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ORIGINAL RESEARCH

Detoxification of soybean oil mill effluent using anaerobic digestion and the suitability of the digestate for fertigation

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Abstract

Purpose The upsurge of vegetable oil production in Nigeria and the equally increasing concern for the environment which arises due to indiscriminate disposal of phytotoxic vegetable oil mill effluent in a less regulated country like Nigeria makes the re-use of the effluent for fertigation a suitable strategy for its disposal if the appropriate treatment technique is adopted.

Method A laboratory experiment was set up to study how the detoxification of soybean oil mill effluent (SOME) under different anaerobic digestion time (0, 20 and 40 days) and application rates (0, 50 and 100 m^3/ha) will influence the suitability of the effluent for fertigation.

Results SOME has a pH of 8.3, which decreased steadily to 7.4 as digestion time increased to 40 days. EC and potassium levels also decreased as digestion time increased, from 0.37 dS/m and 120.6 g/l to 0.28 dS/m and 70.1 g/l, respectively. However, levels of organic carbon, nitrogen and phosphorus did not change significantly. The effluent impacted negatively on germination after a one-time application, with the germination index going as low as 22% for untreated SOME and gradually increasing to 66% as digestion time increased. Continuous application of the untreated effluent also affected soil microbial activity negatively when compared to the treated effluent.

Conclusion Anaerobic digestion detoxifies SOME and the efficiency of the treatment increased with increasing digestion time. The effluent also contains low to moderate amounts of NPK and therefore has a potential for fertigation.

Keywords Soybean oil mill effluent, Wastewater treatment, Anaerobic digestion, Hydraulic retention time, Fertigation, Soil amendment

Introduction

The process known as fertigation combines fertilization and irrigation as an approach for efficient crop nutrient and water management. The use of treated industry wastewater for fertigation utilizes the organic materials and nutrients found in the effluent for agricultural productivity, while also providing water for irrigation, a practice that has become common in various parts of the world (Regni et al. 2017). The reuse of treated industry wastewater for fertigation does not only solve the problem of water scarcity in semi-arid and arid regions where rainfall amount and distribution is low, it also reduces fertilizer, water and application cost. The demand for portable water for human consumption is another important driving force to reuse treated wastewater.

According to the International Finance Corporation (2007), about 10-25 m^3 of vegetable oil mill effluent per metric ton of product is generated globally. This wastewater contains moderate amounts of nutrients and has the potential to be used for fertigation as an alternative means of disposal. Soybean oil mill effluent (SOME) just like other vegetable oil mill wastewater is characterized by high total solids, organic load and nutrients and when used as a soil amendment, soil nutrient content tends to increase (Mekki et al. 2007; Okorie et al. 2017; Yu et al. 2018; Cai et al. 2020). Despite this increase in

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soil nutrients, the effluent has been found to inhibit plant growth in cases where the untreated wastewater was used (Davarnejad et al. 2019; Kukwa et al. 2020). Aggelis et al. (2003) found that vegetable oil mill effluent contains phytotoxic compounds in addition to high Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD) and oil and grease content. The polyphenol content in soybean oil mill effluent is about 80 mg/l (Kukwa et al. 2020), which make it a huge source of environmental pollution if not properly treated.

Several treatment techniques have been developed which are either physical, chemical or biological and each of these treatment techniques have their drawbacks. For instance, Ozonation removes color from wastewater but is not efficient in COD reduction (Anagnostopoulos and Symeopoulos 2013), coagulation and precipitation require pH control (Ahmaruzzaman 2008), while aerobic digestion which breaks down waste components under aerated condition through the activities of aerobic microbes is not cost effective due to its high energy requirement, even though it is characterized by high treatment efficiency (Chow et al. 2020). Unlike the aerobic digestion, anaerobic digestion breaks down biodegradable materials in the absence of oxygen and therefore requires lesser energy, since the biogas released during anaerobic digestion could be used as a source of renewable energy (Demirbas et al. 2017). The simplicity and cost effectiveness of anaerobic digestion makes it a suitable wastewater treatment technique for a developing country such as Nigeria (Ersahin et al. 2011). However, in the treatment of a phytotoxic waste such as soybean oil mill effluent, the goal is not so much on the biogas but rather focused on the release of a properly treated digestate which does not pose a secondary pollution incidence when applied on agricultural land.

The treatment efficiency of any waste is dependent on several factors among which include physical and chemical properties of the waste, pollutant concentration, treatment system adopted, the operating temperature and hydraulic retention time (HRT). In anaerobic digestion, HRT is a factor that stands out because it is positively correlated to all other factors (Ejhed et al. 2018). HRT affects the contact between substrates and microorganisms which favors higher treatment efficiency. If the time in the digester is too short, the feedstock biogas production potential is never realized and feedstock passes through the digester not fully treated (Feng et al. 2018). In order to benefit from the cost effectiveness of anaerobic digestion in the treatment of soybean oil mill effluent in Nigeria, it is important to understand the digestion time required to completely detoxify the effluent. This research therefore studies the detoxification of soybean oil mill effluent (SOME) under different anaerobic digestion time, while monitoring how the digestion time and application rate influence its suitability for fertigation.

Materials and methods

Study area

The study was conducted in the soil science laboratory and landscape unit of Modibbo Adama University of Technology, Yola, Nigeria. The area has a mean monthly temperature of 28.5 ˚C (Ishaku 2011).

Experimental procedure

The study was a laboratory experiment consisting of a lab-scale anaerobic digester set-up and potted soil. Freshly released soybean oil mill effluent (SOME) was collected from a vegetable oil mill in Adamawa state (Afcott Nigeria Plc). The effluent was diluted with 50% water as a pre-treatment to encourage stable operation of the digester (Fang et al. 2012; Hu et al. 2019), after which it was divided into three (3) parts and allowed to undergo anaerobic digestion under ambient temperature at different digestion time of 0, 20 and 40 days. Anaerobic digesters were set up using dark coloured 1.5 L plastic containers covered with balloons. The balloons were used to monitor gas emission as described by Rea (2014).

At the end of each digestion time, the effluent was applied to potted soil at the rates of 0, 50 and 100 m^3/ha. The soil was collected at the depth of 0-20 cm from the teaching and research farm of Modibbo Adama University of Technology, Yola, from which 1 kg of soil was weighed into each of the 27 1 L-planter bags used for the experiment.

These 27 planter bags consisting of 9 treatments replicated 3 times were arranged in a factorial design. The treated soil was left for 2 weeks for mineralization to occur before laboratory analysis and germination test were carried out.

Laboratory analysis

SOME and soil samples were analyzed in the laboratory before and after the experiment in order to study changes in effluent characteristics under different digestion time and to determine the effect of the treated SOME at different application rates on soil properties. SOME samples were analyzed for electrical conductivity (EC), pH, total organic carbon, sodium adsorption ratio (SAR), total nitrogen, phosphorus and potassium while soil samples were analyzed for EC, pH, soil organic carbon, available nitrogen, available phosphorus, exchangeable potassium, water holding capacity (WHC) and microbial biomass carbon (MB-C).

EC and pH were measured in an aqueous solution of 1:2 and read off an EC meter and a pH meter, respectively (Thakur et al. 2012). Total organic carbon (TOC) was determined by oxidation with potassium dichromate in a concentrated H_2SO_4 medium followed by measurement of excess dichromate using ammonium ferrous sulfate ($(NH_4)_2Fe\ (SO_4)_2$) (Thakur et al. 2012). Total nitrogen, Phosphorus and potassium were analyzed after acid digestion of wastewater samples. Total nitrogen was determined using Kjeldahl indophenols (colorimetric) method at a wavelength of 635nm and values obtained by extrapolation from a standard calibration curve; total phosphorus was determined by vanado-molybdo-phosphoric acid colorimetric method, and absorbance values measured at 490 nm after which values were calculated by extrapolation from the standard calibration curve, while total potassium was determined by flame photometer and the potassium concentration calculated by extrapolation from the standard calibration curve (APHA 2012). Available nitrogen was determined using alkaline potassium permanganate method (Thakur et al. 2012). Available phosphorus was determined using the molybdate method after extracting with Bray no. 2 solution and exchangeable potassium was determined using a flame photometer after extracting with ammonium acetate (Udo et al. 2009). Soil water holding capacity was estimated by measuring the soil moisture content of saturated undisturbed soil samples allowed to drain for two days. Sodium content was analyzed using a flame photometer after ammonium acetate extraction and SAR was calculated with the following formula:

$$SAR = \frac{Na^{+}}{\sqrt{\frac{[Ca^{2+}]+[Mg^{2+}]}{2}}}$$

Soil microbial biomass carbon was determined by the rapid chloroform-fumigation extraction method at atmospheric pressure (Witt et al. 2000). Samples were treated with alcohol-free $CHCl_3$ and extracted with 0.5 M K_2SO_4. The extracted carbon was then determined by dichromate oxidation.

Germination test

The effect of digestion time on germination was tested on sesame (*Sesamum indicum* L). 20 sesame seeds were sown per pot and allowed 10 days to germinate before germination and seedling vigour indexes were measured. The germinated seedlings (G) were counted, and the seedling length (SL) measured. Germination and seedling vigour indexes were calculated using the following formula as described by Tiquia et al. (1996):

Germination Index (GI) =

Seedling Vigour Index = SL × GI

Where G0 represents the total seeds planted per pot.

Data analysis

The data collected were subjected to Analysis of Variance using Statistix 8. Also, LSD was employed in separating the means at 5% level of probability.

Results and discussion

Physical and chemical properties of soil before amendment

The initial characteristics of the soil used in this experiment are shown in Table 1. The soil was found to be medium-textured and belongs to the "clay loam" textural class, with a pH of 7.1. An EC (solution) value of 0.80 dS/m also shows that the soil contains a minimal level of harmful salts. Organic matter, available nitrogen and available phosphorus were 6.99 g/kg, 5.6 mg/kg and 9.8 mg/kg, respectively. These indicated low values, which may be due to the continuous cropping system on the university teaching and research farm. Soil pH of 7.1 may have also contributed to the low level of available P in the soil. Exchangeable potassium, however, showed a medium range value at 70.13 mg/kg.

The water holding capacity of the soil was 20%. This means that the soil is capable of holding 60 mm of water at a root depth of 30 cm. The soil has the capability to hold adequate amount of nutrient-rich irrigation water at the effective rooting depth of most shallow-root crops.

Effect of digestion time on some properties of SOME

The properties of fresh SOME and the effect of digestion time on the characteristics of soybean oil mill effluent are shown in Table 2. The EC of the freshly collected SOME was 0.37 dS/m which significantly decreased to 0.28 dS/m after undergoing anaerobic digestion for a retention period of 20 and 40 days ($p \leq 0.005$).

Meanwhile, there was no significant difference between the EC values of the effluent at the two digestion time. The freshly collected SOME was alkaline at a pH of 8.3. As digestion time increased from 20 to 40 days, SOME pH decreased significantly ($F(2,6) = 28.789$, $p = 0.01$). Sodium Adsorption Ratio (SAR) for the fresh SOME was 0.78, but decreased significantly with increasing digestion time from 0.78 to 0.26 ($F(2,6) = 687.731$, $p = 0.0005$). While the difference between the total organic carbon in the fresh SOME and the 20-day digester was not significant ($p = 0.087$), there was a significant difference in the TOC when you compare SOME which was retained in the digester for 40 days ($p = 0.00$). A 40-day digestion time reduced the organic load of the SOME by 0.3 g/kg. As for the nutrients found in the effluent, apart from potassium which decreased significantly as digestion progressed, similar pattern was not observed for N and P. Nitrogen content did not show any significant difference with respect to digestion time. Phosphorus content on the other hand did not show any difference when fresh SOME was digested for 20 days, however as the digestion time in-

Table 1 Physical and chemical properties of the soil

Parameter	Value	SE
pH	7.1	0.1
EC (dS/m)	0.80	0.1
TOC (g/kg)	6.99	1.2
OM (g/kg)	12.23	1.2
Av. N (mg/kg)	5.6	1.7
Av. P (mg/kg)	9.8	0.1
Exch. K (mg/kg)	70.13	2.1
ECEC (Cmol/kg)	5.83	0.1
SAR	0.24	0.0
WHC (%)	20.00	1.2
Sand (%)	38.4	
Silt (%)	23.6	
Clay (%)	38	
Texture	clay loam	

Table 2 Effect of digestion time on properties of soybean oil mill effluent

Parameters	Digestion time (Days)				
	0	20	40	LSD(0.05)	SE
pH	8.3a	7.8b	7.4c	0.29	0.12
EC(dS/m)	0.37a	0.28b	0.28b	0.03	0.00
OC (g/l)	17.98a	17.81a	17.68b	0.21	0.08
SAR	0.78a	0.32b	0.26c	0.03	0.01
N (g/l)	2.83a	2.77a	2.73a	1.08	0.44
P (g/l)	0.32a	0.32a	0.31a	3.46	1.41
K (g/l)	120.6a	81.3b	70.1c	7.92	3.23

creased to 40 days, phosphorus content decrease from 32 ug/kg to 31 ug/kg; this however, was not significant.

Several studies have confirmed that vegetable oil mill effluents have characteristics that are quite similar (Asfi et al. 2012; Eze et al. 2013; Mekki et al. 2013). These effluents have been found to contain very minimal harmful salts that could cause salinity problems, acidic pH level which tends to increase to alkaline levels when the effluent is treated and of course moderate to high organic load and mineral NPK. Soybean oil mill effluent just like all the other effluents reviewed does not pose any salinity problems whether treated or not, however, it is quite unlike these other vegetable oil mill effluents, since an untreated and freshly collected SOME was alkaline with a pH as high as 8.3. The only other vegetable oil mill effluent with similar characteristic is cottonseed oil mill effluent (Okorie et al. 2017). The pH recorded also agrees with the work of Najiaowa et al. (2017) who reported soybean oil mill effluent to be alkaline.

There was also slight disparity in other chemical properties of soybean oil mill effluent when compared with other vegetable oil mill effluents. While effluents such as palm oil mill effluent and olive oil mill wastewater were reported to contain very high organic load, nitrogen, phosphorus and potassium (Kamyab et al. 2018; Babić et al. 2019; Lee et al. 2019), SOME was observed to contain these nutrients in permissible levels, except potassium which was quite high. This could be due to the fact that several of the studies conducted on other vegetable oil mill effluents was on the slurry effluent. On the contrary, the present study utilized soybean oil mill effluent which was produced after water, thick sludge and oil were separated; in this case, it was the water collected that was studied for fertigation and not the sludge. Most of the nutrients in vegetable oil mill effluent goes to the sludge once it is dewatered (Magdich et al. 2012). According to Umeugochukwu (2016), it, however, does not mean that phytotoxic components are not found in the water after sludge has been separated and removed.

Anaerobic digestion has the capability to detoxify soybean oil mill effluent and the treatment efficiency depends on the wastewater retention time within the digester. Observations clearly showed that detoxification increased as digestion time increased from 0 to 40 days. Unlike N and P, the potassium content of the freshly collected effluent was high but decreased significantly as digestion time increased. The 20-day retention time often used for aerobic digestion is not adequate for anaerobic digestion, especially where the effluent contains high organic load. Significant organic carbon reduction happened with a digestion time of 40 days. This corresponds with the findings of Shi et al. (2017) which confirmed that pH values with hydraulic retention time of 40 and 60 days were in the acceptable range compared to a retention time of 20 days. The authors argued that propionate was dominant in the reactor with retention time of 20 days, inhibiting the activities of methanogens. Nges and Liu (2009) observed from their batch tests that 90% of biogas is produced within the first 14 days of digestion and that peak daily biogas production occurs during the first 5 days of digestion; however, the shorter hydraulic retention time which is adequate for biogas production is not acceptable if the wastewater is to be reused for agricultural purpose. Similarly, Nges and Liu (2010) confirmed this in another study that shortening of solid retention time led to increase in gas production rate and volumetric methane productivity like-wise a decrease in volatile solids and volatile fatty acid destruction efficiency.

In this study, a digestion time of 40 days gave a better treatment efficiency than a digestion time of 20 days, but did not completely recover the effluent.

Soil chemical properties after SOME application

The effect of SOME treatment on some soil chemical properties is shown in Table 3. Soil pH increased significantly ($p<0.05$) with the addition of untreated SOME from 7.1 to 7.5. However, at 40-day digestion time, there was no significant change in the soil pH when the treated SOME was applied. This observation for treated SOME confirms the reports on treated palm oil mill effluent (POME) and olive oil mill wastewater (OMW) by other researchers (Mekki et al. 2012; Nwoko and Ogunyemi 2010). They opined that POME and OMW samples were acidic and when treated did not cause any significant change to the soil pH at a lower rate of concentration. In the case of olive oil mill wastewater, Mekki et al. (2006) equally reported that a follow-up of this parameter for 6 months showed that even untreated OMW has no significant effect on the soil pH.

Soil treated with SOME did not show any significant differences in their EC values ($p = 0.323$) to suggest that digestion time may have affected soil salinity status. On the other hand, soil organic car-

Table 3 Effect of SOME treatment on some soil chemical properties

Parameter	Application rate (m^3/ha)	Digestion time (Days)			LSD(0.05)	SE
		0	20	40		
pH	0	7.1b	7.2b	7.1b		
	50	7.5a	7.2b	7.1b		
	100	7.5a	7.2b	7.1b	0.19	0.09
EC	0	0.09a	0.11a	0.09a		
	50	0.10a	0.10a	0.09a		
	100	0.10a	0.11a	0.09a	0.03	0.02
OC (g/kg)	0	7.85ab	6.96a	5.52bc		
	50	10.34a	4.66c	5.36bc		
	100	11.03bc	5.83bc	5.44bc	2.90	1.38
N (mg/kg)	0	5.60a	5.40a	5.60a		
	50	4.67a	6.53a	7.47a		
	100	8.40a	7.47a	8.40a	4.89	2.33
P (mg/kg)	0	9.60a	8.33a	9.61a		
	50	9.07a	9.13a	10.67a		
	100	11.33a	9.42a	11.47a	0.11	0.05
K (mg/kg)	0	70.30b	72.00b	70.33b		
	50	180.00a	140.67ab	110.00b		
	100	183.33a	156.00ab	116.67b	55.54	26.43

bon decreased significantly as SOME digestion time increased (p=0.003). Albeit, the difference observed was only significant between the fresh SOME and the treated SOME. The difference between 20-day digestion time and 40-day digestion time was not significant. M¨oller et al. (2008) and Singh et al. (2010) also observed a decrease in total organic carbon content during anaerobic digestion of organic waste at a hydraulic retention time of 20 days. An insignificant change in organic carbon content beyond 20 days may be as a result of the organic concentration of the waste (Tambone et al. 2010). A low organic load impacts negatively on microbial activity and biogas production (Torkian et al. 2003). Nevertheless, organic loading rate is not only related to substrate concentration, but also to hydraulic retention time. A short hydraulic retention time reduces the time of contact between the biomass and the substrate (Sánchez et al. 2005). In this case, the reason behind the insignificant change in organic carbon content between 20-day digestion time and 40-day digestion time may be the low substrate concentration of SOME (Sánchez et al. 2005).

The difference in soil available N was not significant (p=0.636). Likewise, the difference in soil available phosphorus did not show any significance (p=0.531). Nevertheless, Soil K decreased with increasing SOME retention in the digester (p = 0.001). Insignificant changes in soil available P may be due to the pH level of the soil and effluent it was treated with. Also, the low soil available N may be because SOME was not rich in total nitrogen. Studies by Emmerling and Barton (2007) and De Boer (2008) show that digestates from highly degradable wastes such as poultry droppings, pig manure and cereal grains have reasonably high NH_4^+-N because they are characterized by high total nitrogen and a lower C: N ratio, while wastes with low total nitrogen are characterized by low NH_4^+-N (M¨oller et al. 2010).

In addition, there was also no significant difference in the changes that occurred due to increase in the quantity of effluent applied and no significant interaction was observed between digestion time in the anaerobic digester and the quantity of the effluent applied to the soil.

SOME phytotoxicity after soil application

The phytotoxicity effect of soybean oil mill effluent on germination and other parameters after a one-time application is shown in Table 4. Germination index (GI) and seedling vigour index (SVI) showed no significant difference with relation to wastewater retention time in the digester (p = 131, p = 168). There was, however, a significant difference in how quantity of SOME applied affected GI and SVI (p = 0.002, p = 0.001). GI and SVI decreased as SOME quantity increased. This significance difference was evidence across all application rates for GI [q0 – q1 =17.039; q0 – q2=34.077; q1 – q2=17.038]. As for SVI, significant difference was only observed between q0 and q2 and between q1 and q2 with q2 having the lowest seedling vigour. The treatments which did not receive SOME showed greater GI and SV. The fresh SOME had low GI and SV, which became worse as the quantity of SOME increased. This, however, began to increase as digestion time increased. Nevertheless, none of the treatments had a good germination (GI ≥ 80%). LSD showed that the significant difference observed for GI was only between F1 and F2 with a mean difference of 17.037, with F2 performing obviously better.

Table 4 SOME phytotoxicity on sesame after a one-time application

Parameter	Application rate (m^3/ha)	Digestion time (Days)			LSD (0.05)	SE
		0	20	40		
GI (%)	0	82.22a	68.89ab	68.67ab		
	50	60.00ab	48.89bc	66.78a		
	100	22.22c	48.89bc	60.89a	29.12	13.86
SVI	0	498.00a	385.11ab	392.44ab		
	50	422.67ab	247.11bc	301.78abc		
	100	131.11c	247.11c	293.11abc	206.01	98.06
MB-C (ug/kg)	0	4.11a	5.66a	5.75a		
	50	7.39a	7.51a	7.15a		
	100	7.04a	10.56a	8.45a	17.36	8.26

Furthermore, GI showed a positive interaction between digestion time and effluent quantity (p = 0.04), which means that the effect of SOME treatment may be compounded by effluent concentration. Microbial biomass carbon, on the other hand, showed no significant difference to prove that digestion time or SOME application rate had drastic effect on soil microbial activities (p =430, p = 223).

Low GI in untreated SOME may have been due to the presence of phytotoxic compounds in the effluent, which degraded as time in the digester increased. Mekki et al. (2007) observed that olive mill effluent contains phenolics which had an inhibiting effect on seed germination. In addition, Aggelis et al. (2003) and Magdich et al. (2012) noted a negative correlation between soil polyphenol content and tomato germination index. These claims support warning that the presence of phenolic compounds in olive oil mill effluents make them highly toxic and ecologically noxious and so could affect the growth of plants. Similar effects have also been observed in palm oil mill effluent (Nwoko and Ogunyemi 2010).

In order to understand whether SOME causes phytotoxicity due to continual application of the effluent, phytotoxicity parameters were measured after a weekly application of soybean oil mill effluent to sesame for 6 weeks. This period is considered the most sensitive growth stage of sesame. The phytotoxicity effect of the treated SOME on sesame after weekly application is shown in Table 5. There was significant difference in the effect of digestion time on microbial biomass carbon (MB-C) in soil samples that received a weekly application of the effluent for 6 weeks. MB-C increased with increasing time in the digester (F2 – F1(MB-C) = 1.525 ug/kg), but decreased as quantity of SOME applied increased.

This shows a significant interaction between digestion time and effluent quantity. Continuous application, however, did not affect plant height and number of leaves.

The suitability of SOME for fertigation

In addition to its low level of harmful salts, organic load and mineral nutrients, soybean oil mill effluent also showed low sodium adsorption ratio and therefore, it is found to have a huge potential for fertigation when properly treated. Although the effluent showed some toxic effect on germination and seedling vigour indexes and on soil microbial activities after continuous application, anaerobic digestion proved to be an adequate treatment technique for SOME, with treatment efficiency increasing as digestion time increased.

Table 5 Phytotoxicity of SOME on sesame after weekly application (for 6 weeks)

Parameter	Application rate (m^3)	Digestion time (Days)		LSD(0.05)	SE
		20	40		
Plant Height 6WAP (cm)	0	14.33a	14.33a		
	50	14.63a	14.00a		
	100	13.17a	13.67a	1.68	0.77
No of Leaves 6WAP	0	7.67a	7.33a		
	50	7.33a	7.67a		
	100	6.00b	8.00a	1.33	0.61
MB-C (ug/kg)	0	10.91a	8.80b		
	50	4.58d	5.28cd		
	100	0.60e	6.34c	1.47	0.67

SOME may not contain enough nutrient for a one-time application without supplementation, but it contains moderate levels of primary nutrients which may eventually become sufficient after a continuous or daily application through fertigation over the course of a plant cycle. A one-time application of 50 m^3 of SOME allowed a digestion time of 40 days added extra 4.68, 2.65 and 99.17 kg/ha of N, P and K, respectively to the soil, while a one-time application of 100 m^3 of SOME added extra 7, 4.65 and 115.85 kg/ha of N, P and K, respectively. According to Bar-Yosef (1999), a tomato greenhouse experiment found that the daily nutrients supply by fertigation ranged between 1-4, 0.1-0.6 and 0.1-6 kg N, P and K per hectare per day depending on the stage of growth, while maize crop required a daily supply of 0.14-14, 0.31-3.88 and 1.17-25.35 kg N, P and K per hectare per day for 100, 000 maize stands. Although a 100 m^3 of treated soybean oil mill effluent applied on a weekly interval would not completely meet the nutrient requirements of a crop like maize without supplementation, it shows a lot of potential in the production of low demanding crops such as tomato.

This result does not agree with reports on vegetable oil mill effluents such as POME and OMW. Okwute and Isu (2007) and Nwoko and Ogunyemi (2010) reported high nutrient content and increase in growth, dry matter, grain yield and nutrient content of Maize and Tomato when POME was applied. OMW has also been reported to contain high nutrient content whether untreated or treated (Asfi et al. 2012; Magdich et al. 2012; Mekki et al. 2013). The high nutrient content of these other vegetable oil mill effluents may be due to the slurry effluents which were considered in those studies, unlike the current study in which only the waste water was studied after the removal of sludge.

Conclusion

In conclusion, untreated soybean oil mill effluent inhibited germination and microbial activities, however, anaerobic digestion proves to be an adequate treatment method for the effluent. As digestion time progressed from 0 – 40 days, detoxification of SOME increased. A 20-day digestion time is not as efficient as 40 days, although a 40-day digestion time did not completely recover SOME when compared to the control.

However, application of both untreated and treated SOME did not have a drastic effect on soil properties observed. Soil pH remained in the neutral range and soil salinity level remained below the threshold for many crops. SOME increased soil organic matter content but not to a large extent. SOME also increased soil available nitrogen, phosphorus and potassium after soil application. It, therefore, has a potential for fertigation since it can supply daily doses of NPK for low-demanding crops when fully recovered.

Recommendation

Soybean oil mill effluent could be used for the fertigation of low-demanding crops after undergoing treatment, and anaerobic digestion is recommended as a cost effective treatment method for the detoxification of the effluent. A 40-day digestion time may not be adequate for a sensitive crop, especially at the germination stage. Further study should therefore be conducted to determine the retention time in the digester that completely recovers soybean oil mill effluent.

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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