sludge dose; X, Y, in the row, promote the clustering of cultivars between sludge doses in each substrate.

Significant Cultivate x Substrate interaction ($p < 0.05$) for plant height was also observed by Medeiros et al. (2008), in which substrate with biofertilizer rich in organic matter provided the highest shoot height for lettuce Grand Rapids cultivar compared to commercial substrates.

Leaf length

Leaf length is directly linked to leaf area and photosynthetic activity, in addition to being the main requirement for lettuce marketing. With the addition of sludge to the substrate, Elba (Vida Verde), 'Vitória Verdinha' (Vida Verde and Bioplant 434) cultivars and all cultivars grown in the Bioplant 401 substrate did not show significant reduction (Table 6). It was observed that Bioplant 401 substrate + 40% sludge promoted the lowest SQI, but cultivars reestablished growth in the field, showing no statistical difference when compared to 0% sludge dose.

Table 6. Triple Substrate x Cultivar x Sludge dose interaction for leaf length (cm).

Substrate	Cultivar	WTP sludge dose			Mean
		0	20	40	
Vida Verde*	Veneranda	15.5 BaX	15.8 AaX	13.0 BbY	14.8
	Camila	15.8 BaX	13.3 BbY	12.7 BbY	13.0
	Elba	16.0 BaX	16.7 AaX	17.2 AaX	16.6
	Vitória Verdinha	15.5 BaX	14.8 BaX	14.2 BaX	14.8
	Diva	18.5 AaX	17.0 AaY	15.0 BbY	16.8
Bioplant 434*	Veneranda	17.3 AaX	15.0 BaY	15.7 AaY	16.0
	Camila	15.0 AaY	17.3 AaX	14.5 AaY	15.6
	Elba	17.7 AaX	18.2 AaX	15.3 AaY	17.1
	Vitória Verdinha	16.7 AaX	17.2 AaX	15.2 AaX	16.4
	Diva	17.0 AaY	19.3 AaX	15.3 AbZ	17.2
Bioplant 401*	Veneranda	16.2 BaX	15.8 BaX	16.0 AaX	16.0
	Camila	14.5 BaX	16.8 BaX	15.5 AaX	15.6
	Elba	17.8 AaX	18.8 AaX	17.8 AaX	18.1
	Vitória Verdinha	16.3 BaX	16.8 BaX	16.2 AaX	16.4
	Diva	19.0 AaX	18.8 AaX	18.0 AaX	18.6
Mean		16.6	16.8	15.4	

Means with the same letter belong to the same grouping by the Scott-Knott test ($p > 0.05$): capital letters (A, B), in the column compare cultivars in each substrate and in each sludge dose; lowercase letters (a, b), in the column, compare the performance of each cultivar 'between' substrates in each sludge dose; X, Y, in the row, promote the clustering of cultivars between sludge doses in each substrate.

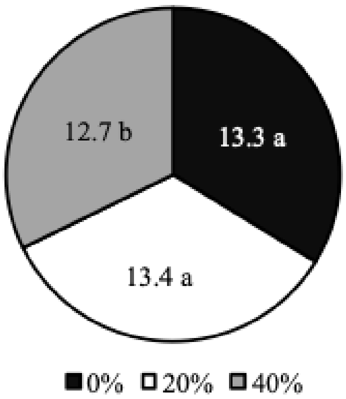
The Diva cultivar, which showed the highest SQI (0.43; Bioplant 434 + 0% sludge dose; Table 3) had the largest leaf length (Table 6), in the field, with 20% sludge dose (19.3 cm). During transplanting, damage to roots and the low soil/root interface interaction made water absorption difficult. Therefore, it is possible that seedlings with greater shoot mass also had establishment difficulties due to dehydration as a result of high transpiration and low water absorption.

Although there is reduction in SQI (Table 3), seedlings of Elba and 'Vitória Verdinha' (Vida Verde and Bioplant 434) and Veneranda cultivars (Bioplant 434) grew and resumed development, with no statistical difference between 0 and 40% sludge doses (Table 6). When seedlings were produced using Bioplant 401 substrate + 40% sludge, they presented the lowest SQI. However, after transplanting, no significant differences ($p > 0.05$) were observed between sludge doses for each cultivar and substrate, indicating the overcoming of cultivars at field level.

Leaf width

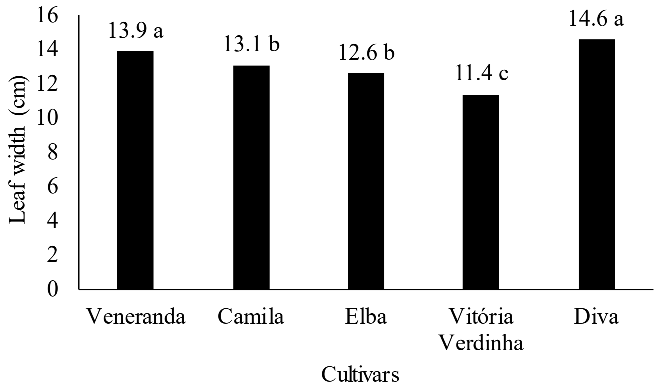
Significant difference ($p < 0.05$) was observed between sludge doses, in which 40% reduced leaf width in the evaluated cultivars (Figure 3). The clay content in the clod may have hindered root expansion, reflecting on water stress and leaf width reduction, aiming to minimize water loss by transpiration.

Figure 3. Effect of WTP sludge doses on leaf width. Means followed by the same letter belong to the same grouping by the Scott-Knott test ($p > 0.05$).



Veneranda and Diva cultivars had the largest leaf widths (Figure 4), even with the reduction of SQI with the increase of sludge doses in the different substrates (Table 3), reinforcing the growth resumption at field level.

Figure 4. Leaf width of five lettuce cultivars. Means followed by the same letter belong to the same grouping by the Scott-Knott test ($p > 0.05$).



Yield

In general, the addition of up to 20% sludge to the substrate did not reduce the yield of cultivars, with the exception of Diva cultivar, in which there was linear reduction (Table 7). Similar yield (6.6 Mg ha-1) for the Veneranda cultivar was observed by Vieira et al. (2020), in Arapiraca, with irrigation depth of 143.7% of ETc + cattle manure. Elba cultivar, evaluated in Mossoró/RN, reached 23.2 Mg ha-1 (Souza et al. 2018), indicating the influence of soil and climate conditions on the genetic potential of cultivars.

Table 7. Triple Substrate x Cultivar x Sludge dose interaction for yield (Mg ha^{-1}).

Substrate	Cultivar	WTP sludge dose			Mean
		0	20	40	
Vida Verde*	Veneranda	5.2 BaY	6.3 AaX	3.5 AbZ	5.0
	Camila	4.5 BaX	5.2 AaX	3.7 AaY	4.5
	Elba	4.3 BbY	7.3 AaX	4.2 AaY	5.3
	'Vitória Verdinha'	5.2 BaY	7.7 AaX	5.2 AaY	6.0
	Diva	8.5 AaX	6.5 AaY	5.4 AaZ	6.8
Bioplant 434*	Veneranda	6.6 AaX	5.0 AaX	5.2 AaX	5.6
	Camila	3.2 BaY	5.7 AaX	3.9 AaY	4.3
	Elba	6.5 AaX	5.5 AaX	4.3 AaY	5.4
	Vitória Verdinha	5.8 AaX	6.0 AaX	3.9 AbY	5.2
	Diva	4.6 BbY	6.2 AaX	4.6 AaY	5.1
Bioplant 401*	Veneranda	5.9 BaX	5.8 AaX	5.4 AaX	5.7
	Camila	4.9 BaX	5.4 AaX	4.0 AaX	4.8
	Elba	5.6 BaX	6.0 AaX	5.1 AaX	5.6
	Vitória Verdinha	5.3 BaY	7.0 AaX	5.9 AaY	6.1
	Diva	7.6 AaX	6.5 AaX	4.3 AaY	6.1
Mean		5.6	6.1	4.6	

Means with the same letter belong to the same grouping by the Scott-Knott test ($p > 0.05$): capital letters (A, B), in the column, compare cultivars in each substrate and in each sludge dose; lowercase letters (a, b), in the column, compare the performance of each cultivar 'between' substrates in each sludge dose; X, Y and Z, in the row, promote the grouping of cultivars between sludge doses in each substrate.

Veneranda, Elba and 'Vitória Verdinha' cultivars, when produced in the Vida Verde substrate + 20% sludge, had increased yield ($p < 0.05$). This substrate has in its composition the commercial product Yoorin Master 1, which contains low solubility phosphate and micronutrients. Therefore, it is possible that cultivars have benefited from this additional supply of nutrients, with impact on ATP production and other metabolic reactions (Taiz et al. 2017).

Among cultivars, Diva showed higher yield ($p < 0.05$) when cultivated in Vida Verde (8.5 Mg ha^{-1}) and Bioplant 401 substrates + 0% sludge (7.6 Mg ha^{-1}). Veneranda, Elba and 'Vitória Verdinha' cultivars showed superior yield when cultivated in Bioplant 434 substrate + 0% sludge. On the other hand, the Diva cultivar, which presented the highest SQI (0.43; Table 3), did not reflect on yield. In this aspect, in absolute terms, of the 21 combinations that presented SQI ≥ 0.22 (Table 3), 15 presented yield equal to or greater than the general average, mainly when cultivated in Bioplant 401 substrate + 20% sludge. The 40% sludge dose, regardless of substrate, reduced SQI and yield, not being indicated for lettuce production.

At 35 DAT, it was observed that the 'Vitória Verdinha' cultivar presented early bolting, showing precocity in relation to the other cultivars, which is an undesirable characteristic, as it makes the product unsuitable for marketing (Cardoso et al. 2018). High temperatures and high light intensity, often observed in semiarid regions, promote photoinhibition and photorespiration in species with C_3 photosynthetic metabolism (Taiz et al. 2017) such as lettuce (Zhou et al. 2020), affecting yield (Ghorbanzadeh et al. 2021), which may explain the lower yield when compared to studies conducted in other agroecosystems.

In general, seedling traits of lettuce cultivars related to its quality were influenced by WTP sludge doses, highlighting the inclusion of 20% in replacement of Vida Verde® and Bioplant 401® substrates. However, when the seedlings were cultivated in the production field, 40% sludge promoted a reduction in commercial yield, as a result of the low SQI, with the exception of cultivars Veneranda, Camila and Elba, which returned growth and promoted yield similar the doses 0 and 20%, when Bioplant 401(R) substrate was used. This information evidenced the existence of genotype x environment interaction, with cultivars adapted to the composition of specific substrates, allowing the producer to select the substrate that promotes greater expression of the genetic potential of the cultivar.

Conclusions

The inclusion of WTP sludge to Pindstrup® commercial substrate is not recommended for the production of lettuce seedlings of evaluated cultivars. The 40% WTP sludge dose reduces the seedling quality index and commercial yield. The inclusion of up to 20% sludge for any substrate and cultivar is recommended, indicating technical feasibility, with potential cost reduction in seedling production, in addition to providing environmentally appropriate destination for urban solid waste.

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