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ORIGINAL RESEARCH

The potential of fermented cottonseed oil-mill effluent as inexpensive biofertilizers and its agronomic evaluation on medium-textured tropical soil

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Abstract
Purpose Upsurge of oil-mill industries and associated generation of wastewaters constitutes a huge environmental problem in Nigeria. As an option to reckless disposal, such effluents are often fermented and used as biofertilizers for nutrient-poor soils, but the potential of cottonseed oil-mill effluent (COME) and agronomic evaluation of such potential has yet been studied.
Methods A pot trial was conducted in northern Nigeria to assess the effects of COME fermented for 20 days and applied at five rates (0, 50, 100, 150 and 200 g 5-kg^{-1} soil) on soil fertility 2 weeks after application and performance of African Spinach over the next 5 weeks.
Results Soil pH increased steadily from 7.5 in unamended soil (control) to 8.0 at the maximum rate of fermented COME. Soil organic matter showed similar trend; from 16.7 to 27.7 g kg^{-1}. Also, soil available nitrogen, available phosphorus and exchangeable potassium all indicated lowest values (0.28, 4.36 and 8.25 mg kg^{-1}, respectively) in the control and the values increased steadily with increase in COME rate up to 0.47, 24.94 and 29.75 mg kg^{-1}, respectively, at the maximum rate. By contrast, plant height, leaf area, number of leaves and fresh leaf yield of spinach were highest in the control and decreased with increase in COME rate until total inhibition of plant growth at ≥150 g 5-kg^{-1} soil.
Conclusion Fermentation of COME for 20 days before use permits the expression of its fertilizer value in soil; however, the fermentation level attained within this period translates into a sub-optimal detoxification status that is too low for crop growth.

Keywords Wastewaters · Fermentation · Organic amendment · Soil fertility · Plant growth

Introduction

Processing and refining of vegetable oils generates effluents (wastewaters), about 10–25 m^3 of effluent per metric ton of product (International Finance Corporation, IFC 2007). According to FAO's (2013) records, Nigeria is the third largest producer of vegetable oil in the world and accounts for 55% of African output, with Nigerians consuming about one million metric tons of vegetable oil per annum. Such a feat in vegetable oil production and consumption implies that large quantities of effluents are generated daily. Like other developing countries, Nigeria tends to be loosely regulated with regard to the environment despite having undergone significant industrialization. With this situation, there is bound to be indiscriminate disposal of effluents in the country and this can cause environmental pollution and degradation. An alternative to reckless disposal is the fermentation and use of effluents as biofertilizers (Eneje and Ifenkwe 2012; Alfa et al. 2014).

One major constraint to increased agricultural productivity in the tropics is low soil fertility due both to inherent factors and unsustainable soil/agronomic management practices. In view of high cost of mineral fertilizers, the use of biofertilizers (including feacal wastes) is an acceptable and increasingly popular technique of soil fertility

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management. Although poultry droppings which is the most commonly used of all such organic wastes can be more efficacious than those of plant origin (Nwite et al. 2013; Moyin-Jesu 2015), it is scarcely available and this is compounded by the fact that it is competed for by uses other than agronomic production (Ezenne et al. 2014). This raises the cost of such organic fertilizers too and hence drives the search for relatively inexpensive ones. Vegetable oil can be obtained from a variety of fruits, seeds and nuts. In Nigeria, there are thousands of vegetable oil processors and producers, many of whose raw materials are oil-seed crops including cotton (*Gossypium herbaceum*). Mainly in the northern part of the country, cottonseed is among crops serving as sources of vegetable oil. The soil resources of especially the northeastern part are typically low in organic matter (often as low as 0.17%) and fertility status (Tekwa et al. 2011; Jamala et al. 2012). Rather than constituting environmental nuisance, cottonseed oil-mill effluent (COME) can be harnessed into use as biofertilizers in this region and similar regions of the tropics.

Research has revealed that effluents from vegetable oil industries are composed of heterogeneous organic compounds including polyphenolic fractions and metabolisable carbon-source compounds (Umeugochukwu 2013). Whereas some researchers propose that, with chemical/biological oxygen demand in the order of tens of hundreds mg per liter, effluents have high organic load and nutrients that are enough to restore degraded soils and enhance crop yields (Akwute and Isu 2007; International Finance Corporation (IFC) 2007; Saadi et al. 2007; Osaigbovo and Orhue 2011; Asfi et al. 2012; Eze et al. 2013), others argue that the complex organic pollutants in them contradict their potential as biofertilizers (Aggelis et al. 2003; Mekki et al. 2007). Indeed phenols are found in the effluents and these are responsible for their phytotoxic effect and antibacterial activity (Capasso et al. 1992; Pascual et al. 2007). Vegetable oil-mill effluents contain about 11.5% phenols as almost all the phenols in oil fruits go to the effluents during extraction process; only about 1% is retained in the oil extracted (Umeugochukwu 2013).

Polyphenolic fraction degrades with time and can be transformed into humic substances (Piotrowska et al. 2006). However, researchers have used different mechanisms to degrade phenols and other organic pollutants in vegetable oil effluents much faster. Although many treatment methods such as aerobic treatment, anaerobic digestion and composting have been proposed, biodegradation remains the dominant removal mechanism, especially under aerobic condition (Kittikun et al. 2000; Mekki et al. 2007; Nwoko and Ogunyemi 2010).

There have been studies pointing to the beneficial of effects of application of such other vegetable oil effluents as olive and palm oil-mill effluents on soil fertility indices and agronomic productivity (Macci et al. 2010; Nwoko and Ogunyemi 2010), but we are not aware of any corresponding evidence for cottonseed oil-mill effluent (COME). When fermented, palm oil-mill effluent contains substantial amounts of plant nutrients and represents a low-cost source of plant nutrients (Nwoko and Ogunyemi 2010). Therefore, conversion of COME to organic fertilizers could be a suitable strategy for its disposal when the effects on soil properties are known, especially after having undergone fermentation in order to degrade the phytotoxic compounds in them.

In the present study, fermented COME was applied to an arable medium-textured soil in northern Nigeria and the effect on fertility indices of the soil evaluated with African Spinach (*Amaranthus cruentus* L.) as test crop. Spinach is a leafy vegetable with a short growing season of 4–6 weeks. With the edible portion (leaves) being rich in nutrients (Tindall 1975), the role of spinach in human diet cannot be overemphasized, hence its high demand. To increase the availability of spinach throughout the year and at a reduced price too, smallholder farmers who do the bulk of the production need an inexpensive source of organic manure. The objective of this study, therefore, was to assess the biofertilizer value of COME (after fermentation for 20 days) when applied at different rates to low-fertility tropical soils and to evaluate the effect of the fermented COME on soil fertility indices using spinach.

Materials and methods

Study area

The study was a pot experiment using a loamy soil from the Teaching and Research Farm of Modibbo Adama University of Technology, Yola. Yola is located at latitude 9°12′ N and longitude 12°28′ E in the Northern Guinea Savannah of North East, Nigeria, and on altitude of 158.8 m above sea level (Adebayo and Tukur 1999).

Soil sample collection and potting

Soil was randomly collected from the Teaching and Research Farm, Modibbo Adama University of Technology, Yola from the depth zone of 0–20 cm using a spade. Soil samples were bulked into composite sample. Then 5 kg of soil was weighed into uniform plastic pots.

Procurement and fermentation of the effluent

Fresh cottonseed oil-mill effluent (COME) was collected from Yola Oil Mill (YOMILL) in Adamawa State, Nigeria. The freshly collected COME was a slurry brown effluent that was oily and odorous, but as fermentation progressed it became dewatered and darker in color. Fermentation was achieved by stirring the effluent at least two times daily for 20 days in an enclosed but well-aerated room (Nwoko and Ogunyemi 2010). This process creates an aerobic condition under which aerobic microorganisms that promote degradation thrive. The choice of 20 days as fermentation duration was based on Galli et al.'s (1997) and Nwoko and Ogunyemi's (2010) reports on olive and palm oil-mill effluents, respectively, that though these effluents had high organic loads including phenol, fermentation for about 20 days was adequate for the breakdown of these phytotoxic compounds.

Experimental treatments and procedure

The fermented COME was applied to the soil after 20 days of fermentation at the rates of 0, 50, 100, 150 and 200 g per 5-kg soil (with the first-mentioned rate serving as control). These five treatments were replicated four times, giving a total of 20 potted soils arranged in a Completely Randomized Design (CRD), whereby the potted soils were staggered irrespective of treatment and replication. The effluent was thoroughly mixed with the soil in the pots, moistened and left for 2 weeks for mineralization to occur.

Laboratory analysis

The soil was analyzed in triplicates to determine its initial physicochemical properties including texture, pH in water (pH-H_2O), electrical conductivity (EC), organic matter, available nitrogen, available phosphorus and total exchangeable bases and acidity. Also, sample of the COME was analyzed in a similar manner for pH-H_2O, EC, organic carbon, total nitrogen, total phosphorus and elemental potassium before fermentation. The parameters considered for soil 2 weeks after amendment were pH-H_2O, EC, organic matter, available nitrogen, available phosphorus and exchangeable potassium.

All analyses were done following the methods described by Ademoroti (1996) and Udo et al. (2009). In these methods, pH and EC were measured electronically with glass electrode pH and EC meters, respectively; organic carbon by dichromate wet oxidation method; nitrogen by macro Kjeldahl distillation procedure; and phosphorus and exchangeable bases/acidity extracted using Bray 1 solution and ammonium acetate, respectively.

Planting and crop data collection

African Spinach (*Amaranthus cruentus* L.), a leafy vegetable, was used to evaluate the fertility of the soil as affected by amendment with varying rates of fermented COME. Seeds were sown at three per potted soil 2 weeks after application of fermented COME. Seedlings were thinned down to one per potted soil after emergence.

The spinach plants were observed for 5 weeks during when the potted soils were watered at 2-day intervals and kept weed-free. Watering was done to field capacity of the soil, assumed to be its moisture content at −33 kPa (Obalum et al. 2011). Data were collected every week on plant growth attributes such as plant height, leaf area and number of leaves. Total biomass yield was also assessed at the end of the 5 weeks. Plant height was measured as height from soil level to the tip of the highest leaf. Leaf area was estimated by placing and tracing the leaves on a graph sheet. To assess the total biomass yield, plants were cut off from soil level at 5 weeks of age. Plants were weighed to get the fresh weight and thereafter oven-dried at a temperature of 65 °C for 24 h to get the dry matter yield. Both fresh weight and dry matter yield were extrapolated to hectarage basis.

Data analysis

Soil and crop data collected were subjected to one-way analysis of variance (ANOVA) used for an experiment in CRD with blocking. The LSD technique was employed to separate means at 5% probability level. Furthermore, correlations were performed between application rate of the fermented COME and plant growth attributes.

Results and discussion

Physical and chemical properties of soil before amendment

The pre-amendment basic properties of the soil used for the study are shown in Table 1. By its particle size distribution, the soil is medium-textured and belongs to the textural class sandy clay loam. With a pH in water of 6.0 ± 0.1, the soil was slightly acidic. Organic matter concentration, available nitrogen, available phosphorus, total exchangeable bases and acidity, and effective cation exchange capacity (ECEC) all indicated low values in this soil. For instance, both available nitrogen and available phosphorus were below their critical ranges of values of 1.50–2.00 and 10–16 mg kg^{-1}, respectively for arable crop production in tropical soils (Sobulo and Osiname 1981; Adeoye and Agboola 1985). Similarly, the soil was deficient of exchangeable potassium, as this parameter was clearly below the critical range of values of 63–99 mg kg^{-1} (Akinrinde and Obigbesan 2000). The three primary macronutrient elements of nitrogen, phosphorus and potassium (NPK) were, therefore, limiting in this soil. That

Table 1 Physical and chemical properties of the soil used for the experiment before amendment

Parameter	Value
Sand (%)	51
Silt (%)	19
Clay (%)	30
Textural class	Sandy clay loam
pH	6.0 ± 0.1
EC (dS m^{-1})	0.12 ± 0.1
Organic matter (g kg^{-1})	17.80 ± 1.2
Available N (mg kg^{-1})	0.18 ± 0.1
Available P (mg kg^{-1})	6.20 ± 0.1
Exchangeable K (mg kg^{-1})	6.70 ± 1.7
TEB (cmol kg^{-1})	3.74 ± 0.2
TEA (cmol kg^{-1})	0.92 ± 0.08
ECEC (cmol kg^{-1})	4.66

EC electrical conductivity, *N* nitrogen, *P* phosphorus, *K* potassium, *TEB* total exchangeable bases, *TEA* total exchangeable acidity, *ECEC* effective cation exchange capacity

of available phosphorus was unexpected, considering the fact that the soil was only slightly acidic. This observation thus highlights the well-known low status of phosphorus availability in tropical soils (Owusu-Bennoah et al. 1995; Obalum and Chibuike 2017).

Properties of cottonseed oil-mill effluent

Results of the analysis of the unfermented COME are presented in Table 2, showing that the effluent was alkaline, had a moderate electrical conductivity and a high organic carbon concentration. Its contents of total nitrogen, total phosphorus and elemental potassium are also shown. The effluent had a C/N ratio of 8.8. In a soil fertility trial, Uzoh et al. (2015) reported lower values of C/N ratio in the range of 3–5 for swine and cattle fecal wastes used as soil amendments. The unfermented COME would therefore be expected to decompose at a slower rate in the soil compared to these conventional organic soil amendments.

Table 2 Some chemical properties of the unfermented cottonseed oil mill effluent

Parameter	Value
pH	7.9 ± 0.2
EC (dS m^{-1})	0.33 ± 0.7
Organic carbon (g kg^{-1})	133.40 ± 4.7
Total N (g kg^{-1})	15.20 ± 1.2
Total P (g kg^{-1})	36.08 ± 2.2
K (g kg^{-1})	30.00 ± 1.7
C/N mass ratio	8.8

EC electrical conductivity, *N* nitrogen, *P* phosphorus, *K* potassium

The observation that the unfermented COME was alkaline is attributed partly to the notion that the whole effluent may have not been fresh after all and partly to the unique attribute of COME. When freshly discharged, raw vegetable oil effluent is acidic but the pH gradually tends toward alkalinity as biodegradation takes place (Hemming 1977). The alkaline pH of the 'unfermented' COME may be considered its advantage over such other effluents as olive and palm oil-mill effluents (Nwoko et al. 2010; Mekki et al. 2013), especially with the acidic nature of most tropical soils vis-à-vis the tendency for reckless disposal of effluents onto such soils and the possible effect on overall ecosystem wellbeing.

The organic carbon content of the unfermented COME was high. This is unsurprising as high content of organic carbon seems to be a common attribute of vegetable oil-mill effluents (Nwoko et al. 2010; Osaigbovo and Orhue 2011; Eze et al. 2013; Mekki et al. 2013). However, the level of nitrogen in the unfermented COME was low while the levels of phosphorus and potassium in it were high when compared with values reported for olive and palm oil-mill effluents (Nwoko et al. 2010; Mekki et al. 2013).

Soil chemical properties after effluent application

The chemical properties of the soil after effluent application are presented in Table 3. Application of fermented COME had differing effects on chemical properties of the soil. The pH of the soil steadily increased with increasing levels of fermented COME, reflecting the alkaline nature of the effluent. Notably, however, differences in soil pH among potted soils that received between 50 and 200 g of fermented COME per 5-kg soil were not significant, implying that application beyond 50 g per 5-kg soil had no beneficial effect on the soil pH. The soil pH became slightly alkaline at all levels of fermented COME, including the control. This increase in the pH of the soil suggests that improved soil moisture regime as was the case during the 2-week interval before planting could ameliorate the acidity of this soil.

The increases in organic matter concentration in the soil due to the fermented COME were not significant. However, the soil's contents of nitrogen, phosphorus and potassium increased steadily with increase in application level of fermented COME. The increases in these plant nutrients in the soil are therefore attributable to its amendment with the effluent. The increases were mostly significant as also reported for olive and palm oil-mill effluents (Nwoko et al. 2010; Osaigbovo and Orhue 2011; Mekki et al. 2013).

Table 3 Some chemical properties of the soil 2 weeks after effluent application

COME rate (g 5-kg^{-1} soil)	pH-H_2O	Organic matter (g kg^{-1})	Available N (mg kg^{-1})	Available P	Exchangeable K
0	7.5 ± 0.1	16.7 ± 0.7	0.28 ± 0.1	4.36 ± 5.0	8.25 ± 1.0
50	7.8 ± 0.2	18.7 ± 0.6	0.32 ± 0.1	16.30 ± 6.6	15.75 ± 0.5
100	7.90 ± 0.1	26.9 ± 0.3	0.35 ± 0.1	16.40 ± 4.1	21.50 ± 6.1
150	7.9 ± 0.1	27.4 ± 0.7	0.38 ± 0.04	17.04 ± 1.6	25.50 ± 1.7
200	8.0 ± 0.1	27.7 ± 1.4	0.47 ± 0.1	24.94 ± 7.1	29.75 ± 2.2
$LSD_{0.05}$	0.07	NS	0.05	3.97	2.29

NS not significant, *N* nitrogen, *P* phosphorus, *K* potassium

Effect of cottonseed oil-mill effluent on performance of African Spinach

The effects of fermented COME on plant height, leaf area, number of leaves and dry matter yield are shown in Tables 4, 5, 6 and 7, respectively. The results show that the spinach plants grown in the unamended control had higher values of all the growth parameters and yield compared to those grown in COME-amended potted soils. As the application rate of the effluent increased, the growth and yield of the spinach plants declined further. Coefficients of the correlations, *r*, between the effluent application rate and the plant growth parameters for plant height, leaf area and number of leaves were -0.81^{**}, -0.71^{**} and -0.88^{**}, respectively.

The above poor performance of spinach in COME-amended potted soils started from emergence; while it took seeds sown in the control only 4 days to emerge, it took those in potted soils amended with 50 and 100 g of the effluent over 6 days to emerge, and there was no emergence at all where higher rates were applied. Similar results for palm oil-mill effluent were reported by Kittikun et al. (2000) and Osaigbovo and Orhue (2011) who attributed their observation to the oily nature of the effluent. The oily nature of the fermented COME might have impaired aeration of the soil which led to poor germination and performance of spinach. In addition, with a C/N ratio of approximately nine resulting to the release of excess nitrogen, the subsequent release of excessive ammonia may have impeded germination and the development of seedlings.

The poor performance of spinach plant may also be attributed to the pH of the amended soils which was moderately alkaline as Amaranthus is adapted to soils that are slightly acidic to slightly basic, i.e., pH of 6.5–7.5 (Meyers and Putnam 1988). This probably inhibited the availability of micronutrients which are also needed for plant growth and development. Above all, it was possible that the 20-day fermentation period was not adequate to

Table 4 Effect of fermented cottonseed oil mill effluent (COME) on plant height (cm) of African Spinach (*Amarantus cruentus* L.)

COME rate (g 5-kg^{-1} soil)	Weeks after planting			
	2	3	4	5
0	9.53	14.63	19.98	22.43
50	3.75	4.85	6.05	8.10
100	0.45	0.45	0.45	0.45
150	0.00	0.00	0.00	0.00
200	0.00	0.00	0.00	0.00
$LSD_{0.05}$	1.14	1.54	1.64	2.03

Table 5 Effect of fermented cottonseed oil mill effluent (COME) on leaf area (cm^2) of African Spinach (*Amarantus cruentus* L.)

COME rate (g 5-kg^{-1} soil)	Weeks after planting			
	2	3	4	5
0	2.13	5.25	7.25	8.00
50	0.30	0.65	1.15	1.28
100	0.03	0.03	0.03	0.03
150	0.00	0.00	0.00	0.00
200	0.00	0.00	0.00	0.00
$LSD_{0.05}$	0.22	0.65	0.61	0.55

Table 6 Effect of fermented cottonseed oil mill effluent (COME) on number of leaves of African Spinach (*Amarantus cruentus* L.)

COME rate (g 5-kg^{-1} soil)	Weeks after planting			
	2	3	4	5
0	6.25	8.75	9.75	10.00
50	3.25	4.25	5.50	6.50
100	0.50	0.50	0.50	0.50
150	0.00	0.00	0.00	0.00
200	0.00	0.00	0.00	0.00
$LSD_{0.05}$	0.50	0.79	0.88	1.13

Table 7 Effect of fermented cottonseed oil mill effluent (COME) on dry matter yield[a] of African Spinach (*Amarantus cruentus* L.)

COME rate (g 5-kg^{-1} soil)	Fresh weight		Dry weight	
	(g/pot)	(kg ha^{-1})	(g/pot)	(kg ha^{-1})
0	2.21	880.00	0.55	242.00
50	0.32	140.80	0.04	17.60
100	0.01	4.40	0.0002	0.09
150	0.00	0.00	0.00	0.00
200	0.00	0.00	0.00	0.00
$LSD_{0.05}$				3.00

[a] The yield per pot is shown side-by-side with its hectarage equivalent

achieve complete detoxification of the COME, such that the phytotoxic compounds were still in sufficient quantities in the effluent to interfere with normal uptake of available nutrients. With olive oil-mill effluent, Macci et al. (2010) reported a fermentation level at which the effluent lost its toxicity and stimulated plant germination and growth.

Conclusion

Although cottonseed oil-mill effluent is carbon-rich and contains many plant nutrients, its application to soil after fermenting for 20 days could only boost the soil fertility but not crop performance, indexed here by the growth and yield of spinach. The higher is the application rate of this fermented effluent/wastewater, the greater are its beneficial effects on soil fertility and detrimental effects on crop performance. These contrasting effects of the fermented effluent on soil fertility and plant growth suggest that fermentation period of 20 days may be adequate for the effluent to express its fertilizer value in soil but this may not detoxify it of phytotoxic compounds to an agronomically safe level, hence contradicting its potential as biofertilizers. Therefore, further study is needed on the interaction of fermentation duration and application rate of this wastewater to enhance its fertilizer value in crop production while averting any environmental hazards of such means of its disposal. Due to the observed phytotoxicity of the cottonseed oil-mill effluent, other pre-treatment options for this wastewater should also be explored such as chemical oxidation and biological treatment (Yaser et al. 2013) as well as coagulation and membrane separation (Zahrim et al. 2014).

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