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ORIGINAL ARTICLE

Yield and quality of maize from spent engine oil contaminated soils amended with compost under screenhouse conditions

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Abstract
The study investigated the effects of poultry manure compost (PMC) on the growth performance and yield of maize (*Zea mays* L.) when cultivated on spent engine oil (SEO) contaminated soil with a view to assessing its nutritional composition. The experiment consisted of three SEO treatments (0%, 1% and 2% w/w) with six levels (0, 2, 4, 6, 8 and 10 t ha^{-1}) of PMC applications. Each treatment was replicated thrice and arranged in a 3 × 6 × 3 factorial completely randomized design to give a total of 54 pots. At full physiological maturity, maize grains were harvested and threshed manually for analysis. As the bioavailability of metals increased with increasing PMC, their uptake by maize plants was enhanced. The soil amended with 10 t ha^{-1} and contaminated with 1% SEO recorded the highest uptake rates of 1.761×10^{-2}, 2.345×10^{-2} and 4.285×10^{-2} day^{-1} for Fe, Cu and Pb respectively. Also, the significantly ($P<0.05$) highest yield of maize (5.8 t ha^{-1}) and the highest nutritional values of crude protein (11.27 g 100 g^{-1}) and crude fibre (2.71 g 100 g^{-1}) were obtained with zero SEO soil contamination at 10 t ha^{-1} PMC applications. There was evidence of yield and nutritional quality reduction of maize when cultivated on SEO contaminated soils with or without poultry compost fertilization.

Key words: maize; metal uptake; poultry compost; soil health; spent engine oil; nutritional quality; public health

INTRODUCTION

The current increase in the purchase and usage of fairly well-used, otherwise called 'second-hand' automobile and generator engines has led to an increase in the usage of lubricating oil and other petroleum products for their servicing in developing countries of Africa. The spent engine oil obtained after servicing and subsequent draining from automobile and generator engines is arbitrarily thrown into the soil surface within the vicinities of car mechanic workshops, especially, in Nigeria (Anoliefo and Vwioko 1995). Much of the vacant land that has received and is still receiving this contaminant is being cultivated, particularly with maize, cassava and vegetables by the mechanics and the people that live in the

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neighbourhood (Adewole and Uchegbu 2010). This is probably because car mechanic activities in Nigeria are usually under the control of semi-literate individuals (Adewole and Uchegbu 2010) and agri-business is presently at subsistence level (Oluwasola 2011).

Spent engine oil is a mixture of various hazardous chemicals such as polycyclic aromatic hydrocarbon and heavy metals (Wang et al. 2000). Most of these metals such as Zn, V, Pb, Al, Ni and Fe, which are below detection levels in unused lubricating oil, give high values in used oil (Parreira et al. 2011). These metals come from engine parts as a result of wear and tear (Njoku et al. 2012), in addition to the various aliphatic and aromatic compounds that formed the original base of the oil. The heavy metals may be retained in soils in the form of oxides, hydroxides, carbonates, exchangeable cations, and/or bound to organic matter in the soil (McGrath et al. 1995); while some may escape beyond the plants' root zone into the water table (Adelekan and Abegunde, 2011). Soils polluted with spent engine oil had a reduced soil microbial population and activity (Nwoko et al. 2007), reduced soil fertility status (Alloway and Ayres 1997) and reduced crop performance and yield (Njoku et al. 2012).

Many of the mobile constituents from the spent engine oil could be intercepted by the roots of the growing crops and transported to the edible parts of the crops. Such harvested crops could pose a health risk to consumers. The person with a high accumulation of heavy metals such as Pb and Cd and aromatic compounds such as polycyclic aromatic hydrocarbons and chlorinated biphenyls may cause liver and kidney damage (Pirkle et al. 1998, Abioye et al. 2012). In Nigeria, the current trend of peri-urban farming, with or without soil amendment on contaminated soils, is alarming. Also, there is an increase in the use of organic manures because they are abundantly available and cheap compared to the conventional scarce and expensive inorganic fertilizers. The choice of poultry manure as a soil amendment in this experiment, is to help ameliorate the degradation of spent engine oil and also, to help provide the nutrient elements required for the growing of a test crop.

Therefore, this study determined the growth pattern, yield and nutritional quality of maize when different rates of composted poultry manure were used as soil nutrient supplements. The study also determined the uptake rate of metals (Fe, Cu and Pb) by maize when cultivated on different concentrations of spent engine oil contaminated soils in pot culture.

MATERIALS AND METHODS

Experimental design and agronomic details

The experiment was conducted in a screenhouse of the Faculty of Agriculture, Obafemi Awolowo University, Ile-Ife, Nigeria. Bulk surface soil samples (0–15 cm) were collected from an exhaustively cropped farm in the University, air-dried for seven days, sieved using 2 mm sieve and analysed using standard methods. Fifty-four polythene pots with drainage holes at the bottom, each containing 10 kg of surface soil, were randomly placed on a table in the screenhouse in a factorial combination of three treatment levels (2.0%, 1.0% and 0% w/w) of spent engine oil and six different fertility management levels (0, 2, 4, 6, 8 and 10 t ha^{-1}) of composted poultry manure. The spent engine oil was obtained from a car workshop in Ile-Ife, Nigeria. Different doses of aerobically composted poultry manure and spent engine oil were added to the soil inside the pots, homogenized by stirring using a glass rod, wetted with distilled water and allowed to equilibrate for two weeks. Two weeks after the application of spent engine oil and poultry compost, three seeds of SUWAN-1-YELLOW maize (obtained from the Institute of Agricultural Research and Training, Ibadan, Nigeria) per pot were sown.

The maize stands were regularly watered throughout the growing stage. The maize plants were thinned to two stands per pot at two weeks after planting (WAP). The thinned stands were retained inside the pots from which they were removed so as to put back into the soil what might have been taken up by the plant within the first two weeks of growth. Fortnightly, growth parameters of maize such as plant height, number of leaves and stem girth were measured till 12 weeks after planting when the experiment was terminated. The post-cropping analyses of the soils were carried out to determine the concentrations of Fe, Cu and Pb. The root, shoot and maize seeds were oven-dried at 70 °C for 48 h for the determination of the uptake of Fe, Cu and Pb using standard methods.

Soil and poultry manure samples analyses

Fresh poultry droppings heaped under a shed was allowed to compost aerobically for three months. The poultry manure was stirred to enhance composting once in every two weeks during the period. The poultry compost was air-dried, ground and analysed. The soil and manure compost pH were electrometrically determined (McLean 1982). The pH was determined when the electrode of the standardized pH meter was inserted into the partly settled suspension of soil/distilled water and manure compost/distilled water in the ratio 1:1. The carbon contents in the soil and manure compost were determined using the Walkey-Black method (Nelson and Sommers 1982). This is a wet oxidation method when 1 N $K_2Cr_2O_7$ is titrated against the wet oxidized samples using concentrated H_2SO_4 and *o*-phenanthroline ferrous complex as an indicator. The total nitrogen content of the soil and manure compost was determined by the macro-Kjeldahl method of Bremner and Mulvaney (1982). Each of the samples was carefully heated inside a dry 500 ml macro-Kjeldahl flask with concentrated H_2SO_4 and a tablet of mercury as catalyst. Also, 4% H_3BO_3 and 45% NaOH mixture were added into the heated sample and distilled. The total N was obtained when 0.01 N HCl was titrated against the distillate.

The available phosphorus concentrations in the soil and manure compost were determined using the Bray P1 method (Olsen and Sommers 1982). The extracting solutions for available P were 0.5 N HCl and 1.0 N NH_4F. Exchangeable cations ($K^+ + Na^+ + Ca^{2+} + Mg^{2+}$) were extracted with 1 M ammonium acetate buffered at pH 7.0 (Thomas 1982) and the concentrations of Ca^{2+} and Mg^{2+} in the soil and manure compost extracts were read using a Buck Scientific 210/211 VGP Atomic Absorption Spectrophotometer (AAS) (East Norwalk, Connecticut, USA) while Na^+ and K^+ concentrations were read on a Gallenkamp flame photometer. Iron and Cu were extracted with 0.1 M HCl while Pb was extracted with 5 ml of the mixture (conc. HNO_3 and conc. $HClO_4$ in the ratio 2:1) with 5 ml of conc. H_2SO_4 (Juo 1979) and their concentrations in the soil extracts were read using an AAS.

The exchangeable acidity ($H^+ + Al^{3+}$) in the soil and manure compost were extracted with 1 M KCl according to Thomas (1982) and the extract was titrated with 0.05 M NaOH using phenolphthalein as an indicator (Odu et al. 1986). Appropriate similar procedures were used for the determination of selected properties of the used oil. The properties of the soil, poultry manure compost and spent engine oil used for this experiment, are presented in Table 1.

Table 1. Properties of soil, poultry manure compost and spent engine oil used for the experiment

Property	Soil	Poultry manure compost	Spent engine oil
pH (1:1 Soil-water)	6.60±0.43	5.92±0.36	–
Organic carbon (g kg^{-1})	12.6±1.7	31.5±2.6	28.8±2.1
Total nitrogen (g kg^{-1})	0.73±0.03	3.6±0.2	2.9±0.7
Available phosphorus (mg kg^{-1})	3.7±0.3	4.4±0.3	0.1±0.01
K (mg kg^{-1})	0.3±0.01	21.7±1.8	–
Na (mg kg^{-1})	0.4±0.02	8.7±1.1	–
Ca (mg kg^{-1})	0.6±0.03	18.5±1.3	–
Mg (mg kg^{-1})	0.9±0.03	6.5±0.8	–
Exchangeable acidity (mg k^{-1})	0.5±0.03	0.7±0.03	–
Fe (mg kg^{-1})	137.0±5.7	8.3±1.1	466.3±8.1
Cu (mg kg^{-1})	0.5±0.04	Bdl	7.9±1.2
Pb (mg kg^{-1})	0.5±0.03	Bdl	312±5.6

Bdl = below detection limit

Shoots, roots and quality analyses of maize

Twelve weeks after sowing, the maize cobs were manually harvested and the experiment was terminated. Each pot from where maize was harvested was brought under the flow of tap water to remove the soil attached to the roots of maize. Distilled water was thereafter used to rinse the roots. Maize shoots were collected per treatment pot using a knife cleaned from all the replicates. Plant tissues were separated into root and shoot; oven-dried at 70 °C for 48 hours and ground using a Thomas stainless-steel milling machine.

Iron, Cu and Pb concentrations in the root and shoot of maize were determined using 5 ml of the mixture of concentrated HNO_3 and $HClO_4$ in the ratio 2:1, and 5 ml of concentrated H_2SO_4, to digest 0.5 g of each sample for 2 h at 150 °C (Juo 1979). The concentrations of Fe, Cu and Pb in the extracts were determined by AAS. The nutrient concentrations obtained were multiplied by the mean dry weights of the roots and shoots to get the nutrients uptake per treatment. Quality analysis of the harvested maize was carried out according to the method of the Association of Official Analytical Chemists (1990).

Rate of uptake of Fe, Cu and Pb by maize

The metal values were fitted into the first-order kinetics model:

$$C = C_o e^{-kt} \qquad (1)$$

where C is the final Fe, Cu and Pb values in soil (mg kg^{-1}) at time t, Co is the initial Fe, Cu and Pb values in soil (mg kg^{-1}), k is the uptake rate constant (d^{-1}) and t is time (d).

Statistical analysis

Data collected were subjected to descriptive and one-way analysis of variance to test their treatment effects. The experimental precision achieved was reported by standard error at the probability level of 95%.

RESULTS AND DISCUSSION

Plant height of maize

The effects of poultry compost at different levels of SEO on the mean plant heights of maize plant measured at two-week intervals are represented in Fig. 1a–f. Pots with PMC fertilization and without contamination with SEO had the highest maize plant height. The absorption of mineralised PMC became manifest in the fourth week after sowing. The N and P in the PMC were easily absorbed by the maize plants and enhanced rapid plant growth. Soil nutrients are less mobile in soils contaminated with SEO (Atuanya 1987) and this condition will adversely alter the growth pattern of plants (Okon and Udofot 2012). The mean plant height was inversely related to the SEO contamination and directly related to the quantity of poultry compost fertilization. The reduced plant height of maize in SEO contaminations may be attributed to the stress imposed by artificially created drought conditions as well as the non-availability of nutrients for the roots during the SEO exposition suffered by plant roots due to the roots' inability to get sufficient water and plant nutrients from the soil (Uhegbu et al. 2012).

Stem girth of maize

The effect of poultry compost at different levels of SEO on the mean stem girth of the maize plant measured at two-week intervals are represented in Fig. 2a–f. From 2 WAP to 12 WAP, the order of increase of the stem girth of maize plant was: 0%>1%>2% at different fertilization levels. Also, from 10 WAP to 12 WAP there was no appreciable increase in the stem girth of maize plant at 1% and 2% contaminations.

Number of leaves of maize

The effect of poultry compost at different levels of SEO on the mean number of leaves of maize plant measured at two-week intervals are represented in Fig. 3a–f. Leaf production reduced with the increase in the concentration of SEO. Reduced soil aeration due to thin film layer formation on the topsoil by the applied SEO could have reduced the air passage through the soil pores, thereby leading to the suffocation of the maize plants (Udo and Fayemi 1975) and hence, reduction in the number of leaves. However, the addition of composted poultry manure enhanced leaf production. This agreed with the previous findings of Okon and Udofot (2012), though green manure from *Gliricidia sepium* leaves and *Glomus mosseae*, an arbuscular mycorrhizal fungus, were used to enhance the germination, growth and biomass yield of *Telfairia occidentalis* when cultivated on spent engine oil.

Rate of uptake of Fe, Cu and Pb by maize

First order kinetics was used to determine the rates of uptake of selected heavy metals (Fe, Cu and Pb) found in spent engine oil under different rates of poultry manure compost and these are shown in Table 2. The soil amended with 10 t ha^{-1} and contaminated with 1% SEO recorded the highest uptake rates of 1.761×10^{-2}, 2.345×10^{-2} and 4.285×10^{-2} per day for Fe, Cu and Pb, respectively. The uptake rates at 0% and 2% SEO contamination levels were much lower. The uptake rates of Fe, Cu and Pb at 0% SEO level was low because these were soil-native-concentration dependent and the values were low. Also, the low uptake rates obtained at 2% SEO contamination could be attributed to lower chelating tendencies on the soil surface exhibited by these metals at high contamination of petroleum hydrocarbons

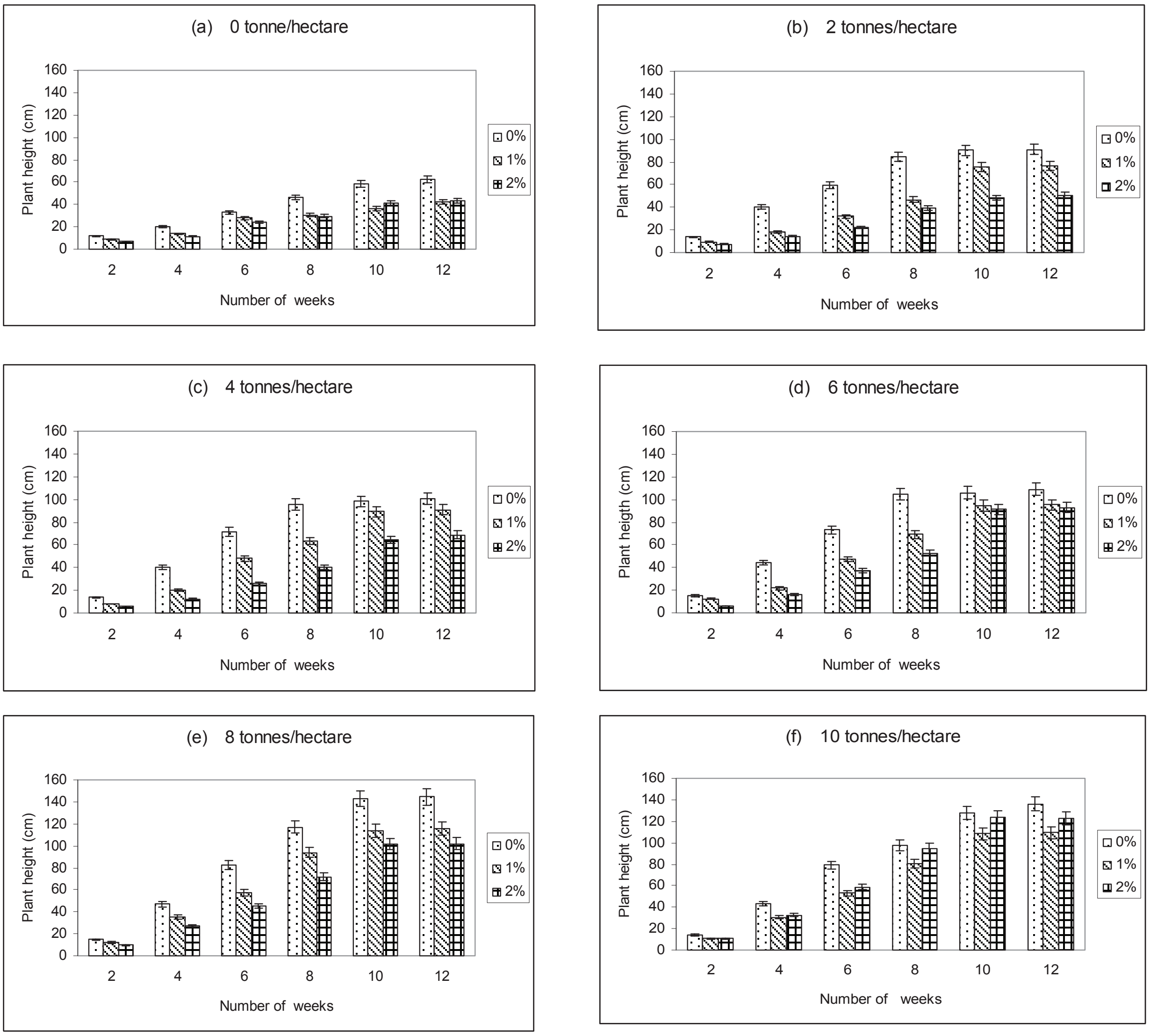

Fig. 1a–f. Mean plant height of *Zea mays* at different level of poultry compost and spent engine oil contaminations

Legend: 0%, 1%, 2% = Contamination levels of spent engine oil
0, 2, 4, 6, 8, 10 = Different levels of poultry compost (tonnes/hectare)
Vertical bars represent the SE

in the soils. Similar to this, though with soil microorganisms, was the observation of Rahman et al. (2002) who obtained lower degradation rates of crude oil at higher concentration levels; although the adsorbed cations increased with the increase in added poultry compost, suggesting a progressive increase in the surface area of soil organic matter as added poultry compost increased and these metals were taken up by the maize plant.

Our study demonstrated a higher uptake of metals by maize in SEO contaminated soil and the added poultry manure enhanced this uptake. Obviously, the presence of SEO as a soil contaminant was responsible for the increase in the uptake of these metals, particularly Fe and Pb by maize. However, Cu uptake was low, probably because of its low concentration in SEO. This result suggests that SEO imposed 'some burdens' on the soils and crops during cultivation.

The metals in the soil and SEO structure might have been loosened (Blaylock et al. 1997), and with the added manure (Okon and Udofot 2012) are made more bioavailable. This agreed with an earlier work of Abioye et al. (2012) where organic-based fertilizers (brewery spent grain, banana skin and spent mushroom compost) were found to enhance the degradation of used motor oil, thereby enhancing the availability of SEO constituents.

Yield and nutritional quality of maize

Mean yields of maize grain at different contamination levels of SEO and PMC applications are presented in Table 3. The highest mean yield (5.8 t ha^{-1}) of maize grains obtained without soil contamination was not significantly higher than 5.2 t ha^{-1} obtained with 1% SEO soil contamination, but significantly (P<0.05) higher than 3.9 t ha^{-1} at 2% SEO soil contamination, if 10 t ha^{-1} of poultry compost fertilizer was applied.

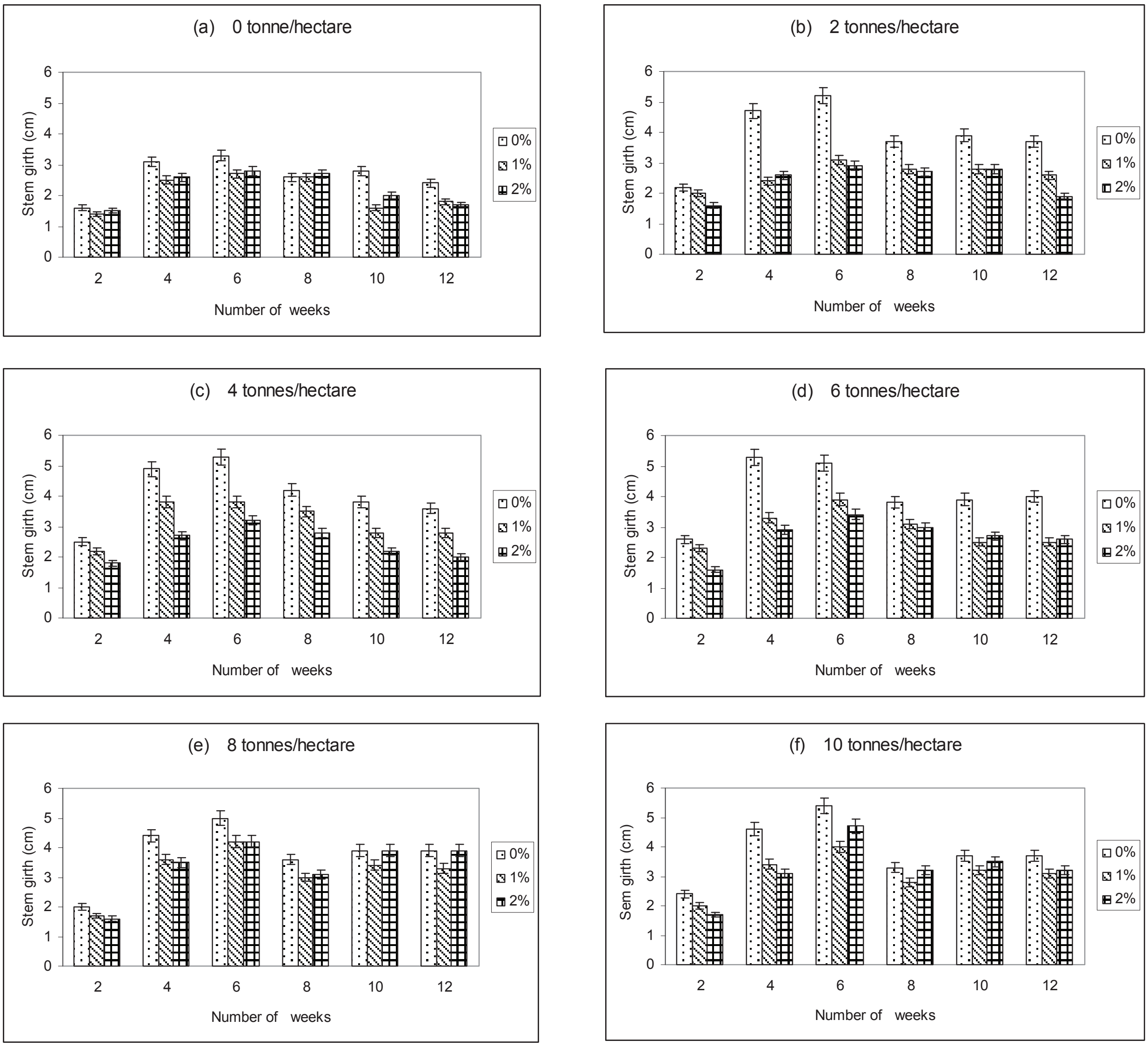

Fig. 2a–f. Mean stem girth of *Zea mays* at different level of poultry compost and spent engine oil contaminations

Legend as in Fig. 1

Table 2. Uptake rates (x 10^{-2} day^{-1}) of heavy metals by maize in the pot culture

PMC level (t ha^{-1})	Iron	Copper	Lead
No spent engine oil			
0	0.347^b	1.020^a	1.003^b
2	0.368^b	1.030^a	1.123^b
4	0.444^b	1.167^a	1.189^b
6	0.498^b	1.230^a	1.341^b
8	0.546^b	1.270^a	1.429^b
10	0.651^b	1.441^a	2.105^b
% (w/w) of spent engine oil			
0	1.533^a	1.332^a	3.887^a
2	1.617^a	1.341^a	3.967^a
4	1.644^a	1.429^a	4.028^a
6	1.713^a	1.441^a	4.178^a
8	1.758^a	1.527^a	4.258^a
10	1.761^a	2.345^a	4.285^a
2% (w/w) of spent engine oil			
0	1.415^a	0.784^b	3.648^a
2	1.498^a	0.784^b	3.683^a
4	1.554^a	1.151^a	3.700^a
6	1.626^a	1.163^a	4.035^a
8	1.639^a	1.279^a	4.066^a
10	1.735^a	1.425^a	4.084^a

Legend:
0, 2, 4, 6, 8, 10 = Different levels of poultry compost (PMC)
Means with the same letter in each column are not significantly different using Duncan's Multiple Range Test at $P<0.05$

In addition, at 2% SEO soil contamination with 10 t ha^{-1} of PMC, a significantly ($P<0.05$) higher mean yield (3.9 t ha^{-1}) of maize grains was obtained when compared with mean yield obtained at lower doses of PMC in zero percent SEO soil contamination. Poor soil conditions brought about by added SEO adversely affected the physiological growth, and hence the poor yield of maize. Insufficient aeration and reduced soil microbial activity are associated problems for soil polluted with spent engine oil (Udo and Fayemi 1975, Anoliefo and Vwioko 1995). It was expected that the yield of maize grains would increase with the increase in the application of compost fertilizer and it would decrease with an increase in SEO. Native soil properties at zero fertilization with no SEO application were not enough to support maize cultivation, hence, zero yield was obtained.

The highest nutritional values (g 100 g^{-1} dry matter) of maize grains such as reducing (available) sugars 1.75, vitamin C 1.83, crude protein 11.27, crude fibre 2.71, and carbohydrates 87.18 were obtained with zero SEO soil contamination at 10 t ha^{-1} PMC application (Table 3). These values reduced with an increase in SEO. Iken et al. (2002), in a comparative analysis of the nutrient composition of selected maize varieties, obtained a crude protein level ranging from 11.4 to 9.7 g 100 g^{-1} and crude fibre from 2.1 to 1.6 g 100 g^{-1}, which were comparable to our results from zero SEO soil contamination. However, lower values of carbohydrates (60.3–64.0 g 100 g^{-1}) obtained in their maize varieties compared with our results could be due to varietal differences. Crude fibre, the bulk of roughage in food was highest, also at zero soil contamination.

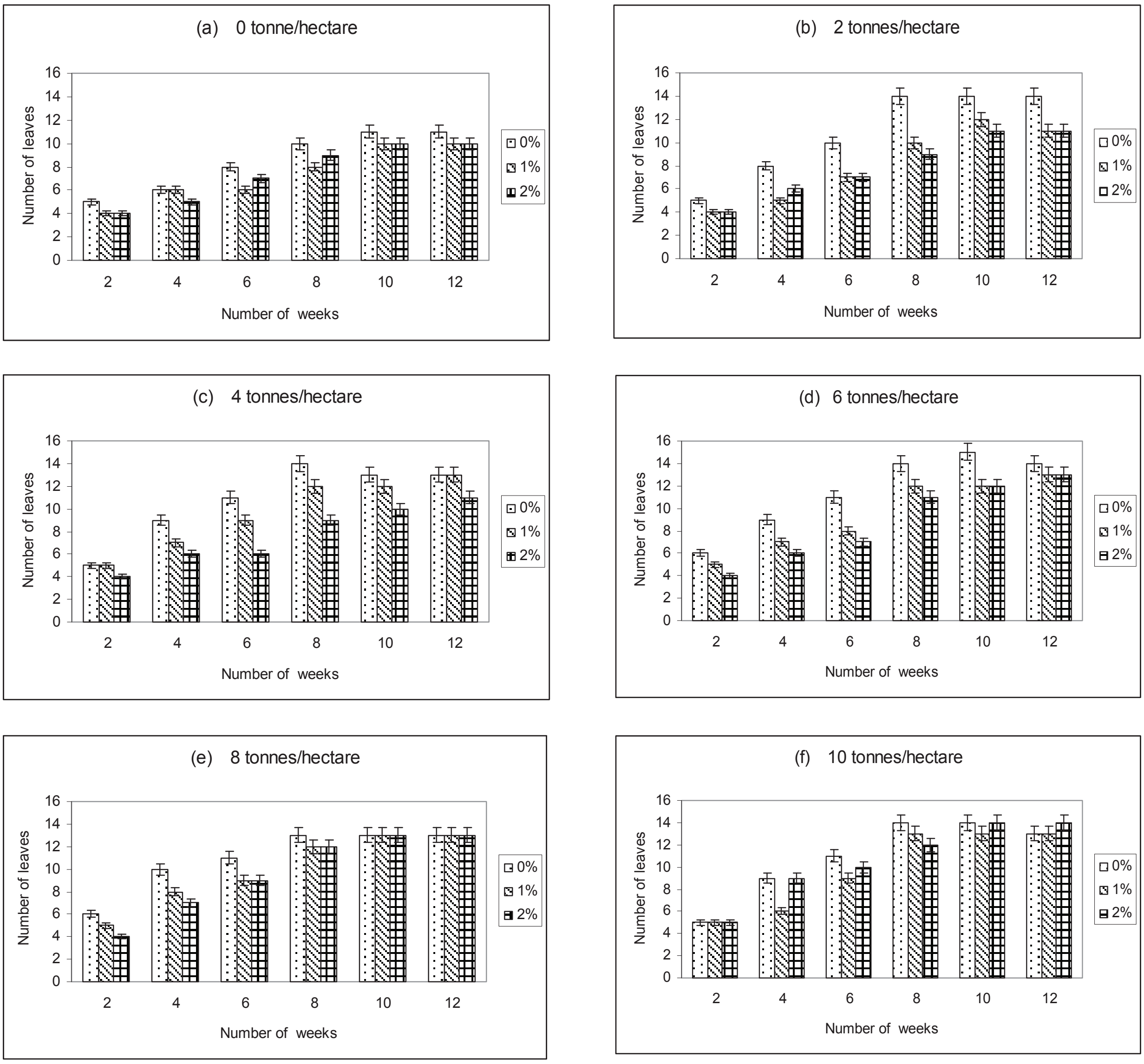

Fig. 3a–f. Mean number of leaves of *Zea mays* at different level of poultry compost and spent engine oil contaminations

Legend as in Fig. 1

Table 3. Effects of spent engine oil on the yield (t ha^{-1}) and nutritional quality (g 100 g^{-1}) of maize grains (on dry matter basis) under different level of poultry compost (PMC) applications

PMC level (t ha^{-1})	Dry weight	Reducing sugar	Vitamin C	Crude protein	Crude fiber	Ash	Carbo-hydrates
No spent engine oil							
0	ny	ny	ny	ny	ny	ny	ny
2	0.7^{d}	1.38^{b}	1.56^{b}	9.35^{c}	1.86^{c}	2.76^{b}	75.07^{b}
4	2.1^{c}	1.57^{b}	1.63^{b}	9.57^{c}	2.13^{b}	3.02^{b}	76.77^{b}
6	2.8^{bc}	1.26^{b}	1.74^{b}	10.28^{b}	2.04^{b}	2.62^{b}	78.66^{b}
8	3.0^{b}	1.44^{b}	1.74^{b}	10.37^{b}	2.67^{a}	2.35^{b}	79.34^{b}
10	5.8^{a}	1.75^{a}	1.83^{a}	11.27^{a}	2.71^{a}	3.44^{a}	87.18^{a}
1% (w/w) of spent engine oil							
0	ny	ny	ny	ny	ny	ny	ny
2	ny	ny	ny	ny	ny	ny	ny
4	ny	ny	ny	ny	ny	ny	ny
6	1.3^{c}	1.11^{b}	1.38^{b}	9.12^{c}	1.78^{c}	2.21^{b}	78.93^{b}
8	1.5^{c}	1.22^{b}	1.37^{b}	10.00^{c}	2.38^{b}	3.26^{a}	77.52^{b}
10	5.2^{a}	1.58^{b}	1.41^{b}	11.15^{b}	2.44^{b}	3.53^{a}	77.04^{b}
2% (w/w) of spent engine oil							
0	ny	ny	ny	ny	ny	ny	ny
2	ny	ny	ny	ny	ny	ny	ny
4	ny	ny	ny	ny	ny	ny	ny
6	0.8^{d}	1.09^{b}	1.33^{b}	9.49^{c}	1.92^{c}	2.48^{b}	86.10^{a}
8	0.9^{d}	1.17^{b}	1.22^{b}	9.57^{c}	2.15^{b}	2.94^{b}	76.64^{b}
10	3.9^{b}	1.49^{b}	1.09^{b}	10.48^{b}	2.07^{b}	3.31^{a}	76.46^{b}

Legend:

0, 2, 4, 6, 8, 10 = Different levels of poultry compost (tonnes/hectare)

ny = no yield

Means with the same letter(s) in each column and group are not significantly different using Duncan's Multiple Range Test at $P<0.05$

We concluded that the cultivation of spent engine oil contaminated soil with maize is a pathway through which metals could enter the food chain and composted poultry manure enhanced metal uptake. Also, the quantity and quality of the maize grains produced was however reduced with or without poultry compost fertilization on spent engine oil contaminated soils. From this study, it may be deduced that the best quality maize, particularly in terms of the crude protein and crude fibre obtained in zero percent SEO contaminated soil should be of interest for enhanced human health of the developing countries in the humid tropics.

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