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ORIGINAL RESEARCH

Effects of fertigation with raw sewage on the vegetative development of maize and beans

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Abstract

Purpose Fertigation plays an important role in the so-called circular economy since it relies on the reuse of water and nutrients; therefore, this method is fundamental for production in areas with scarce resources. This study aimed to evaluate the effects of fertigation of soil plots with sewage on soil attributes, germination of seeds, and growth of bean and corn.

Method Due to the low concentrations of macronutrients in the sewage, the applied dose was calculated based on the water deficit. Three plots cultivated with maize and three plots cultivated with beans were fertigated, while the same number of plots received irrigation and mineral fertilization in amounts equivalent to the dose of nitrogen administered in the sewage for comparison.

Results There was an increase in the cation exchange capacity (74.6%), nitrogen (10.4%), available phosphorus (190.5%), and organic matter (44.9%) contents in the fertigated soil compared to those in the soil of the plots that received chemical fertilization, resulting in greater germination and corn and bean growth. Analyses indicated that the coliform count in beans is below the detection limit of the technique used.

Conclusion Based on the results obtained, there are indications that fertigation can provide improvements in soil attributes at values higher than those provided by chemical fertilization, reducing the need to apply these macronutrients and irrigation water to the soil. Furthermore, fertigation can be sanitary and safe, since the count of microorganisms in the beans was not higher than that recommended by the World Health Organization (WHO).

Keywords Wastewater, Germination, Fertility, Health risk, Sewage reuse

Introduction

Population growth and the consequent increase in demand for drinking water worldwide, in addition to the quantitative and qualitative water resource scarcity, have created conflicts over the use of water and led to an increase in its distribution costs (Booker et al. 2012; Justes et al. 2014). In parallel, food demand is directly related to population increases. Thus, the need for increasing food production is imminent, but there is no provision for unlimited mineral fertilizer reserves, and there is great concern about the future availability of this resource (Pantano et al. 2016).

As the population grows and the goods produced from raw natural materials are used, wastewater, such as sewage, is generated. This is formed by 99.9% water and 0.1% impurities (Von Sperling 2014), among which are

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organic matter, nitrogen, phosphorus, potassium, and micronutrients, which, if deposited in nature unregulated, may lead to several negative environmental impacts on the physical environment (soil, air, and water). Thus, conventional agricultural practices do not present themselves as sustainable, with soil chemical exhaustion and water contamination, and must be rethought.

Fertigation consists of the controlled disposal of wastewater in the soil, with doses defined according to the nutritional needs of crops (Matos and Matos 2017). Thus, it plays an important role in the so-called circular economy, since water and nutrients are reused, presenting itself as fundamental for production in areas with natural resource scarcity (Hamilton et al. 2007; Keraita et al. 2008; Kihila et al. 2014). Furthermore, the use of this technique in Brazil has the potential to reduce costs associated with chemical fertilizers, mitigate environmental problems caused by the lack of basic sanitation, especially in agricultural areas, and increase the productivity of cultivated crops.

Different studies have demonstrated the potential for wastewater use in agricultural production. Santos et al. (2016), for instance, found that it is possible to increase cotton production by 44% by performing fertigation with raw sewage rather than relying on chemical fertilization. The reason for this finding is that sewage has a wide range of macro- and micronutrients in addition to organic matter (Thapliyal et al. 2011), which differs from mineral fertilizers, favouring the greater development of crops. In the same evaluation by Santos et al. (2016), it was also observed that crop production was 22% higher when raw sewage was used than when treated sewage was used due to the removal of nutrients and organic matter during the treatment stages, leaving the ions that are more difficult to remove, such as sodium and potassium (Western Consortium for Public Health 1992). As a result, costs for irrigation water and chemical fertilizers are reduced, since part of the water and nutrient demand may be supplied by fertigation (Marques et al. 2017).

Due to these wastewater characteristics, authors such as Erthal et al. (2010), Lo Monaco et al. (2009, 2011), Souza et al. (2010), Souza et al. (2015), Pereira et al. (2016), and Jorge et al. (2017a) obtained positive results from the application of different effluents, with improvements in soil physical and chemical attributes and higher crop productivity. In addition to evaluating crop growth, the effect of fertigation on the production of seedlings (Silva et al. 2013) and seeds (Oliveira et al. 2014) has also been evaluated to further promote agricultural practices.

To evaluate crop fertigation results, the germination index (GI, or percentage of seeds that thrived), germination velocity (GVI), and seed vigour (SVI) (Abdul-Baki and Anderson 1973; Oliveira et al. 2014; Divya et al. 2015; Paiva et al. 2016) are commonly used, and the nutrient contents in plant tissue and dry mass production are determined (Silva et al. 2012). Since fertigation with sewage or with wastewater from animal farms may introduce pathogenic organisms into the soil, it is necessary to perform a crop health assessment (Paiva et al. 2016).

The World Health Organization (WHO 2006) presents two irrigation types that are aimed at preventing the transmission of various diseases and that optimize the conservation and recycling of water resources. The first is restricted irrigation, in which there can be no more than one human intestinal nematoid per litre, and the second is unrestricted irrigation, in which no more than a thousand thermotolerant coliform bacteria can be present per hundred millilitres.

Thus, this study aimed to evaluate the effect of raw sewage fertigation on the soil and the germination and growth of two crops: maize and beans. Furthermore, we also assessed the plant health of fertigated beans.

Materials and methods

Study area

The experiment was performed at the wastewater treatment plant of the Federal University of Lavras (WWTP-UFLA), Lavras, Minas Gerais, Brazil. The WWTP-UFLA has a treatment system consisting of thick and thin grids (preliminary treatment), upflow anaerobic sludge blanket (UASB) reactors and submerged aerated filters (SAFs) (secondary treatment), and chlorination disinfection and contact tanks with UV lamps. It is of interest to the institution that this wastewater could be used in green areas of the campus. The choice to use raw sewage rather than treated sewage is due to the observations of several studies as conducted by Santos et al. (2016), which showed that there is a reduction in the green mass production potential after sewage treatment steps, given the nutrient and organic matter removal.

During the experimental period (90 days), seven collections were made, with sewage sampling performed before the beginning of the experiment (previous characterization) and during fertigation use (six collections), with sampling performed on day 0 of application and then every two weeks until the 90th day of fertigation, completing the evaluation cycle. The aim was to evaluate the chemical element concentrations present in the wastewater applied to the plots.

The following variables were analysed from the samples following methodologies described in APHA et al. (2012) and Matos (2012): potential of hydrogen (pH) (*MS Tecnopon mPA210* pH meter) and electrical conductivity (EC) (*Hanna Instruments HI 8731* conductivimeter), determined by potentiometry; total solids (TS) and total suspended solids (TSS), by gravimetry; biochemical oxygen demand (BOD), by the Winkler method; chemical oxygen demand (COD), by the closed reflux method; total Kjeldahl nitrogen (TKN), by the Kjeldahl method; sodium (Na) and potassium (K), by flame photometry (*Jenway EW-83055-05* flame photometer); and total phosphorus (P) (*UV-VIS AF1403009* spectrophotometer), by the colorimetric method.

Table 1 shows the characterization of sewage from the WWTP-UFLA before its use in the fertigation of the experimental pots. These data were used as a reference for the delineation of the experimental conditions. Analyzes were performed two weeks before the beginning of the experiment, in order to allow the definition of the dose to be applied.

Table 1 Physical and chemical characterization of WWTP-UFLA sewage before fertigation

pH	EC	BOD	COD	TKN	Na	TSS	TS	K	P
-	$dS.m^{-1}$	--mg.L^{-1}--							
6.98 ± 0.25	0.747 ± 0.146	691 ± 101	1,200 ± 200	13 ± 2	35 ± 1	585 ± 74	1,258 ± 13	33 ± 1	15 ±3

Fertigation and irrigation management

According to Matos and Matos (2017), the depth at which fertigation should be applied depends on crop needs and the nutrient concentration in the wastewater, reaching the depth by the reference chemical element, the one supplied with the smallest amount of solution. However, given the low concentrations of nutrients and sodium in the sewage from the WWTP-UFLA, this calculation was based on crop evapotranspiration and daily precipitation (water balance), according to Equation 1, considering an application efficiency of 100%. The soil water storage capacity term was considered null because it is linked to the root system of crops. In the case of corn and beans, it would be 50 and 40 cm, respectively, greater than the depth of the experimental pots (20 cm).

$$ID = \sum ETci - \sum Pi - \Delta SWS \qquad \text{(Equation 1)}$$

where:

ID = irrigation/fertigation depth (mm);

ETci = crop evapotranspiration in the irrigation period (mm); Pi = precipitation in the irrigation period (mm); and ΔSWS = soil water storage variation (mm).

To calculate the reference evapotranspiration (ETo), the Penman-Monteith (FAO) method (Allen et al. 1998) was employed (Equation 2) using the EvapoWeb website (http://evapoweb.com.br/) developed by the Federal University of Lavras. On the other hand, Equation 3 allows the calculation of crop evapotranspiration (ETc), which considers the crop coefficient (kc) value.

$$ETo = ((0.408 \,.\, \Delta \,.\, (Rn - G)) + \gamma \,.\, (900 \,/(T + 273)) \,.\, u_2 \,.\, (e_s - e_a)) \,/\, (\Delta + \gamma \,.\, (1 + 0.34 \,.\, u_2)) \quad \text{(Equation 2)}$$

where:

ETo = reference evapotranspiration ($mm.d^{-1}$);

Δ = slope of the saturation vapor pressure curve ($kPa.(^{o}C)^{-1}$)

Rn = daily radiation balance ($MJ.m^{-2}.d^{-1}$);

G = total daily heat flow in the soil ($MJ.m^{-2}.d^{-1}$);

γ = psychometric coefficient ($kPa.(^{o}C)^{-1}$));

T = average air temperature at a height of 2 metres (°C);

u_2 = wind velocity at a height of 2 metres ($m.s^{-1}$);

e_s = vapor saturation pressure (kPa); and

e_a = current vapour pressure (kPa).

$$ETc = ETo \,.\, kc \quad \text{(Equation 3)}$$

where:

ETc = crop evapotranspiration ($mm.d^{-1}$);

ETo = reference evapotranspiration ($mm.d^{-1}$); and

kc = crop coefficient.

The meteorological data required in the experiment were obtained from the Conventional Meteorological Station of the National Institute of Meteorology (INMET), located on the UFLA campus. According to the Köppen climate classification, the climate of Lavras is classified as cwa – monsoon-influenced humid subtropical climate. The kc was established according to the crop phase, with the initial value equal to 0.4, the intermediate value equal to 1.15, and the final value equal to 0.35 for both crops (Mendonça et al. 2007). These kc values were obtained for beans based on average values for different world regions (Allen et al. 1998). Thus, as it was necessary to evaluate the effect of the same irrigation depth on both crops, it was also used as a reference for corn. Water and sewage applications were performed 3 times per week, with irrigation/fertigation separated throughout the day, in the morning and afternoon. For irrigation/fertigation application, a manual method was utilized, using a watering can to supply the required depth with the solution applied to the surface of the leaves.

Sowing and fertilization

The experiment was conducted in twelve 21 cm x 20 cm x 22 cm soil pots, six of which were cultivated with corn (*Agrisure TL® – BT11* – cultivar) and the others with beans (*EMBRAPA BRS Pérola* cultivar), aiming to be an exploratory study of the effect of fertigation in pots and for the evaluated cultures. These crops were chosen to enable the evaluation of the possible different responses by species of great importance in Brazilian food and the study of a representative leguminous plant (capable of fixing atmospheric nitrogen) (Ponciano et al. 2003; Machado et al. 2008), being fast-growing food of great relevance to poor areas (Nassary et al. 2020). Therefore, they are an alternative for areas that lack sanitation solutions and can provide water and nutrients for food production (Marques et al. 2017; Marques et al. 2020).

A total of 0.01 m³ of soil collected at the UFLA campus, characterized as Red Latosol (Curi et al. 2016), was placed in each pot (Fig. 1). The repetitions were placed side by side in rows – in the first row referring to the fertigated crop and in the next, the irrigated crop (Fig. 1). The soil pots were placed in an uncovered area with sunlight for most of the day. In addition, the soil samples were homogenized before being distributed among the pots; therefore, there were no differences between the conditions of the treatments and repetitions (only of crops and availability of water and nutrients).

At sowing, two seeds were placed in each pot. If the seedlings did not emerge after 14 days, 2 more seeds were sown in each pot.

To assess the fertigation effect, six plots (three with maize and three with beans) received sewage, while the other six received water and chemical fertilization. Fertilization was performed with NPK fertilizer (4-14-8), with an amount of N equivalent to what would be applied to the soils if the UFLA sewage maintained the chemical characteristics presented in Table 1. As it is a wastewater with a low concentration of nutrients, the calculation was made based on the estimated water loss in the first week of fertigation and how much would be added with sewage (considering the concentration presented in Table 1). Based on these values, it was extrapolated for application during the work evaluation period (10 weeks).

As suggested in Minas Gerais State Soil Fertility Commission (CFSEMG 1999), chemical fertilizers were divided into 30% for planting, 35% at 30 days, and 35% at 60 days after seedling emergence. As there is a large variation in the wastewater nutrient concentration, due to the different uses of the water on the campus, it was evaluated (at the end of the experiment) whether the amount of N added by fertigation was lower or higher than that administered via chemical fertilization. The nutrient amount added was compared with the recommended nutrient addition for these crops (CFSEMG 1999).

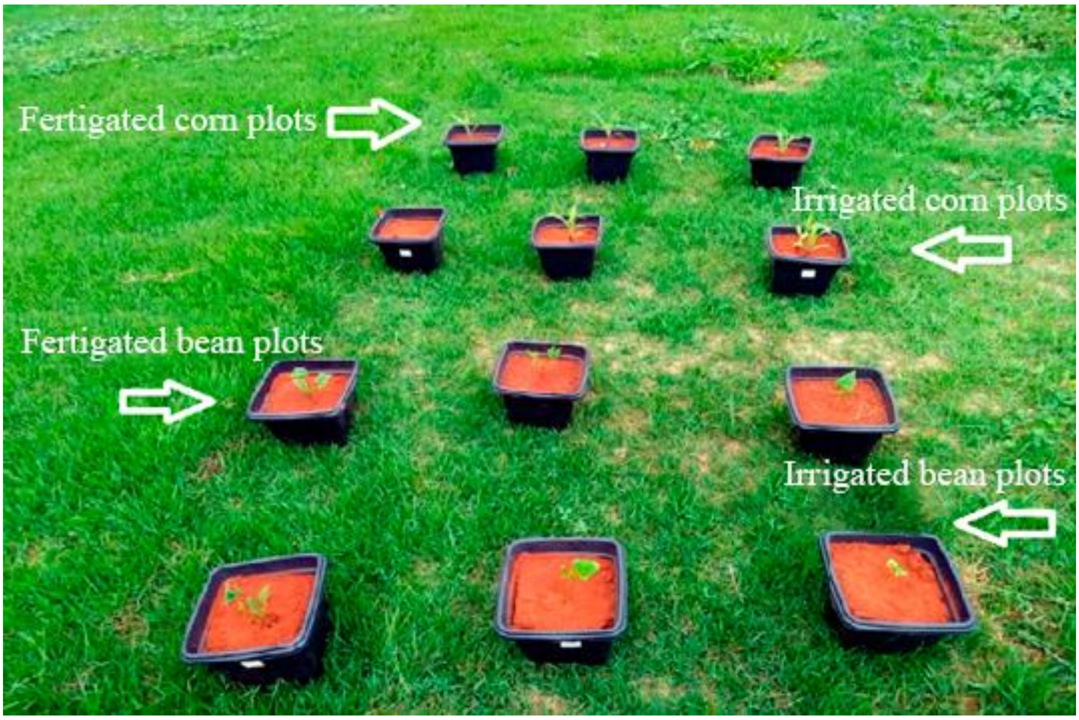

Fig. 1 Disposing of corn and bean pots (in triplicate)

Fertigation effects

To assess the influence of fertigation, the experiment was divided into two phases. In the first phase, from August 28 to October 28, 2018, the pH of the soil collected on the campus was not corrected by liming, and there was no nutrient supplementation before the beginning of the experiment to observe what benefits the sewage could provide in unprepared soil. With these methods, it was possible to investigate the use of the sewage (WWTP-UFLA sewage) as a macro- and micronutrients source in poor soils, allowing for the reduction of expenses with chemical fertilization and irrigation. Thus, the first germination period, stem length, GI, GVI, and SVI were monitored, with SVI being calculated as suggested by Abdul-Baki and Anderson (1973), by Equation 4:

$$SVI = GI\ (\%) * \text{plant length} \qquad \text{(Equation 4)}$$

The plant length used in this equation is the average of the root and stem lengths. At the end of the experiment, plants were carefully removed from the pots to allow measurement of root length (to enable SVI to be calculated), while stem length was measured weekly. The soil characteristics (i.e., pH and nutrient contents) were also evaluated for the fertigated soil as well as the soil that received the chemical fertilizer, with the samples being sent to the UFLA Soil Fertility Laboratory. The analyses were performed on soil from the surface layer (0-20 cm), and a composite sample was created from plots exposed to the same treatment (fertigated or irrigated and fertilized).

As a function of the lower than expected crop growth, the second phase (after October 28) was carried out. To provide better development, in addition to chemical fertilization and fertigation with WWTP-UFLA sewage, sludge from the same station was added, taking into account the soil and sewage sludge characterization (Table 2) performed by Farias (2018) and the need for nutrient addition (CFSEMG 1999).

This practice was performed to improve water retention in the soil following organic matter (OM) addition (Matos 2014) and to provide additional P, as the crops showed indications of deficiency in this macronutrient (e.g., they had purple-coloured leaves in the early growth stage) as indicated in the literature (CFSEMG 1999). In each plot, 15 grams of wet sludge was added six weeks after planting, in a single application. Thus, all soils in the treatments received organic fertilization in the same amount and application conditions so that the differences between the plots continued to be the crop (beans or corn) and the type of fertilization (chemical fertilization or fertigation with WWTP-UFLA sewage).

Total and thermotolerant coliform analyses

For microbiological analysis of the samples, 2.0 g of bean grains was collected 90 days after the beginning of fertigation (the last day of application), and the samples were subsequently weighed and macerated. Then, 20 mL of the diluent was added (0.1% peptone water in the proportion of 1:10 (w:v) with the weight of the sample). This dilution was considered 10^{-1}. The samples were homogenized by manual agitation for 60 seconds in peptone solution for further dilutions up to 10^{-7}. The total and thermotolerant coliform analyses followed Method 9211: multiple-tube fermentation technique (APHA et al. 2012). With this approach, the presumptive method for total coliforms was performed, including the use of lauryl sulfate broth and incubation at 35 °C for 48 hours in a bacteriological oven. The results were quantified by the most probable number (MPN) method and replicated in EC medium broth for thermotolerant coliforms at 44.5 °C for 24 hours. The results of this test were then visually assessed by the presence of CO_2 and the MPN method.

Table 2 Average values and standard deviation of the raw sewage sludge characteristics of the WWTP-UFLA UASB reactors in different phases

Variable	*In natura* sludge
Humidity (%)	86.30 ± 0.08
pH (1:2.5)	6.60 ± 0.03
EC (dS.m^{-1})	1.660 ± 0.007
TOL (%)	4.61 ± 0.79
OM (dag.kg^{-1})	7.95 ± 1.36
P (g.kg^{-1})	2.22 ± 0.93
TKN (g.kg^{-1})	48.62 ± 1.53
TS (g.kg^{-1})	176.6 ± 9.3
TFS (g.kg^{-1})	69.2 ± 5.4
TVS (g.kg^{-1})	107.4 ± 4.9

TOL, total organic load; TFS, total fixed solids; TVS, total volatile solids; and OM, organic matter. The characterization was carried out in the same year as the sludge was used in the present work. **Source**: Farias (2018)

Results and discussion

Irrigation and fertigation

Table3 shows the monthly precipitation, evapotranspiration, and irrigation depths recorded in the monitoring period. Because the experiment occurred in a period of intense rainfall and the pots were kept uncovered, simulating conventional planting, it was necessary to apply less sewage. Thus, the differences between the treatments (clean water and sewage) would be larger in a dry season.

It is important to note that the calculation of the irrigation and fertigation depth to be applied was done week by week, which is why there is a difference between the subtraction of the evapotranspiration and precipitation and what was applied.

Fertigation influence on soil without fertilization

Table 4 shows the results of the soil chemical analyses performed on samples collected six weeks after the beginning of sewage application (and before the addition of sludge) to the corn and bean pots.

Table 3 Values of precipitation, crop evapotranspiration (ETc), and sewage and clean water application accumulated per month

Month	Precipitation (mm)	Crop evapotranspiration (mm)	Irrigation depth (L)	Irrigation depth (mm)
September	52.60	102.60	2.98	70.95
October	201.10	79.98	2.12	50.48
November	218.50	65.00	0.96	22.86

Table 4 Results of chemical analyses of soil (0-20 cm) before and after irrigation and fertigation with WWTP-UFLA sewage

Soil *		Virgin	Irrigated	Fertigated	Fertigation increase (%)
pH	-	7.5	7	7.3	-
K	$mg.dm^{-3}$	43	203	137.8	-32.1
P	$mg.dm^{-3}$	0.51	9.7	1.33	-86.3
Na	$mg.dm^{-3}$	1.2	3.6	64.5	1,691.70
Ca^{2+}	$cmol.dm^{-3}$	0.75	1.38	3.61	161.6
Mg^{2+}	$cmol.dm^{-3}$	0.25	0.37	0.24	-35.1
Al^{3+}	$cmol.dm^{-3}$	0.02	0.01	0.01	0
$H+Al^{3+}$	$cmol.dm^{-3}$	1.33	1.04	0.84	-19.2
EB	$cmol.dm^{-3}$	1.34	2.27	3.97	74.1
t	$cmol.dm^{-3}$	1.36	2.28	3.98	74.6
T	$cmol.dm^{-3}$	2,38	3.6	4.81	33.6
V	%	56.4	63	82.5	31
M	%	0.25	0.44	1.47	234.1
OM	$dag.kg^{-1}$	0.97	0.98	1.42	44.9
P_{rem}	$mg.L^{-1}$	1.9	2.84	8.25	190.5
N	$g.kg^{-1}$	1.12	1.54	1.7	10.4

* Soils without sludge addition.

The values presented indicate that fertigation with WWTP-UFLA sewage provided increased levels of Na, Ca, cations (EB), remaining P (or available P), and N, being superior to chemical fertilization. With the higher OM contribution, it also provided an increase in the cation exchange capacity (CEC) of the soil (effective and potential) through the availability of negative charges and bases (Matos and Matos 2017), which resulted in a higher pH than in the irrigated soil.

Although the OM content increases after sewage application, soils may still be classified as having low fertility according to OM contents (Nascimento et al. 2004). Duarte et al. (2008) found values close to those reported in this study when applying treated sewage to soil at a rate of approximately 1.6 dag.kg^{-1}, indicating that OM incorporation by fertigation is a slow process, which is why the WWTP sludge was added.

N levels commonly found in cultivated soils range from 0.6 to 5.6 g.kg^{-1} in the surface layer (Matos 2012). Hence, the values presented here are within the expected range, falling close to the lower limits. The need for complementary addition of N to increase the crop production potential was observed, and this could have been achieved by applying sewage over a longer time and with a higher rate (in drier seasons). This hypothesis is corroborated by the results of Silva (2017), in which the proportion of WWTP-UFLA sewage in irrigation water was increased, resulting in higher nutrient content and higher grass yield.

As observed in this study, Lo Monaco et al. (2009) and Erthal et al. (2010) also found an increase in base concentration in soil fertigated with wastewater from Arabica coffee and cattle farming, indicating the potential of this technique. However, these authors drew attention to the salinization risk and chemical imbalance that can occur if an excessive amount of wastewater is applied, as also highlighted by Cerqueira et al. (2008). The most significant increase in the plots was observed for Na (Table 4), which is not a nutrient used by most crops and should be in low concentrations in irrigation water (Ayers and Westcot 1991), leading to the need to monitor fertigated soil. Matos and Matos (2017) recommended application rates of up to 30 g.m^{-2}.yr^{-1} Na. Thus, based on Table 1, 857.1 mm of sewage or 71.4 L.m^{-2} per month could be applied in one year, values higher than those reported in the evaluated months. After three months, there was an addition of 63.3 mg per dm^{-3} (1.266 mg.dm^{-2} – in 20 cm of soil), which would result in 0.1266 g.m^{-2}. Maintaining the application of wastewater to the soil for another nine months and the characteristics of the sewage and the soil (e.g., differences between the input and leaching), it would result in a content of 0.3822 g.m^{-2} in one year, 78x less than the recommended application limit.

Macronutrient amount applied with chemical fertilization and fertigation

Regarding the P and K levels, chemical fertilization was more effective due to the low concentrations of these variables in the UFLA sewage. To compare the nutrients administered by each treatment relative to mineral fertilization, Table 6 was constructed based on the concentrations obtained in the wastewater characterization performed during the crop fertigation period (Table 5).

Table 5 Physical and chemical characterization of the WWTP-UFLA sewage during the fertigation period

pH	EC	BOD	COD	Na	K	P	N	TSS	TS
-	dS.m^{-1}	-------------------------------------mg.L^{-1}-------------------------------------							
7.10 ± 0.16	0.785 ± 0.135	376 ± 187	861 ± 342	36 ± 1	33 ± 1	12 ± 2	22 ± 3	398 ± 189	1,149 ± 534

Table 6 Average macronutrient amount applied to plots by mineral fertilization and fertigation with WWTP-UFLA sewage during the monitoring period

Average macronutrient amount applied in milligrams to each plot					
N		P		K	
Mineral fertilizer	Sewage	Mineral fertilizer	Sewage	Mineral fertilizer	Sewage
43.2	149.30	201.6	73.44	115.2	199.98

For comparison, the typical concentration ranges of N, P, K, and Na in the sewage were 35-70, 5-25, 10-60, and 24-47 mg.L^{-1}, respectively (Von Sperling 2014; Matos and Matos 2017), indicating differences between the university wastewater and typical sewage.

Table 6 indicates that the amount of P added to the plots by mineral fertilization was higher than that provided by fertigation, which explains the differences observed in Table 4. The reason for this finding may be the reduction in the phosphate concentration in the formulation of industrial products such as detergents – a significant source of P in sewage –, which leads to a decrease in its values in sewage (Quevedo and Paganini 2018). On the other hand, while the added mass of N and K was higher in the sewage plots, it did not result in an effective gain in the soil compared to that in the chemical fertilization plots. It is believed that because K is highly mobile in the soil and the addition of other cations may displace it and cause its leaching, soil is not as rich in this macronutrient as it could be with fertigation. Pereira et al. (2011) and Santos et al. (2016) reported a similar phenomenon, especially in the presence of excess Na. Other authors, such as Ferreira et al. (2011), also suggested the need to complement K addition by mineral fertilization to increase the production potential of fertigated coffee trees with sewage.

Regardless, there is potential to reduce crop costs due to water and chemical fertilization by applying fertigation. According to Marques et al. (2017), by applying sewage from the Onça sewage treatment plant in Belo Horizonte to elephant grass production, it was possible to save 58% of the water demand, or approximately US$ 6.00 per hectare, and US$ 445.00 per hectare in mineral fertilizer application.

Vegetable species growth analysis (before and after sludge addition)

The seed germination in both treatments (irrigation and fertigation pots) was late, taking into account that new sowing was necessary, as none of the 12 pots had maize or bean emergence 14 days after planting. After this period, more seeds were planted, and after 7 days, the stems of the species began to appear.

Seedlings appeared in the 6 fertigated pots, producing 8 germinations from 12 seeds, resulting in a GI of 67%. In the conventionally planted pots, the GI was lower, at 58%. Ávila et al. (2006) reported that micronutrient-treated corn seeds had a higher germination rate, which may explain the higher GI of the fertigated plots, which received higher micronutrient inputs. Subsequently, the GVI was calculated, resulting in a value of 1.14 for the fertigated pots and 1.0 for the conventionally irrigated pots; the SVI, 14 days after emergence, had a value of 8.04 for the crops that received sewage and 5.8 for the conventionally cultivated crops. The results obtained corroborate the hypothesis of Divya et al. (2015), who indicated that depending on the added dose of sewage, fertigation may be more effective than irrigation in germination and seed growth. The plants emerged with similar height and vigour, with a variation of approximately 1 centimetre or more in height in favour of fertigation. After germination, thinning was performed, and only one plant was retained per pot to avoid competition for nutrients, water, and light.

In the study period, a growth pattern was observed in which the fertigated crops had a clear advantage (visual analysis in the graph) over the conventionally irrigated and fertilized crops, as shown in Fig. 2. Marques et al.

(2020) also observed greater plant development of elephant grass receiving raw sewage than that observed by the chemically fertilized one. With fertigation, the production was up to 29.9 $Mg.ha^{-1}.yr^{-1}$, while with chemical fertilization, it was 17.5 $Mg.ha^{-1}.yr^{-1}$.

A visual analysis of the crops in the final phase of the experiment indicates that fertigation allowed taller crops, as highlighted in Fig. 2. It is necessary to highlight, however, that in the first weeks, there were challenges with the crops establishing and developing vigorously. After adaptation, and especially after sewage sludge addition, there was greater establishment and growth of the crops.

Khaliq et al. (2017) obtained increased concentrations of total organic carbon and chlorophyll in green bean and white radish crops with soil fertilized with sewage sludge than crops from soil enriched with chemical fertilizer.

On the other hand, Kummer et al. (2016) tested mixtures of sewage sludge and urea. When using 100% sewage sludge as fertilizer, there was a significant increase in vegetative growth and grain yields of wheat and soybeans. Similarly, Effendi et al. (2021) achieved higher rice productivity in soil mixed with organic sludge at the concentration of 25 $t.ha^{-1}$.

Thus, the addition of biosolids provides improvements in physical (water retention in the soil), chemical (soil nutrition), physical-chemical (increased cation exchange capacity and pH change), and biological (greater microbial diversity and productivity) attributes, which may have resulted in greater development of the evaluated cultures. It is noteworthy that greater soil structuring is also a benefit of organic fertilization; however, as this is a long-term effect, there was not enough time to observe changes in this soil property (Matos and Matos 2017).

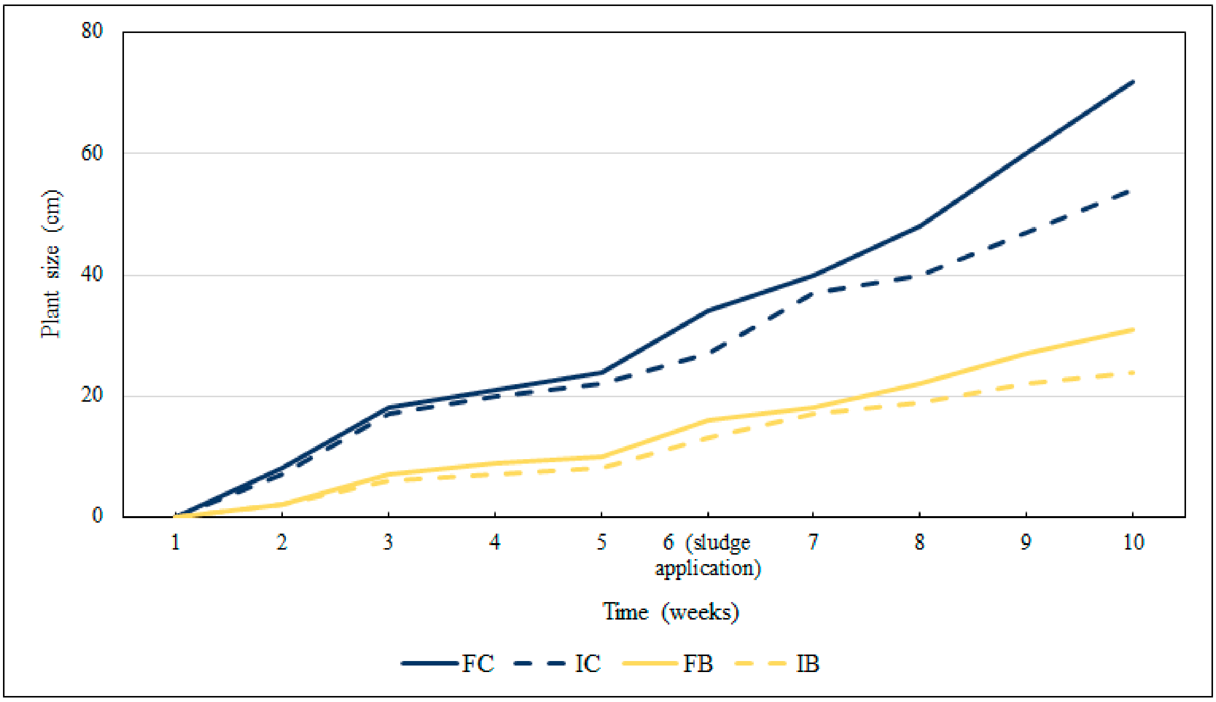

Fig. 2 Crop growth analysis relative to time (repeats average) and the type of technique applied

IB = irrigated bean; FB = fertigated bean; IC = irrigated corn; and FC = fertigated corn.

Crop microbiological quality analysis

In Brazil, there is no specific federal legislation on sewage application to the soil. There are criteria for only a few states, such as Minas Gerais, in the State Council for Environmental Policy (COPAM) 65 deliberation (Minas Gerais 2020).

One of the concerns related to fertigation with sewage is the microbiological contamination of crops, especially when raw sewage is used, which is why the World Health Organization (WHO) has recommended maximum values for the presence of pathogens in each use (WHO 2006).

To assess this issue and the microbiological risk associated with this technique, the amount of total and thermotolerant coliform bacteria in the beans present inside the pods was determined on the last day of fertigation with sewage, as shown in Table 7.

Table 7 Microbiological analysis of beans fertigated with sewage

Sample	Total coliforms (35.0 °C)	Thermotolerant coliforms (44.4 °C)
	MPN.(100 mL)$^{-1}$	
Bean	< 1.1 x 10^1	< 1.1 x 10^1

The results did not indicate potentially infective water leaching from the crops according to the WHO (2006) guidelines, which established a threshold of 10^3 MPN.(100 mL)$^{-1}$; neither for unrestricted irrigation, which has a limit value of 10^5 MPN.(100 mL)$^{-1}$. According to Bastos and Bevilacqua (2006), the reference used by Basic Sanitation Research Program (PROSAB) indicates that the solution contained in the beans was within the standards established by the entity, which are 1x10^3 MPN. (100 mL)$^{-1}$ for restricted irrigation and 1x10^4 for unrestricted irrigation. It is important to note that no analysis was performed on corn because it does not present grains for complete analysis; converting to bean mass, the count would be less than 1.1 MPN(100 mL)$^{-1}$.

Several studies dealing with fertigation in different cultures have been reported in the literature. In a bell pepper culture, Souza et al. (2013) recorded 10.58 MPNg^{-1} of total coliforms and the absence of thermotolerant coliforms after 70 days of fertigation with swine wastewater. Alves et al. (2017), after 45 days of fertigation of banana with sewage following a secondary treatment in a UASB reactor, reported 23.00 and 9.20 MPN.g^{-1} of total and thermotolerant coliform concentrations, respectively, in the fruit peel. However, tomatoes fertigated with organic dairy cattle wastewater (composed of 15% manure and 85% water) in an experiment conducted by Jorge et al. (2017b) presented a concentration of thermotolerant coliforms <3 MPN.g^{-1}. Furthermore, this last study verified that the use of different nitrogen rates in fertigation does not affect the microbiological characteristics of the fruit.

Water reuse for agricultural purposes may result in biological risks, since wastewater may contain pathogenic microorganisms, such as viruses, protozoa, and helminths. However, Hespanhol (2002) points out that the mere presence of these organisms, either in soil or in crops, does not necessarily indicate disease transmission.

In the case of crop contamination by wastewater, depending on the amount, form, and season of application, among other factors, N may inhibit or favour pathogen occurrence. According to Zambolim et al. (2001), plants cannot be harmed by pathogens for three reasons: a) resistance, i.e., the ability to limit penetration, development, or reproduction of the causal agent; b) tolerance, i.e., "coexistence" with pathogens, maintaining adequate growth and production; and c) escape, i.e., lack of coincidence between the stages in which the crop is most susceptible and the pathogen is most active. In addition, for fruit to be contaminated, it must contact the wastewater, and the application must be continuous (Pereira et al. 2011; Alves et al. 2017). Santos et al. (2006), for instance, observed that two weeks without fertigation is sufficient to eliminate the risk of contaminated fruit. Therefore, this exploratory treatment gives evidence that fertigation can help soil nutrition and may not result in a health risk even if the application is made directly to the edible part, which was evidenced in other studies. Thus, it is recommended that more research be carried out on the subject, so that the fertigation technique can advance and be implemented, especially in places without proper sanitation services, allowing combine adequate final disposal of sewage and agricultural production.

Conclusion

Based on the results obtained, there are indications that: Fertigation can provide an increase in the cation exchange capacity, nitrogen, organic matter, and available phosphorus levels in the soil at values higher than those provided by chemical fertilization. Nevertheless, the soil sodium content must be evaluated due to the risks of soil salinization.

Although sewage application provided less total phosphorus and potassium to the soil than is necessary for crops, its addition reduced the need to apply these macronutrients and irrigation water to the soil.

As a result of improved soil attributes, more maize and bean seeds germinated, and the plants grew more in the plots that received sewage.

Finally, fertigation can be a safe technique from a microbiological perspective, and it provides essential macro- and micronutrients for bean cultivation.

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Compliance with ethical standards

Conflict of interest The authors declare that there are no conflicts of interest associated with this study.

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