Improving Food Security by Adapting and Mitigating Climate Change-Induced Crop Pest: The Novelty of Plant-Organic Sludge in Southern Nigeria

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Contents

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Abstract

Climate change is a global issue threatening food security, environmental safety, and human health in tropical and developing countries where people depend mainly on agriculture for their livelihood. Nigeria ranks among the top in the global yam production. It has the largest population in Africa and has been able to secure food for its growing population through food crops especially yam. Unfortunately, the recent increase in termites' colonies due to climate change threatens yam yield. Besides harming man and environment, pesticides are expensive and not easily accessible to control the pests. This prompted a study which aimed at applying a biotrado-cultural approach in controlling the termites, as well as improving soil chemical properties and yam production. The study hypothesized that *Chromolaena odorata* and *Elaeis guineensis* sludge improved soil nutrient and yam yield and consequently decreased termites' outbreak. In a randomized design experiment of five blocks and five replicates, five different treatments including unmanaged (UM), *Vernonia amygdalina* (VA), *Chromolaena odorata* (CO), *Elaeis guineensis* (EG) liquid sludge, and fipronil (FP) were applied in termites-infested agricultural soil. Data were collected and measured on the responses of soil chemical properties, termites, and yam yield to treatments using one-way ANOVA, regression, and multivariate analyses. The result showed that *Chromolaena odorata* (CO) and EG treatments were the best treatments for controlling termites and increase yam production. Termites were successfully controlled in VA and FP treatments, but the control was not commensurate with yam production. The experiment needs to be extended to other locations in the study region. It also requires an intensive and long-term investigation in order to thoroughly understand (i) the influence of climate change on the termites' outbreak, (ii) the extent of termite damage to the crops, (iii) the impacts of climate change and variability on yam yields, (iii) the agricultural and economic benefits of the applied treatments, and (iv) the ecological and human health safety of the treatments.

Keywords

Climate change · Sustainable agriculture · Soil · Pest management · Termites · *Elaeis guineensis* · *Vernonia amygdalina* · *Chromolaena odorata* · Fipronil · Ikpo-Obibi

Introduction

Climate change has globally become a serious threat to environment and man especially in the areas of food security and rapid growing population. Though the impacts of climate change have no geographical boundary, yet the countries in sub-Saharan Africa tend to suffer more because of several reasons including socio-economic, political, and ecological factors (Slingo et al. 2005; Kurukulasuriya et al. 2006). The Assessment Reports of the Intergovernmental Panel on Climate Change

(IPCC) urged that, even with the predicted climate change scenarios, extreme events may still occur with devastating effects in more vulnerable areas, causing severe long-term food insecurity (Boko et al. 2007; Christensen et al. 2007).

Yam (*Dioscorea* spp.) is a tuber crop which serves as a major staple food for about 34% of the world's population. In comparison to other tuber crops, yam is a vital source of essential minerals including carbohydrates, vitamins, proteins, and dietary fibers (Olajumoke et al. 2012). In 2004, the world's yam production was estimated at about 46.8 million metric tons, and West Africa accounted for more than two-third of this global production (Sartie et al. 2012). Nigeria ranks highest in yam production among the sub-Saharan African countries (CGIAR 2004). Yam is a highly preferred food crop in Nigeria because:

(i) It is one of the easiest and fastest food to be prepared in different flavor.
(ii) Yam tubers can be preserved for longer time (4–6 months) at ambient temperature unlike sweet potato (*Ipomoea batatas* L.) and cassava (*Manihot esculenta*). The sustainability of yam as a source of food for every household is high, even during the onset of the rainy season when food tends to be scarce, yam tubers will be available (Loko et al. 2015). Hence, yam is locally referred as "enyi nwa-ogbuenye na'uwu" meaning "the orphan's salvager in time of famine."
(iii) Economically, yam tubers are high sources of income for the indigenous farmers, and this helps to alleviate poverty (Olorede and Alabi 2013).
(iv) Socio-culturally, yam promotes the social life of the people: several festivals (such as New Yam Festival, Yam title coronation, and marriage) are celebrated by communities, groups, and individuals using yam (Osunde and Orhevba 2009).

During cultivation, yam has its tubers buried in the soil which is the habitat of most ant species especially termite. Termite (*Isoptera*) has been described as one of the yam tubers' main destructive fauna (Atu 1993; Loko et al. 2015). Common among the termite species that damage the yams are the *Microtermes*, *Ancistrotermes*, and *Macrotermes* (Loko et al. 2015). The damage consists of feeding and destruction of planted setts of yam (including tubers, leaves, stems), and yam staking materials, as well as release of methane (Zimmerman and Greenberg 1983). Yam tubers to be harvested are sometimes heavily tunneled in termite-infested soil because the *Microtermes* spp. seldom build colonies within tubers and create apparent hollows. In Nigeria, it has been reported that in soils with high termite infestation, farmers lose more than 5 t ha^{-1} of yam due to damage by termites (Atu 1993). However, in the tropics and subtropics, termite has been reported as litter decomposer, and a key player in soil formation (Richard et al. 2006; Belyaeva and Tiunov 2010), yet it degrades the soil quality (Devendra et al. 1998).

Globally, the net impact of climate change has been predicted to include increase in pest damage to agricultural resources (Lovett et al. 2005). In tropical Africa precisely, climate change has crucial role in the striving, reproduction, and crop-destructive ability of the pests by making the environment favorable for them. Due to variations in weather especially rainfall and temperature, termites' outbreak and infestation become acute. Studies have shown that an average annual rainfall and temperature below 100 cm and 27°C, respectively, promote the survival and catastrophic impacts of the pest (Atu 1993; Richard et al. 2006; Belyaeva and Tiunov 2010). Though termites have been reported to be present throughout the year in most tropical countries of Africa (Wood 1995), their agricultural and economic damage tend to be exacerbated during periods of low rainfall (Ahmed et al. 2011). In the study conducted on the potential impact of climate change on termite distribution in Southern Zambia, Ahmed et al. (2011) found that after a drought, the number of pestiferous termite species increased drastically. Similarly, another study, performed in Uganda by Pomeroy (1976), demonstrated that the distribution of termites' mounds was significantly correlated with temperature and that large termite mounds were absent in areas of lower temperature and high rainfall. Kemp (1955) observed that climate was the principal factor determining the distribution of termites in Northeastern Tanganyika (Tanzania). Farmers in Nigeria, Uganda, and Zambia have reiterated that termite problems are more serious now than in the past (Atu 1993; Sekamatte and Okwakol 2007; Sileshi et al. 2009). Damage by the pests is higher during dry periods than in periods of regular rainfall (Logan et al. 1990). The rapid increase in termite damage might also be attributed to climate change-induced drought. For example, in the last two to three decades, drought associated with El Niño episodes has become more intense and widespread in Africa (Harrington and Stork 1995). Many studies have previously established strong nexus among climate change, termites invasion, and damage to agricultural resources (Jones 1990; Kemp 1955; Logan et al. 1990; Nkunika 1998; Bignell and Eggleton 2000; Eggleton et al. 2002; Ahmed and French 2008; Ahmed et al. 2011; Beaudrot et al. 2011; Rouland-Lefèvre 2011; Buczkowski and Bertelsmeier 2017).

Ikpo-Obibi is one of the important yam-producing communities in Nigeria with more than 80% of the population engaging in agriculture. It is pathetic to report the farmers' ordeal with the climate change-induced termites in the process of yam production. Despite the nutritional and socioeconomic benefits of yam, the termites' attack poses great challenge.

In terms of the control measures, most farmers in Africa have attempted the application of different pesticides, yet sustainable solution was never achieved. For example, in Nigeria, some farmers have applied pesticides such as fipronil, aldrin, imidacloprid, chlorpyrifos, sulfluramid, and heptachlor to control the pests by dressing the yam setts and farmlands. The problems of inaccessibility, high costs, human health safety, and ecological effects of these pesticides limit their usage (UNEP 2000; Boonyatumanond et al. 2006; Sánchez-Bayo 2014). The need for a sustainable method of ameliorating this yam pest and to have increased yield became crucial due to higher food demand from the growing population. In other West African country such as Ghana, it was reported that traditional methods (wood ash, cow dung, and aqueous extract of plant residues "dawadawa") have been successfully used to control the yam pests (Asante et al. 2008). The records about such traditional applications are yet to be found in Nigeria. Therefore, the present study aimed at appraising a new biotrado-cultural approach of coping with the climate change by controlling the termites, improving the soil properties, and increasing yam production using aqueous extract of *E. guineensis*, *V. amygdalina*, and *C. odorata*. The study also compared the impacts of these plant materials on the soil, yam yield, and termites in relation to the result from the fipronil treatment. It is hypothesized that (i) *C. odorata* enriched the soil minerals and increased yam yield by reducing the effects from climate change and the termites; (ii) the attraction of *E. guineensis* sludge to termites makes it an intervening material that reduced the pests' attack on the yam tubers and consequently enhanced the soil organic carbon (Corg); and (iii) *V. amygdalina* and fipronil treatments can successfully control termites but they have high concentrations of trace elements which aggravate the impacts of climate change and exert negative effects on the soil and yam production. Within this context, the following questions were addressed: (a) What are the variations in the concentrations of soil chemical properties, under the different treatments applied, and how significant are these concentrations? (b) Which of the applied treatments and season increased soil essential minerals? (c) Does increase in Corg and rainfall increase yam production? (d) How sustainable is the fipronil application in relation to termites' control, soil fertility, and yam yield? (e) To what extent does the variability in climate influence the termites and their impacts on yam production?

Materials and Methods

Study Area

Ikpo is one of the oldest villages among the eight villages in Obibi community in Etche Local Government Area (ELGA) of Rivers State, Nigeria. The farmland is located within latitude 5°06′52.7″N and longitude 7°11′59.4″E (Fig. 1) with an area of about 52.2 km^2 and a gentle sloping altitude ranging from 50 m to 100 m above sea level. The mean annual rainfall ranges from 100.4 cm to 241.7 cm and mean annual temperature ranging from 26.5 °C to 28.3 °C (SPDC 1998) (Fig. 2). The study was conducted from 2013 to 2016 under rainfed conditions. The mean monthly rainfall (cm) and temperature (°C) of the study site varied (Fig. 2) with 2013 and 2014 indicating normal rainfall years, 2015 revealing a dry year, and 2016 wet year. Though the study area has variations in rainfall that shows a bimodal rainfall distributional trend, yet no month without rainfall. Early-season rain begins in either late January or February and ends in July, and this is categorized as the early growing season. On the other hand, the late-season rain starts in August and ends in December (Nwaogu et al. 2017).

Geologically, the study site lies within Niger Delta Basin, and it is characterized by the Benin or coastal plain sand formation. The age of these formations ranges from Miocene to Eocene.

The shallow parts of the formations are composed mainly of non-marine sand deposited in alluvial or upper coastal plain (Doust and Omatsola 1990). The soil

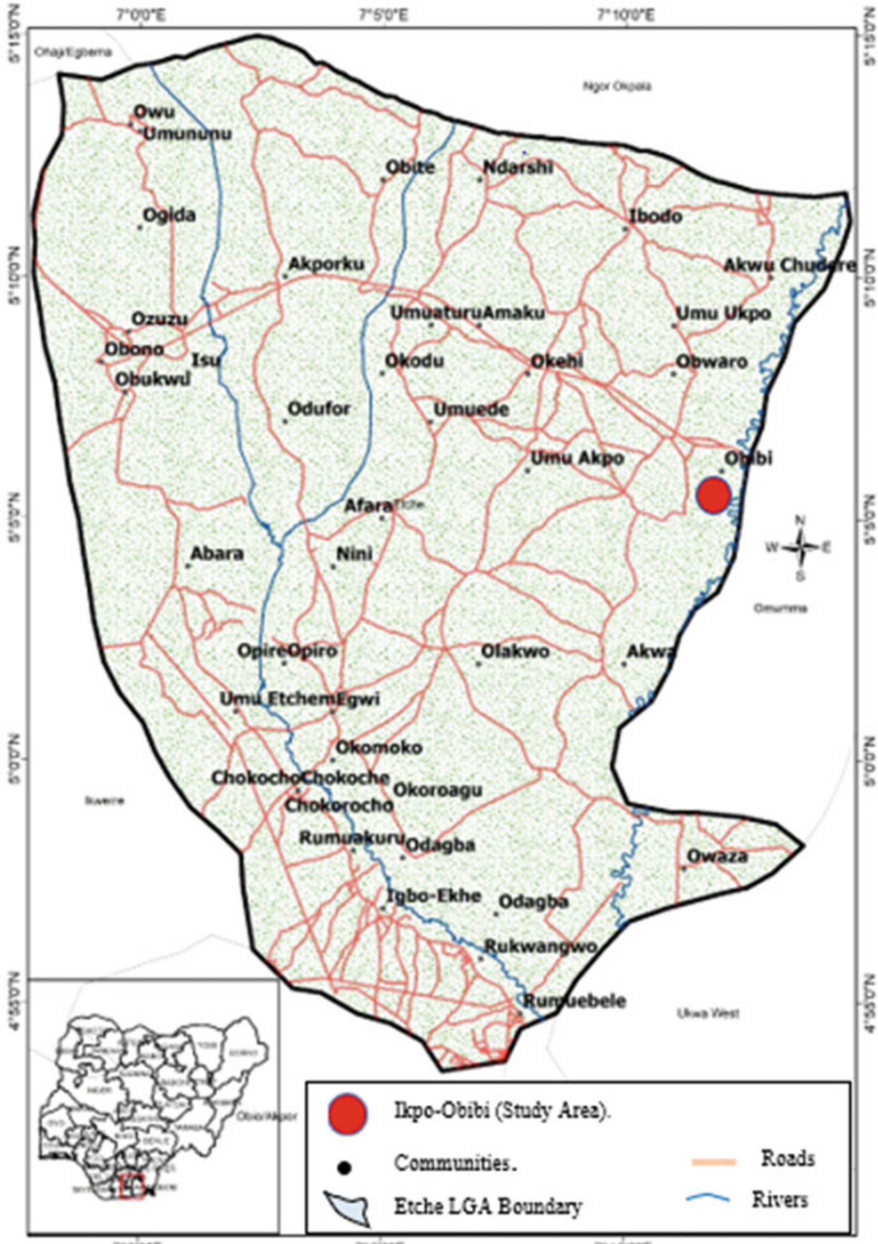

Fig. 1 The study area: Ikpo village in Obibi community, Etche LGA of Rivers State, Nigeria

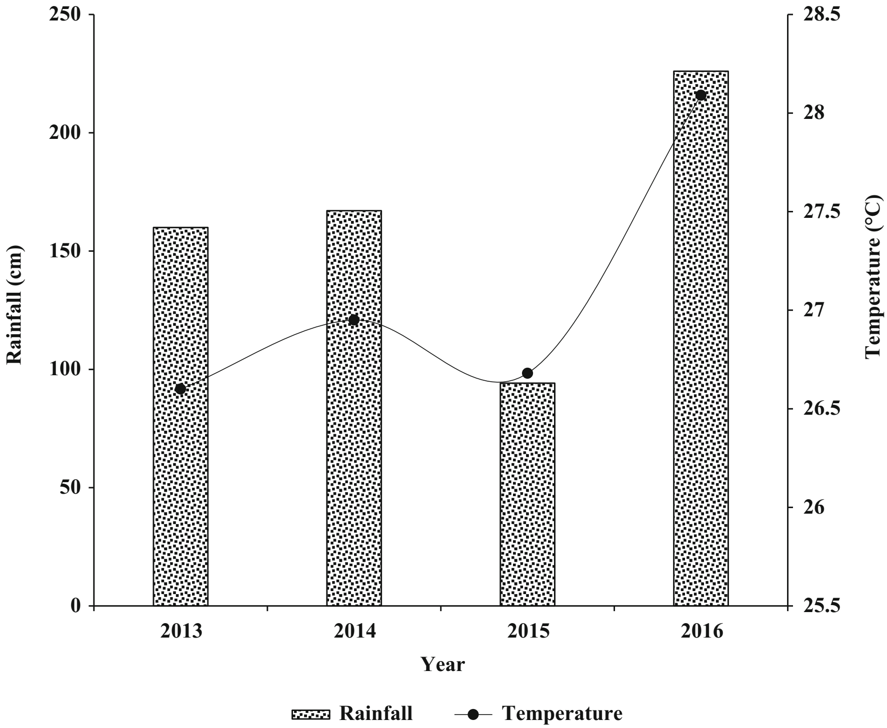

Fig. 2 Mean annual rainfall and temperature of the study area

Table 1 Soil (0–15 cm depth) chemical and physical properties in the study site prior to the experiment

Soil property	Mean ± standard error
Corg (mg kg^{-1})	5481 ± 311
Ntot (mg kg^{-1})	1197 ± 95
P (mg kg^{-1})	92.6 ± 23.3
K (mg kg^{-1})	471.1 ± 37.7
Mg (mg kg^{-1})	334.6 ± 15.9
Ca (mg kg^{-1})	421.4 ± 33.4
Fe (mg kg^{-1})	7.8 ± 1.5
Mn (mg kg^{-1})	6.1 ± 0.9
Cu (mg kg^{-1})	5.9 ± 1.2
Zn (mg kg^{-1})	8.8 ± 1.1
Cr (mg kg^{-1})	5.0 ± 0.3
pH	6.1 ± 0.5
Sand (g kg^{-1})	716 ± 10.4
Silt (g kg^{-1})	118 ± 6.1
Clay (g kg^{-1})	161 ± 4.3
Textural class	Sandy-loam
Bulk density (Mg m^{-3})	1.3 ± 0.1

composition of the study area consisted of fine alluvial content which is an extension of the rich sediments from the River Niger Delta alluvial soil. Presently, the heavy anthropogenic activities (e.g., mining, farming, grazing), pests, and environmental factors have influenced the soil properties (Table 1).

The study area is a typical rainforest region with traces of mangrove and freshwater swamp forests toward the south (Nwankwoala and Nwaogu 2009). There are bushes with trees and shrubs, as well as patches of grasslands dominated by elephant grasses where most farming activities are performed.

There are several termites' mounds which are between 2–7 m high and 2–5 m in diameter that cover the land space forming high termite mound density per hectare. Though the study site has for some years been dominated by termites, the activities of these pests to a large extent depend on climatic conditions. From the growing period to the maturity stage, the termites destroy the development of the crops planted at the site. This at most times leaves the rural farmers with little or nothing to be harvested. At planting and harvesting, five different species of termites were identified as the most common yam-destroying termites: *Amitermes evuncifer*, *Macrotermes bellicosus*, *Microtermes obesi*, *Trinervitermes oeconomus*, and *Trinervitermes geminatus* (Atu 1993; Loko et al. 2015).

Experimental Design, Yam Cultivation, and Treatments

The study was conducted in a randomized block design (Fig. 3). The area covered 5,400 m^2 with about 80% of the entire field being used for the yam cultivation and treatments, while the remaining percentage consisted of the borders around the entire treatment plots. Each plot consisted of 144 m^2 (12 m × 12 m) and was separated by 4 m (column) and 2 m (row) buffer zones. Land preparation for the experiment took place in 2012, and the first phase of the experiment was performed in 4 years (2013–2016) characterized with differences in annual rainfall and temperature. For instance, 2013 and 2014 had a normal rainfall, 2015 was a dry year, and 2016 recorded excess rainfall.

The experimental design includes five blocks, five replicates, five different treatments (UM, unmanaged; VA, *Vernonia amygdalina*; CO, *Chromolaena odorata*; EG, *Elaeis guineensis* liquid sludge; FP, fipronil) (Fig. 3), and their chemical compositions (Table 2).

The land was cleared and the plants' litter removed. Yam planting heaps of 80–100 cm high and 100–120 cm in diameter were prepared every year before the first rainfall of the year. After the first 2–3 rains of the year, yam setts were planted on the prepared heaps/mounds which were at the intervals of 15–20 cm with the cut face placed up (Fig. 4).

Based on the local tradition, the mounds were preferable to the ridges because they promoted easy staking and enhance the production of larger yam tubers when compared with ridges. The VA, CO, and EG treatments were traditionally processed by crushing, soaking in water, and squeezing out the sludge which were stored in 0.7 liter plastics (Appendix Figs. 8, 9, 10, 11, and 12). These were preserved in a cool

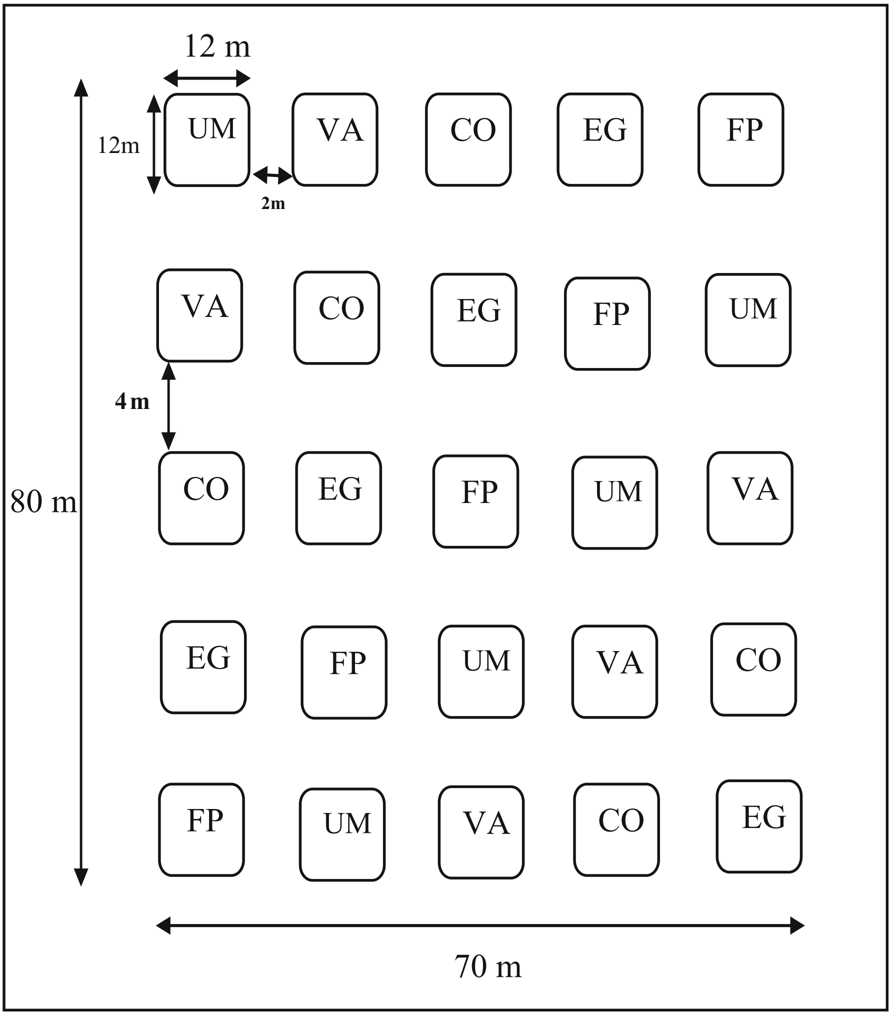

Fig. 3 Experimental design block for the study. Treatments were UM (unmanaged), VA (*Vernonia amygdalina*), CO (*Chromolaena odorata*), EG (*Elaeis guineensis* liquid sludge), FP (fipronil)

temperature to prevent fermentation before being applied to the yam heaps. On the other hand, the aqueous dilution of fipronil (Fipronil (120068-37-3); Alina Zhao, Ningbo Samreal Chemical Co., Ltd., China) was prepared as prescribed on the product label for termites' control. The prepared treatments were applied by dressing the yam setts. Between 0.2 and 0.3 litters of sludge (or aqueous) were dropped in and around every heap where the yam was planted. This was performed three times (in February/March, August, and November) for each growing season. By using hoes, manual weeding was performed three times (in late May, August, and November) for each growing season. Two stakes, each of 200–300 cm in height,

Table 2 Mineral and trace element contents (mg L^{-1}) of the organic materials used for the treatments (mean ± standard error of the mean)

		Treatment material		
		VA	CO	EG
Minerals	P	83.9 ± 5.6	116.1 ± 23.5	154.6 ± 12.1
	K	52.1 ± 7.3	181.9 ± 15.2	271.2 ± 25.6
	Mg	33.8 ± 2.9	104.6 ± 27.7	67.6 ± 7.3
	Ca	76.4 ± 11.1	93.3 ± 12.9	48.7 ± 2.5
Trace elements	Fe	36.1 ± 9.7	22.8 ± 8.1	11.3 ± 1.0
	Mn	3.3 ± 0.4	0.4 ± 0.0	0.3 ± 0.0
	Cu	5.2 ± 1.6	0.7 ± 0.1	0.9 ± 0.2
	Zn	2.4 ± 0.7	0.2 ± 0.0	0.8 ± 0.3
	Cr	2.3 ± 0.3	0.1 ± 0.0	0.2 ± 0.0

Fig. 4 Experiment site with yam soil heaps during planting and one of the termites' mounds

were used for staking the yam plants to vine over them – one stake for two plants and the other stake used for bracing the adjacent. Yam tuber harvesting was done in December each year following the local tradition.

Soil Sampling and Chemical Properties Analyses

In February/March and December, five soil sub-samples (0–15 cm soil depth) from individual treatment plot were randomly collected using a graduated auger. The soil samples were mixed and air-dried; visible pebbles, biomass residues, roots, and other organic debris were removed. Before taken to the laboratory for analysis, the samples were ground in a mortar to pass a 2 mm sieve. All measurements and analyses were performed within 30 days of sampling. The soil pH (H_2O) was determined by the method of McLean (1982). Organic carbon (Corg) was measured using the Walkley and Black wet oxidation method (Nelson and Sommers 1996). Total nitrogen (Ntot) was analyzed using micro-Kjeldahl method (Bremner and Mulvaney 1982). Available P, K, Ca, and Mg were extracted using Mehlich III solution (Mehlich 1984) with reagent and concentrations determined by introducing the inductively coupled plasma-optical emission spectrometry (ICP-OES: 720 Series, Agilent Technologies, USA). On the other hand, the concentrations of the trace elements (Cu, Mn, Cr, Fe, Zn) were determined following the Clayton and Tiller (1979) method. The concentrations were further analyzed using ICP-OES analyzer. The mean of five sub-samples from each monitored treatment was used for the statistical analyses.

Termites Sampling

The number of termites per heap was collected three times per year: in February/ March (during planting), August (during the short break, that is, the August rainfall break), and December (during harvesting). These periods coincided with the low rainfall months which formed the peak season for the termites' activities (Loko et al. 2015). The termites were observed and counted using the Zoom Handheld Lighted Magnifier Glass (MagniPros 5.5″, USA) by randomly selecting the yam heaps and excavating through to the soil profile where the yam tubers could be found. One-third of the heaps were sampled per plot.

Yam Yields

At physiological maturity, after 9–10 months (that is, in December), the yam tubers were harvested by randomly selecting the yam heaps and excavating through to the soil layers where the yam tubers could be found. One-third of the heaps were sampled per plot. The harvested tubers were washed using water. They were thereafter weighed, and result was recorded in yield per hectares.

Statistical Analyses

To test the effects of treatments on the soil chemical properties, yam yield, and number of termites, a one-way ANOVA was used. In addition, a repeated-measures ANOVA was applied to deduce the effect of year, treatment, and year x treatment interaction for number of termites, yam yields, soil minerals, and trace elements. The ANOVA was applied after the assumptions of normality were met. Regression analysis was used to test the relationship between yam tuber yield (t ha^{-1}) and number of termites per yam soil heap. All analyses were conducted using the IBM SPSS Statistics Version 20 (IBM Corporation 2011) (www.ibm-spss-statistics.soft32.com) and the STATISTICA 13.0 software (StatSoft, Tulsa, OK, USA), while all data were expressed as means of five replicates.

Furthermore, a multivariate analysis such as redundancy analysis (RDA) followed by a Monte Carlo permutation test with 999 permutations in the Canoco 5.0 software (Šmilauer and Lepš 2014) was used to measure the effect of the different treatments on soil chemical properties during the 4 years. Ordination diagram was produced by using the CanoDraw program software which prompted the presentation and visualization of the RDA results of the experiment.

Results

Soil Chemical Properties

The concentrations of all the monitored soil chemical properties were significant under the different treatments except for Mn and Cu (Table 3). Most of the measured minerals showed higher concentrations under the CO treatment when compared with VA, EG, UM, and FP treatments. On the other hand, VA and FP treatments had higher trace element concentrations and higher pH when compared with the other treatments. All the essential soil minerals were significantly affected by time and treatment, but not all were affected by the combination of both (i.e., time × treatment interaction) (Table 4).

No significant effect of treatment on soil chemical properties calculated by RDA was recorded in 2015 (Table 5). The variability of soil chemical properties explained by treatments subsequently increased from the initially 24% in 2013 to more than 25% in 2014 and more than 50% in 2016. Variability explained by treatments was constantly above 20% between 2013 and 2016.

The treatments were categorized into three different groups in relation to the concentrations of soil chemical properties as were revealed by the ordination diagram (Fig. 5). Based on the RDA analysis of the data collected during the 4 years, CO and EG treatments formed the first group, VA and FP treatments as the second group, and UM treatment as the third group. The relationships between individual soil element and treatment are visible from the ordination diagram (Fig. 5).

Yam Tuber Yield and Termites

The mean annual yam tuber yields under CO and EG treatments were significant, while UM, VA, and FP treatments never showed any significant differences during the study years (Fig. 6). Year 2015 had the lowest yam tuber yields under the different treatments, while 2013 had the highest.

The results from the total number of termites per yam heap showed that UM and EG treatments were significant at $P < 0.05$, while records for VA, CO, and FP treatments revealed no statistical differences in the years (Fig. 7). Year 2015 had the highest number of termites per heap, whereas 2016 had the lowest. The relationships between yam tuber yield and number of termites per heap were negatively significant under the CO and EG, while UM treatment ($R^2 = 0.50$; $P = 0.045$) showed a marginal weak relationship (Table 6).

Table 3 Mean concentrations (mg kg^{-1}) of soil chemical properties (minerals and trace elements) under the different treatments in 2013–2016. *P*-value represents corresponding probability value. Numbers represent the average of five replicates; ± represents standard error of the mean (SEM); significance differences ($P < 0.05$) between treatments in accordance with the Tukey's post hoc test are shown by different letters in the row (a < b < c < d < e). Treatment abbreviations (UM, VA, CO, EG, and FP) are described in Fig. 3

			Treatments				
	UM	VA	CO	EG	FP	F-ratio	P-value
Minerals							
Corg	5326 ± 106ab	4881 ± 211a	7087 ± 462d	6139 ± 304c	5941 ± 84b	21.2	<0.001
Ntot	897.5 ± 114a	906.6 ± 125a	1815 ± 93c	1699 ± 281b	923 ± 75a	8.5	0.039
P	71.7 ± 23.5a	98.2 ± 16.1ab	203.6 ± 19.9c	117.9 ± 15.32b	95.8 ± 11.7ab	0.7	<0.001
K	221.9 ± 12.2ab	205.1 ± 5.7a	328.4 ± 45.3c	239.2 ± 29.6b	228.0 ± 15.8ab	5.3	0.027
Mg	341.8 ± 75.2c	287.9 ± 73.6b	469.6 ± 66.5e	413.3 ± 81.1d	116.3±28.4a	2.6	< 0.001
Ca	432.2 ± 59.6c	311.4 ± 54.2b	791.8 ± 83.7e	609.6 ± 61.4d	207.1 ± 19.9a	17.1	<0.001
Trace elements							
Fe	8.1 ± 1.5a	41.8 ± 7.3c	24.6 ± 4.1b	13.0 ± 1.5ab	52.3 ± 6.1d	9.1	0.022
Mn	3.1 ± 0.1	3.9 ± 0.7	3.4 ± 0.3	3.8 ± 0.2	4.2 ± 0.5	0.4	0.621
Cu	5.3±0.5	5.1±0.9	5.5±1.1	5.6±1.0	6.7±1.1	1.8	0.948
Zn	8.3±1.1b	17.4±2.5d	6.8 ± 2.1a	10.3 ± 2.3c	27 ± 3.8e	0.9	<0.001
Cr	5.7 ± 0.3a	25.9 ± 2.0c	7.1 ± 1.4ab	9.7 ± 1.8b	32.1 ± 3.1d	3.6	0.031
pH	6.0 ± 0.8a	7.5 ± 0.2d	6.4 ± 1.1b	6.9 ± 0.7c	8.1 ± 0.8e	0.2	0.043

Table 4 Results of repeated-measures ANOVA (time, treatment, time × treatment) of soil chemical properties, number of termites, and yam yields. df, degree of freedom; F, value derived from F-statistics in repeated-measures ANOVA; and *P*, probability value

			Effect			
	Time: df = 4		Treatment: df = 5		Time × treatment: df = 20	
	F-ratio	*P*-value	*F*-ratio	*P*-value	*F*-ratio	*P*-value
Soil chemical properties						
Corg	23.5	*	11.8	*	3.1	*
Ntot	14.1	*	24.3	*	1.8	*
P	3.9	*	5.9	*	0.3	ns
K	3.3	*	17.7	*	0.5	ns
Mg	10.2	*	6.8	*	2.4	*
Ca	9.7	*	18.3	*	1.2	*
Fe	0.6	ns	35.1	*	0.4	ns
Mn	0.9	ns	1.8	ns	0.7	ns
Cu	1.8	ns	0.7	ns	0.5	ns
Zn	31.7	*	11.2	*	2.7	*
Cr	25.5	*	57.1	*	3.1	*
pH	14.1	*	8.5	*	0.5	ns
Number of termites	10.6	*	17.9	*	0.9	ns
Yam yield	37.3	*	22.3	*	1.2	ns

Note: ns, not significant; *, significant at $P < 0.05$

Table 5 Results of RDA analyses of soil chemical properties estimates performed separately for each year. % explanatory variable, concentrations, variability explained by one (all) ordination axis (measures of explanatory power of the explanatory variables); *F*-ratio, *F*-statistics for the test of analysis; *P*-value, probability value obtained by the Monte Carlo permutation test. Tested hypothesis: there is any effect of treatment on soil chemical properties for each year. Applied treatments were described in Fig. 3

Year	Explanatory variables	% explanatory var. 1st axis (all axes)	*F*-ratio 1st axis (all axes)	*P*-value 1st axis (all axes)
2013	UM, VA, CO, EG, FP	11.8 (23.9)	2.4 (1.1)	<0.001 (<0.001)
2014	UM, VA, CO, EG, FP	34.3 (30.7)	8.7 (3.9)	<0.001 (<0.001)
2015	UM, VA, CO, EG, FP	23.6 (21.3)	12.5 (3.6)	<0.31 (0.045)
2016	UM, VA, CO, EG, FP	45.2 (47.8)	11.2 (3.8)	<0.001 (<0.001)

Discussion

Soil Chemical Properties

The chemical elements contained in the treatment materials and the prevailing climate substantially influenced the soil chemical properties and consequently exerted significant effects on the different treatments. For example, the application of *Vernonia amygdalina* and fipronil (FP) elevated the concentrations of most trace

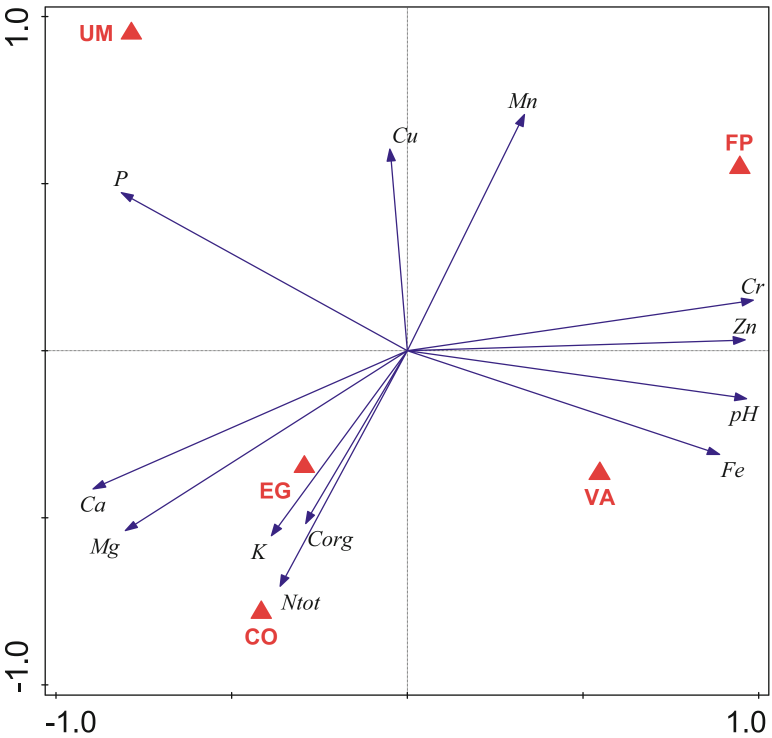

Fig. 5 Ordination diagram showing result of the RDA analysis of soil chemical properties data collected in 4 years (from 2013 to 2016) in different treatments. Treatment abbreviations are explained in Fig. 3

elements in the soil, while *Chromolaena odorata* increased the contents of soil organic carbon and other minerals especially in the favorable climate years. Several studies have reported the effects of the exotic plants and organic residues of *V. amygdalina*, *C. odorata*, and *Elaeis guineensis* on the soil chemical properties and microbes (Kushwaha et al. 1981; Obatolu and Agboola 1993; Quansah et al. 2001; Peveling et al. 2003; Koutika et al. 2004; Callaway et al. 2004; Gbaruko and Friday 2007; Banful and Hauser 2011; Tondoh et al. 2013; Agbede et al. 2014; Gandahi and Hanafi 2014; Nurulita et al. 2014; Ngo-Mbogba et al. 2015; Ajayi et al. 2016; Dawson and Schrama 2016; Veldhuis et al. 2017).

It was discovered in the study that VA and FP treatments recorded relatively high soil pH, and this might be attributed to the high concentrations of the trace elements. This finding was consistent with other studies which have revealed that the elevation of heavy metals in most agricultural soils often leads to soil alkalinity (Nederlof et al. 1993; Lenart and Wolny-Koładka 2013; Almaroai et al. 2014) and V. *amygdalina* like *Baphia nitida* accumulates high heavy metals in the region (Ogbonna et al. 2013). On the contrary, other authors have reported high concentrations of exchangeable Cd and Zn in agricultural soils because of decrease in pH (Sumi et al. 2014).

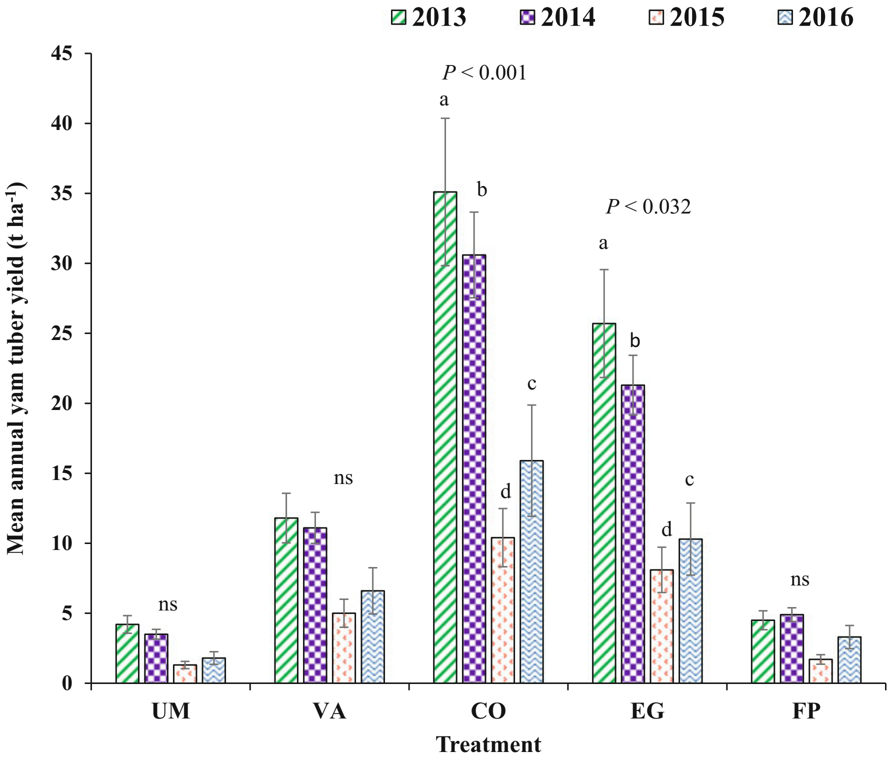

Fig. 6 Mean annual yam tuber yield (t ha^{-1}). Error bars represent standard error of the mean (SEM). *P*-value represents corresponding probability value. *ns* indicates that the results of ANOVA analyses were not significant. Significance differences ($P < 0.05$) between treatments in accordance with the Tukey's post hoc test are shown by lowercase letters (a > b > c > d). Treatment abbreviations were explained in Fig. 3

Although *C. odorata* has been established to be a threat to the soil minerals by some authors (Muniappan et al. 2005), in contrast, several studies in West Africa have positive records about *C. odorata* (Obatolu and Agboola 1993; Goyal et al. 1999; Quansah et al. 2001; Tondoh et al. 2013; Agbede et al. 2014). In agreement with our study, CO treatment revealed increased concentrations of Corg, Ntot, K, and Ca especially in the optimal precipitation years. This might be explained by the deep rooting system of *C. odorata* that mobilizes soil mineral nutrients which are turned into organic and plant-available nutrients in conducive climate (Kushwaha et al. 1981; Tondoh et al. 2013). Other possible reasons for high contents of minerals in the *C. odorata* soil could be due to high contents of leaf biomass and earthworms (Tian et al. 2000; Kone et al. 2012), fast decomposing rate of *C. odorata* (Roder et al. 1995), and the elevated activities of the soil microbes (Mboukou-Kimbasta et al. 2007; Banful and Hauser 2011; Ngo-Mbogba et al. 2015; Dawson and Schrama 2016).

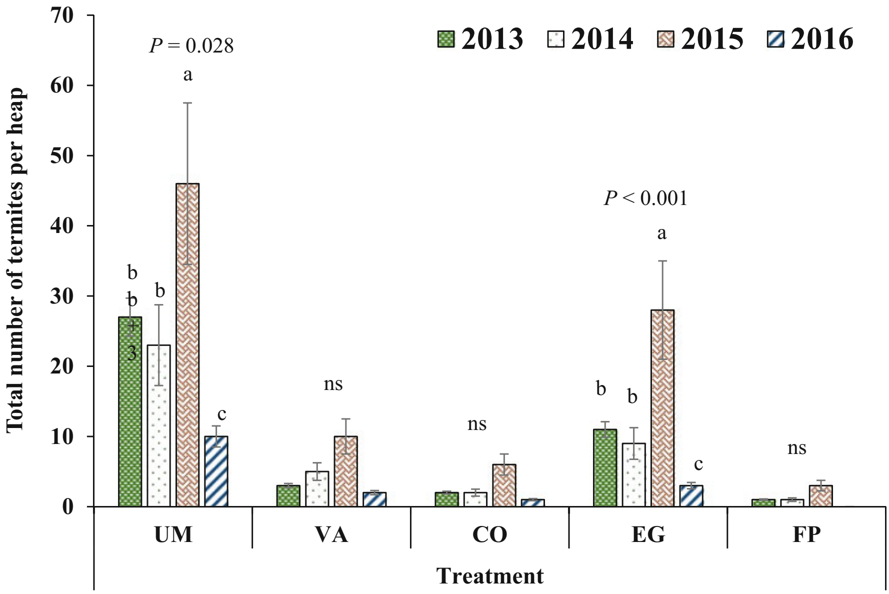

Fig. 7 Total number of termites (*Isoptera*) per yam soil heap. Error bars represent standard error of the mean (SEM). *P*-value represents corresponding probability value. *ns* indicates that the results of ANOVA analyses were not significant. Significance differences ($P < 0.05$) between treatments in accordance with the Tukey's post hoc test are shown by lowercase letters (a > b > c > d). Treatment abbreviations were explained in Fig. 3

Table 6 Relationships between yam tuber yield (kg heap^{-1}) and number of termites per yam heap for the years under the different treatments

Treatment	Equation	R^2	P-value
UM	Y = – 0.0059X + 17.593	0.50	0.045
VA	Y = – 0.014X + 18.824	0.21	0.079
CO	Y = – 0.2456X + 35.04	−0.87	<0.001
EG	Y = – 0.064X + 29.618	−0.75	0.012
FP	Y = – 0.0128X + 15.53	0.24	0.063

On the other hand, *E. guineensis* (EG) treatment had elevated soil organic carbon and total nitrogen in our study. This result was consistent with many studies which reported that the oil palm residues promote the scavenging activities of ants which enrich the soil minerals (Frouz et al. 1997; Gandahi and Hanafi 2014; Nurulita et al. 2014; Gray et al. 2015).

No significant effect of treatment on the soil chemical properties was recorded in 2015 as shown by the RDA analysis. The low amount of rainfall recorded in 2015 contributed to the insignificant role of treatments on the soil because the elements from the treatments required enough soil moisture to show reasonable influence on the soil chemistry (Fernelius et al. 2017).

Yam Tuber Yield and Termites

The highest yam tuber yields were found in the CO treatment. This might probably be explained by high Corg, Ntot, P, K, Ca, and Mg in the soil under the CO treatment which consequently increased the crop yield (Obatolu and Agboola 1993; Quansah et al. 2001; Tondoh et al. 2013; Agbede et al. 2014). Similarly, 2013 and 2014 had the highest yam tuber yields across the different treatments. This was attributed to the optimum rainfall in 2013 and 2014 which did not only favor the activities of the microbial organisms but also helped to decrease the number of the termites' attack on the yam tubers. Though the oil palm (EG) liquid sludge attracted more termites in the soil yet, the EG treatment had higher yam tuber yields than UM and VA treatments. This could be because the termites fed more on the oil palm sludge instead of the yam tubers. Besides, the termites' activities improved the soil minerals (Oviasogie and Aghimien 2003; Muhrizal et al. 2006; Guo et al. 2007; Wu et al. 2009).

The total number of termites per yam heap were significant under UM and EG treatments. This was because of the suitability of the unmanaged and *E. guineensis* (EG) treatments which promoted the termites' activities when compared with the VA, CO, and FP treatments that either constrained or killed the ants (Peveling et al. 2003). Though without high yam yields, fipronil application was the easiest method to eradicate the termites from either destroying the yam tubers or carrying out any activities in the yam farmland. But the risk of fipronil on the soil, environment, and human health has been reported by many authors (Keefer and Gold 2014; Sánchez-Bayo 2014; Lopez-Antia et al. 2016).

Limitations of the Study

Some of the limitations for the study are:

(i) Poor access roads and footpaths to the farm sites where the studies are conducted
(ii) Destruction of some established experiments by mammals such as rabbits (*Oryctolagus cuniculus*), rats (*Rattus*), grasscutters (*Thryonomys swinderianus*), antelopes (*Bovidae*), and others
(iii) Ability to convince the rural farmers to give their farmlands for such research because some of the farmers are afraid that their land might be taken by the government or the research institutes
(iv) Inadequate fund to perform intensive studies: labor, field, laboratory and statistical analyses, and publications
(v) Dearth of literature on the topic in Nigeria and lack of robust data on the climate and other variables

Conclusion

Climate change with its variability was found as a factor which has important influence on yam tuber production because (i) the termite colonies increased when there is low rainfall, (ii) the damage caused by the pests exacerbates during dry season than in wet season, and (iii) optimal rainfall enhances soil moisture and promotes the soil microbial activities and decomposition of organic matter which in turn elevates the soil fertility. *Chromolaena odorata* (CO) treatment has been found to be the best single option in managing the termites' infested farmland to increase yam yield. On the other hand, integrating CO and EG treatment is recommended as this might produce higher yield. Though the termites (pests) were successfully reduced under the VA and FP treatments, this reduction was not commensurate with the yam tuber yield. The high content of the trace elements in the VA and FP treatments was attributed to the reason for declined yields because the fipronil is a good soil-binding substance which limits organic decomposition and nutrient cycling. It is also important to state here that a 4-year study is a short term to conclude that *C. odorata* and *E. guineensis* sludge are sustainable for reducing the yam pests (termites) and their harmful activities.

Since climate change is expected to continue locally and globally, this will have further influence on the distribution and intensification of termites which in turn affects agricultural resources. There is crucial need for the effectiveness of termite management strategies which include integrated pest control methods. Furthermore, as most of the termites are soil inhabitants, soil degradation and low rainfall are the main factors promoting their distribution and forage behavior in both tropical and subtropical ecosystems. Thus, there are high chances for aggravated economic devastation of termites' outbreaks in the region due to climate change. Therefore, the experiment needs to be extended to other locations in the study region. It also requires an intensive and long-term investigation in order to thoroughly understand (i) the influence of climate change on the termites' outbreak, (ii) the extent of termite damage to the crops, (iii) the impacts of climate change and variability on yam yields, (iii) the agricultural and economic benefits of the applied treatments, and (iv) the ecological and human health safety of the treatments.

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Appendix

See Figs. 8, 9, 10, 11, and 12.

Fig. 8 Specimen of *Vernonia amygdalina* (VA) used for the experiment

Fig. 9 Specimen of *Chromolaena odorata* (CO) used for the experiment

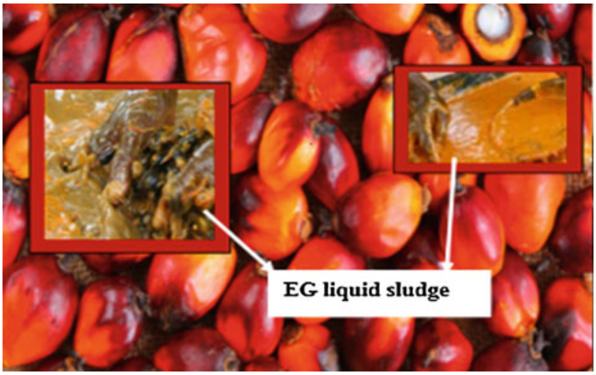

Fig. 10 Specimen of *Elaeis guineensis* (EG) and its liquid sludge used for the experiment

Fig. 11 Processing of the liquid/sludge of *Vernonia amygdalina* (VA), *Chromolaena odorata* (CO), *Elaeis guineensis* (EG)

Fig. 12 Stored liquid/sludge of *Vernonia amygdalina*, *Chromolaena odorata*, *Elaeis guineensis* before they were applied in the experiment

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