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Salt Leaching and Growth of Physic Nut (*Jatropha curcas* L.) on Oxisol under Swine Wastewater Fertigation in Southern Brazil

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Authors' contributions

This work was carried out in collaboration between all authors. The author TPC conducted the entire study, wrote the manuscript and ran the statistical analyses. The authors SCS and MHFT supervised the research and revised the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

Aims: The objective of this study was to evaluate the effect of a 370 m^3 ha^{-1} application of swine wastewater on the vegetative growth of the physic nut (*Jatropha curcas* L.) and the leaching of salts from an oxisol in southern Brazil.
Study Design: The experiment had a randomized design with three treatments (T1 - rain-fed, T2 - irrigated and T3 - fertigated with swine wastewater) and six replications.
Place and Duration of Study: Western Paraná State University, between October 2008 and December 2009.
Methodology: The following parameters were evaluated: canopy height, leaf area, basal diameter, number of side branches, the height of the 1st branch and the number of inflorescences and fruits per plant. The electrical conductivity and pH of the percolating water were evaluated following five rainfall events, using nine lysimeters installed prior to the planting of the experimental plots.

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Results: Significant differences among treatments were observed in plant height (P = .045), and the number of inflorescences (P = .00) and fruits (P = .02). The numbers of inflorescences (5.21) and fruits (9.17) were highest in the SW-fertigated treatment (T3). In relation the concentration of salts, electrical conductivity values were higher for SW-fertigated (0.110-0.154 dS m^{-1}) than either rain-fed (0.087-0.115 dS m^{-1}) or irrigated (0.057-0.075 dS m^{-1}) in all samples.
Conclusion: The application of SW resulted in a significant increase in some parameters of *J. curcas* productivity, and may thus be encouraged as an agricultural reuse practice. However, further studies are required to evaluate the potential environmental pollution caused by this practice.

Keywords: Electrical conductivity; energy crop; non-point pollution; wastewater reuse.

1. INTRODUCTION

In Brazil, a number of plants are used for the production of biofuels, including soybean (*Glycine max* L.), castor bean (*Ricinus communis* L.), oil palm (*Elaeis guineensis* Jacq.), sunflower (*Helianthus annuus* L.), babassu palm (*Attalea speciosa* Mart.), peanut (*Arachis hypogaea* L.), and turnip (*Raphanus sativus* L.) [1]. In recent years, the physic nut, *Jatropha curcas* L., has also become increasingly important for the production of biodiesel [2].

Jatropha curcas is a perennial shrub or small tree of the family Euphorbiaceae that has high yields, and is one of the most promising species for the production of oilseed [3], with an oil content of between 20% and 40% [4]. The yield of *J. curcas* seed may vary considerably (0.1–12 t ha^{-1}), however, depending on growing conditions, although productivity can be expanded by up to 63% with increasing irrigation (from 735 mm to 1646 mm) [5]. While *J. curcas* thus appears to have potential as a crop for biofuel production, further agronomic research is needed to develop the most adequate cultivation practices, in order to maximise seed production.

The genus *Jatropha* is thought to have originated in Central America, and most species are found in humid tropical regions [6]. Productivity in areas with humid climates is approximately double that of arid or semiarid regions, although *J. curcas* is well adapted to arid conditions, which facilitates its cultivation on degraded soils [7]. While *J. curcas* is well-adapted to different types of soil and climate, there is a lack of data on its performance in colder regions, such as southern Brazil, where the climate is humid subtropical. The physic nut is also known to be tolerant of irrigation water with an electrical conductivity of 12 dS m^{-1} [8].

To overcome water shortfalls in crop production, one technically and the economically-feasible option is irrigation with reclaimed water or wastewater [4], a process known as fertigation. The application of swine wastewater (SW) to cropland can provide an efficient way of nutrient cycling, allowing farmers to dispose of the waste produced by intensive animal production, while also minimising the need for conventional fertilisers. One pig produces, on average, 4.17 m^3 of slurry per year, depending on the productive phase [9], and, in general, this slurry is applied to the soil as an agricultural reuse practice that avoids the pollution of bodies of water. In the case of biofuel crops, this reuse of wastewater can help increase seed and oil yields, while simultaneously preventing environmental pollution [2,10]. A recent study [3] also showed that SW favours a reduction of the acidity of the jatropha oil in direct proportion to the amount of effluent applied (from 0 to 200 m^3 ha^{-1}). The authors of this study suggested that this was due to a reduction in linoleic acids, which contributed to the stability and oxidation of the oil and, consequently, a reduction in its free fatty acids.

Despite these potential benefits, the application of wastewater must be monitored carefully, given its potential for the generation of non-point pollution. A number of studies [10,11,12] have shown that fertigation using wastewater may contribute to an increase in the concentrations of dissolved phosphorus, nitrogen (in particular, N-NH_4^+ and N-NO_3^-), potassium, calcium, sodium, manganese, copper, and zinc in local bodies of water. The application of wastewater may also accelerate soil salinisation, as measured by electrical conductivity (EC). Given these considerations, the present study investigated the effects of the application of swine wastewater on the vegetative growth parameters of *J. curcas*, and the electrical conductivity of the leachate in experimental plots in southern Brazil.

2. MATERIALS AND METHODS

2.1 Experimental Design

The present study was conducted in an experimental area in Paraná state, southern Brazil (24°53' S, 53°23' W), at an altitude of 682 m asl. The soil is classified as Rhodic Hapludox or Oxisol [13], and the local climate is mesothermic humid subtropical, Cfa in the Köppen classification system, characterised by hot, humid summers and mild to cool winters. Mean annual rainfall is 1800-2000 mm, mean temperature is 20°C, and relative humidity is 75–80% [14].

The experimental plot (0.162 ha) had a slope of 8–9% and was divided into three subplots of 540 m^2, for each of the three experimental treatments: rain-fed (T1), irrigated (T2), and fertigated with SW (T3). The seedlings were planted in holes in a 4 m x 3 m grid in October 2008. The crop was monitored between May and December 2009. No fertiliser was applied to either the soil or the plants prior to the experiment. Each treatment had 6 replicate plots of 8 m x 9 m, each containing six plants.

Two 15 m^3 reservoirs, one containing water, and the other, SW, were used for irrigation/fertigation. In both cases, the liquid was applied to the experimental plots using a sprinkler irrigation system. This system was installed in a 6 m x 12 m grid, and consisted of a 6 HP moto pump, 5.08 cm tubing and 16 Kadox (model IR-1612F) plastic, one-nuzzle full circle sprinklers with a flow rate of approximately 1200 L h^{-1}.

Three glass-fibre drainage lysimeters (Fig. 1) were installed in each subplot (treatment). These lysimeters were installed according to Aboukhaled *et al.* (1986) and had a capacity of 1 m^3, depth of 1.10 m, the diameter of 1.43 m, and an area of 1.60 m^2. To install each lysimeter, the soil was excavated from the site and PVC tubes (15 m x 25 mm) were installed in the bottom of the hole. A tap was connected to the end of the PVC tube to control the flow of percolated material, which was measured after each rain event. Inside the lysimeter, a mesh was placed over the drainage hole to avoid clogging, and a 0.1 m-deep layer of crushed stone was added to better drain the leachate. A polyester mantle was placed over the stones to separate them from the soil layers, which were replaced in their original order. Each soil layer was lightly compacted, and all the lysimeters were irrigated daily to ensure saturation and settle the soil. Each lysimeter was connected by a pipe to a collecting tank (see Fig. 1).

2.2 Characterisation of the Soil and Effluents

Composite soil samples were obtained prior to the irrigation period by collecting four subsamples (0–20 cm) randomly and mixing them. These samples were analysed using standard techniques [15,16,17] for pH, electrical conductivity (EC), potential acidity (H+Al), cation exchange capacity (CEC), the sum of the bases, potential acidity (H^++Al^{+3}), C, K, Ca, Mg, Na, Cu, Fe, Zn, B, and Mn. The results are shown in Table 1.

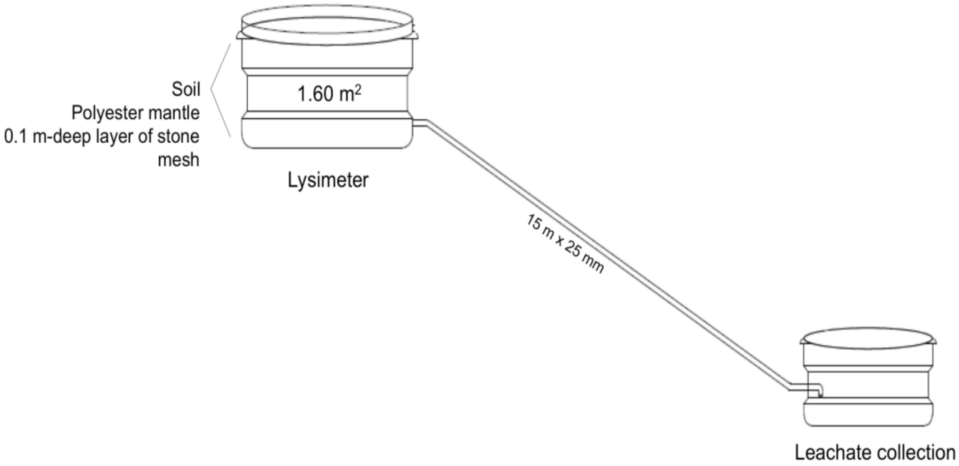

Fig. 1. Diagram of one of the glass-fibre drainage lysimeters installed in the experimental plots

The SW was obtained from the effluent stabilisation pond of the biodigester output of a pig farm. The water and SW were applied at a total dosage of 370 m^3 ha^{-1} throughout the study period, being divided into five biweekly irrigation events, on 22 June, 7 July, 30 July, 14 August and 28 August 2009. A minor malodour was perceived in the area fertigated with swine wastewater. The physical-chemical composition of the water and swine wastewater were analysed following [18], and the results are shown in Table 1.

2.3 Vegetative Growth Analysis

In December 2009, 14 months after planting, four *J. curcas* plants were taken randomly from each subplot for the measurement of vegetative growth parameters. The following measurements were taken in the field: plant height, basal diameter (5 cm above ground level), the number of side branches, the height of the first branch, and the number of inflorescences and fruits (including dry or black fruits). Ten leaves were picked at random from each of the plants, from the topmost branch and rinsed, and their area was measured using an LI-3100C area meter (LI-CORInc., Lincoln, NE, USA).

2.4 Percolate Leachate Analysis

Samples of leachate were collected after each of the five irrigation and rainfall events (13 July, 25 July, 30 July, 25 August and 14 September 2009). A composite subsample was taken to determine pH, using a pH-meter (Tecnal Brazil, TEC 3MP) and electrical conductivity (dS m^{-1}), using an EC-meter (Tecnal Brazil, TEC 4MP). The total volume (L) of percolate was also quantified. Meteorological data (temperature and rainfall) were provided by the Paraná State Meteorological System (Simepar, Brazil).

2.5 Data Analysis

The analysis of vegetative growth parameters was based on the six replicates obtained for each of the three treatments. In the case of the leachate data, three replicates were taken from each treatment. The data were analysed using an Analysis of Variance (ANOVA), with Tukey's *post-hoc* test. All analyses were run in the Sisvar software [19], and a 5% level of significance was considered in all cases. The vegetative growth data were also integrated into a Principal Components Analysis (PCA) run using a Pearson correlation matrix of the variables,

Table 1. Initial parameters of the soil of the experimental plots that received rainwater only (T1), irrigation (T2) or swine wastewater (SW) fertigation (T3)

	Soil Parameters								
	pH	**EC**	**P**	**S**	**CEC**	**Sum of base**	**H$^+$+Al^{+3}**	**Al^{+3}**	**C**
	$CaCl_2$	**dSm^{-1}**	**mg dm^{-3}**		**-------------- mmolc dm^{-3} ----------**				**g dm^{-3}**
T1	6.43	0.04	5,3	6.4	98	62.4	35.9	0.4	16.17
T2	6.07	0.03	6.7	17.1	106	59.6	46.2	0.4	17.83
T3	5.96	0.05	2.9	7.9	109	61.2	48.2	0.4	17.93
	K	**Ca**	**Mg**	**Na**	**Cu**	**Fe**	**Zn**	**B**	**Mn**
	----------- mmolc dm^{-3} ----------				**---------------------- mg dm^{-3} -------------------**				
T1	1.7	46	14	0.5	7.2	39	9.6	0.30	63
T2	1.2	44	14	0.6	6.9	21	6.5	0.30	42
T3	2.1	45	14	0.7	6.9	53	33.0	0.29	61

	Effluent and water parameters						
	pH	**EC**	**Carbon oxygen demand**	**Total N**	**N-NO_3^-**	**P**	**Total Solids**
	$CaCl_2$	**dS m^{-1}**	**--- g L^{-1} ---**	**------------------ mg L^{-1} ----------------------**			
SW	7.95	4.43	1.16	10.21	32.10	1.19	2.77
Water	6.77	0.10	-	1.9×10^{-3}	0.67×10^{-4}	-	-
	Cu	**Zn**	**K**	**Mg**	**Mn**	**Na**	**Ca**
	--------------------------------------- mg L^{-1} ---						
SW	0.53	2.62	413.05	13.92	1.49	11.73	57.74
Water	0.34	0.11	3.64	3.00	0.05	6.61	34.53

T = Treatment (T1 = rain-fed; T2 = irrigated; T3 = SW-fertigated; SW = Swine Wastewater; EC = Electrical Conductivity; H+Al = potential acidity; CEC = Cation Exchange Capacity with a “broken-stick” (eigenvalues [λ] higher than those expected by chance) selection criterion being applied for the definition of the axes. Only Pearson correlation coefficients higher than 0.70 were considered significant.

3. RESULTS AND DISCUSSION

Significant differences were recorded among treatments in plant height, and the number of inflorescences and fruits (Table 2), although the variation in leaf area, basal diameter, the number of side branches, and the height of the first branch did not vary significantly among treatments. Overall, no statistically significant variation was found between rain-fed and irrigated in any of the parameters measured. The plants were tallest in SW-fertigated, followed by irrigated and rain-fed.

In the PCA of the vegetative parameters (Fig. 2), two axes (PC1 and PC2) were selected by the “broken-stick" criterion and explained 67.47% of the variation in the data. The first axis (PC1) has the variables plant height, basal diameter, and the number of inflorescences and fruits in the negative quadrant, while the second axis (PC2) has leaf area and height of the first branch in the positive quadrant.

In a study of 19 month-old *J. curcas* plants irrigated with recycled urban wastewater and desalinated brackish groundwater [7], plant height varied between 0.25 m and 2.25 m. Over a 35-month period, *J. curcas* plants irrigated with recycled urban wastewater by surface drip reached 2.38 m on sandy soil and 2.04 m on clay. In India [2], in a subtropical climate similar to that of the present study site (mean annual rainfall of 800–900 mm), a minimum annual increase in height of 39.2 cm was recorded in rain-fed *J. curcas* plants. In a comparative study of irrigation sources [4], no significant variation in height, basal diameter or crown diameter was found between plants irrigated with water reclaimed from an aeration sewage treatment followed by sand filtration and lagoon storage and those irrigated with water obtained from an aquifer, given that the reclaimed water contained no additional nutrients. This contrasts with the present study (Table 1), which indicates that the nutrients provided by the SW had a positive effect on the production of biomass in comparison with the water irrigation.

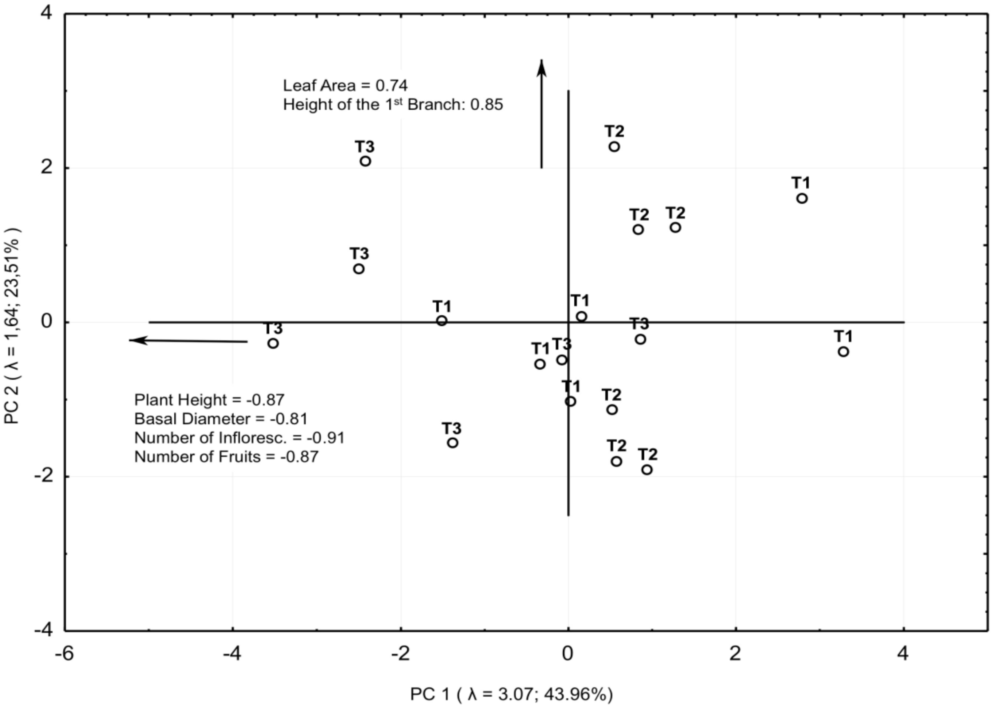

Fig. 2. Principal Components Analysis (CP1 vs. CP2) of the vegetative growth parameters of *J. curcas* in rain-fed (T1), irrigated (T2), and SW-fertigated (T3) treatments

Table 2. Vegetative growth parameters recorded in the *J. curcas* plants collected from the rain-fed (T1), irrigated (T2), and SW-fertigated (T3) treatment plots. All values are means ± standard error

T	Plant height (m)	Leaf area (cm^2)	Basal diameter (m)	Number of Branches	The height of first Branch (m)	Infloresc.	Fruits
T1	1.97^{b}±0.39	125.38 ±13.04	0.070±1.03	7.58±2.02	0.029±6.19	1.79^{b} ±1.72	2.67^{ab}±3.72
T2	2.12^{ab}±0.08	111.52±34.35	0,073±0.51	7.39±1.13	0.032±8.04	0.36^{b} ±0.30	0.83^{b}±0.85
T3	2.40^{a}±0.16	123.93±17.10	0,077±0.89	8.01±1.80	0.027±4.32	5.21^{a} ±2.62	9.17^{a}±6.80
CV	12.53	21.31	12.59	24.25	38.73	27.66	54.47
p-value	.045*	.60	.47	.84	.78	.00*	.02*

T = Treatment; CV = Coefficient of Variation; 1st Branch = height of the first branch; Infloresc. = number of inflorescences per plant; Fruits = number of fruits per plant. The means followed by different lower case letters in the same column are significantly different (p <0.05) according to Tukey's post-hoc test

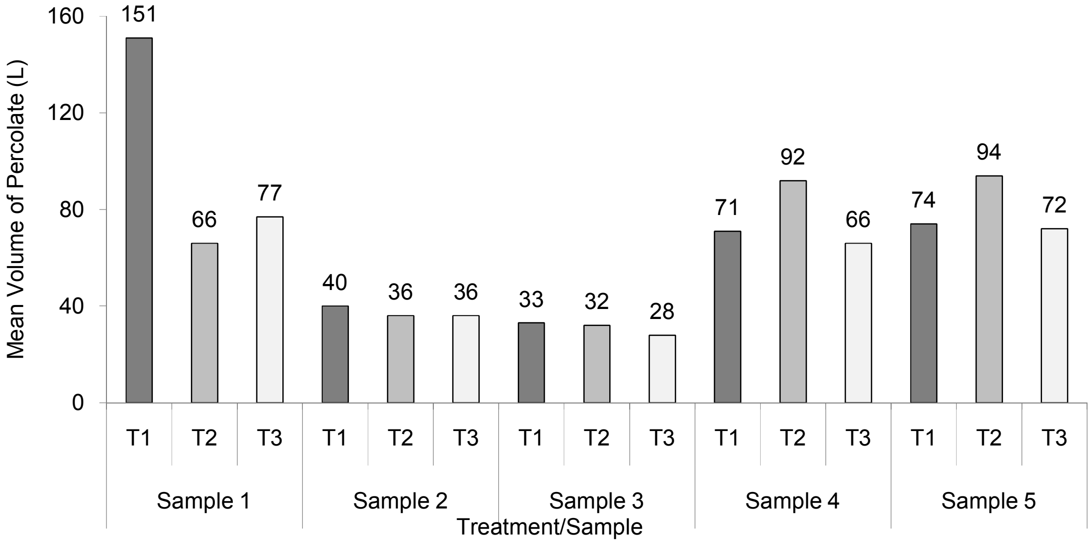

Fig. 3. Mean volume (L) of percolating recorded after each of the five rainfall events (samples 1-5) from the rain-fed (T1), irrigated (T2) and SW-fertigated (T3) treatments

Table 3. Percolate EC (dS m^{-1}) for the rain-fed (T1), irrigated (T2) and SW-fertigated (T3) treatments. Values are means ± standard error

	1st sample	2nd sample	3rd sample	4th sample	5th sample
T1	$0.087^{a}\pm0.008$	$0.115^{ab}\pm0.012$	$0.103^{a}\pm0.009$	$0.098^{a}\pm0.005$	$0.096^{b}\pm0.003$
T2	$0.057^{b}\pm0.007$	$0.075^{b}\pm0.009$	$0.064^{b}\pm0.006$	$0.061^{a}\pm0.012$	$0.060^{b}\pm0.011$
T3	$0.110^{a}\pm0.002$	$0.139^{a}\pm0.007$	$0.119^{a}\pm0.008$	$0.116^{a}\pm0.030$	$0.154^{a}\pm0.015$
CV	11.16	16.8	12.67	37.14	26.45
p	.00*	.02*	.00*	.20	.01*

T = Treatment (1, 2, 3); CV = Coefficient of Variation; EC = Electrical Conductivity; The means followed by different lower case letters in the same column are significantly different (p <0.05) according to Tukey's post-hoc test

While significantly larger numbers of inflorescences and fruits were produced by the physic nut plants in the SW-fertigated treatment (T3) in comparison with rain-fed (T1) and irrigated (T2) treatments, the overall means were relatively low, and some plants in the rain-fed and irrigated treatments presented no seed development whatsoever. In a previous study [2], the number of branches per plant ranged from 2.25 (rain-fed) to 13.20 when the plants were pruned at 30 cm, although the mean value for all the techniques evaluated was approximately 7.56, which was very similar to the value (7.66) recorded in the present study. The distribution of the SW-fertigated plants on PCA axis 1 (Fig. 2) also indicated that fertigation with SW resulted in the greater vegetative growth of *J. curcas.* Overall, then, the present study indicates that the fertigation of *J. curcas* with SW may help reduce the demand for local water resources while increasing the output of this species for the production of biodiesel [4].

The relatively low volume of percolate retrieved from SW-fertigated (Fig. 3) may have been due to the presence of SW solids obstructing the porous surface of the soil, resulting in reduced infiltration of water, in addition to hydrophobic effects of the manure [20] or possibly even the greater vegetative growth of the plants in this treatment, and an associated increase in water uptake by the root system.

Significant variation was recorded in electrical conductivity (EC) in all but one of the samples (Table 3). While the pH is an important parameter here, due to its influence on aquatic ecosystems, no significant variation was recorded in any of the samples, and given this, the results are not presented here.

The volume of percolated water recorded during the present study (Fig. 3) was directly proportional to the precipitation recorded a few days prior to each sample (118.2 mm, 28.8 mm, 21.4 mm, 55.2 mm, and 49 mm, respectively). The concentration of salts, which is indicated by the EC, varied significantly among treatments in most samples, with the highest values being recorded invariably in treatment 3, followed by the rain-fed and irrigated treatments. It is interesting to note here that the EC value observed in the SW-fertigated treatment was higher than the restriction limit of 0.7 dSm^{-1} for irrigation water [21], which indicates that *J. curcas* may be resistant to high concentrations, as shown in previous studies [4,8]. However, salt leaching may accelerate soil salinisation over the long term, which should be a focus of future research. In addition, the leaching of salts was significantly higher in the rain-fed treatment (i.e., no irrigation) in comparison with irrigated treatment, which may indicate that the irrigation water dilutes and dissipates salts in the soil.

Overall, further long-term studies are required to determine the possible effects of the quality of irrigation water on seed productivity, and the quality of the seed for the production of biodiesel. Further research is also necessary to verify more systematically the potential negative environmental effects of the application of wastewater to cropland.

4. CONCLUSION

Under the conditions prevailing at the study site in southern Brazil, fertigation using swine wastewater at 370 m^{3} ha^{-1} improved the vegetative growth of *J. curcas* seedlings in terms of plant height and the production of inflorescences and fruits. We conclude that this application of swine wastewater is feasible for the irrigated cultivation of *J. curcas*, and deserves further investigation, focusing on crop yields and the quality of the seed oil, especially in subtropical areas with relatively cool, dry winters, such as southern Brazil, where the quality of the groundwater may be affected by salt leaching from effluents.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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