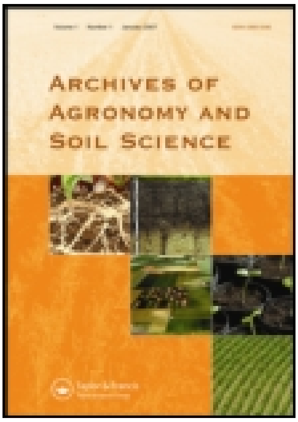

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Response of soil properties and yam yield to Chromolaena odorata (Asteraceae) and Tithonia diversifolia (Asteraceae) mulches

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Response of soil properties and yam yield to *Chromolaena odorata* (Asteraceae) and *Tithonia diversifolia* (Asteraceae) mulches

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Plant materials differ in their chemical composition, rate of decomposition and suitability as mulch materials. Experiments were conducted during 2006–2007 and 2007–2008 cropping seasons for early yam cultivation at Owo in the forest–savanna transition zone of southwest Nigeria to study the effect of *Chromolaena odorata* and *Tithonia diversifolia* mulches applied at 0.0, 5.0, 7.5, 10.0 and 12.5 t ha^{-1} on soil chemical properties, leaf nutrient composition, growth and tuber yield of white yam (*Dioscorea rotundata* Poir). Both *C. odorata* and *T. diversifolia* mulches reduced soil bulk density and temperature; increased concentrations of soil organic matter (SOM), total N, available P, exchangeable K, Ca and Mg, leaf N, P, K, Ca and Mg; enhanced growth and yield of yam compared with control. The values of SOM, total N and available P and leaf N and P concentrations increased with increasing mulch rate. *C. odorata* mulch and *T. diversifolia* mulch applied at 10.0 and 7.5 t ha^{-1}, respectively, was found to be suitable for yam production. *T. diversifolia* mulch compared with *C. odorata* mulch produced higher values of soil chemical properties, leaf nutrient concentrations, growth and yield of yam. *T. diversifolia* mulch produced 19% and 18% higher tuber yield compared with *C. odorata* mulch during 2006–2007 and 2007–2008 cropping seasons, respectively.

Keywords: soil bulk density; temperature; soil chemical properties; leaf nutrient composition; Nigeria

Introduction

Mulching is an effective method of manipulating crop growing environment to increase yield and improve product quality by controlling weed growth, reducing soil temperature, conserving soil moisture, reducing soil erosion, improving soil structure and enhancing organic matter content of the soil (Opara-Nadi 1993). Mulching is a major aspect of yam (*Dioscorea* spp.) production, and various vegetative and artificial materials are used for mulching. Inyang (2005) and Gbadebor (2006) revealed that mulch materials improve soil physico-chemical properties, suppress soil temperature, reduce evaporation and increase the soil moisture, thereby creating enabling soil microclimatic condition for early yam sprouting. Mulching improves biotic activity and adds nutrients to the soil, thereby increasing soil fertility through decomposition (Ojeniyi & Adetoro 1993; Awodun & Ojeniyi 1999). The type of material used as mulch determines its impact on soil physical and chemical properties and crop yield (Awodun & Ojeniyi 1999), and this is due to differences in biochemical quality of plant

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materials. The key factors determining quality of the mulching materials are nutrient value, texture, rate of decomposition, availability, cost, growth rate and vegetative matter turn over.

Siam weed (*Chromolaena odorata*) belongs to the family Asteraceae. It originated from North America and had since been widespread throughout the humid forest zone of West Africa. In southwest Nigeria, it grows luxuriantly and rejuvenates the soil (Obatolu & Agboola 1993; Akanbi & Ojeniyi 2007). The effectiveness of siam weed mulch had been investigated for yam crop (Akanbi & Ojeniyi 2007). Mexican sunflower (*Tithonia diversifolia*) is a shrub belonging to the family Asteraceae. It originated from Mexico and Central America, and it is now widely distributed throughout the humid and sub-humid tropics in Asia and Africa (Sonke 1997). It is an aggressive annual weed growing along major roads, paths and on abandoned farm lands in southwest Nigeria. According to Jama et al. (2000), *T. diversifolia* has aroused research interest because of the relatively high nutrient concentrations (N, P and K) that are found in its biomass and because of its ability to extract relatively high amount of nutrients from the soil. The high N concentration and rapid decomposition of green *T. diversifolia* biomass (Gachengo et al. 1999) make it an effective source of N for crops. It has been used successfully to improve soil fertility and crop yield in Kenya (Jama et al. 2000), Malawi (Ganunga et al. 1998), Rwanda (Drechsel & Reck 1998) and Zimbabwe (Jiri & Waddington 1998). It has the potential of being a mulch material and nutrient source for yam. *T. diversifolia* has received less research attention in the tropics compared with *C. odorata* as to its effect on soil properties and crop productivity. Mulching is a traditional practice in yam cultivation aimed at controlling heat scorching and soil temperature. Maduakor et al. (1984) and Okoh (2004) reported that the majority of traditional yam farmers in Nigeria, Cameroon, Togo and Ghana use different types of mulch materials which range from dry grass, and palm fronds to wood shavings. However, research information on the use of *T. diversifolia* as a mulch material for yam production on an Alfisol of the humid tropics has not been documented when compared with *C. odorata* mulch (Akanbi & Ojeniyi 2007). The actual rate of *T. diversifolia* on the performance of yam does not exist in the tropics. There is a need to ascertain the extent to which this weed species could be used as mulch for soil fertility improvement and performance of yam in order to determine the best rate of application of the weed species. There is scarcity of research information on comparison of *C. odorata* and *T. diversifolia* as to their relative effects on soil properties, growth and yield of yam. It is hypothesized that *C. odorata* and *T. diversifolia* would enhance soil fertility and performance of yam, although information is scarce on this aspect. Therefore, the present study reported in this article sought to compare the impact of *C. odorata* and *T. diversifolia* as mulch materials on the performance of yam on an Alfisol at Owo in the forest–savanna transition zone of southwestern Nigeria.

Materials and methods

Site description and treatments

Field experiments were carried out during 2006–2007 and 2007–2008 early year cropping seasons at Owo, Nigeria. Owo is located at latitude 7° 12′ N and longitude 5° 35′ E within the forest–savanna transition zone of southwest, Nigeria. The average rainfall varied from 1000 to 1240 mm. This forest–savanna transition zone has a bimodal pattern of rainfall with first season commencing from March to July and a dry spell in August followed by the second season, September to November.

The site was manually cleared from 2-year-old fallow after arable cropping was covered by bush dominated by Siam weed (*C. odorata* L.) King and Robinson, Water leaf (*Talinum triangulare* Jacq.) Willd, Haemorrhage plant (*Aspilia africana* Pers.) Adams and Guinea grass (*Panicum maximum* Jacq.), interspersed with shrubs. The type of soil is Alfisol classified as Oxic Tropuldalf (USDA 1999) or Luvisol (FAO 1998) derived from quartzite, gneiss and schist (Agbede 2006). The physical and chemical properties of the soil at the site before planting in 2006 and chemical composition of *C. odorata* and *T. diversifolia* mulch materials used are shown in Table 1. The surface and subsoil layers were sandy loam in texture, with increasing clay content in the subsoil layers. The low organic matter before the commencement of the experiment was partly attributed to its fairly high bulk density (Adekiya et al. 2011). The site was deficient in organic matter and all the essential nutrients except P and Mg according to the value recommended for crop production in ecological zones of Nigeria (Akinrinde & Obigbesan 2000). The organic matter and other nutrients were higher at the surface layer than at the subsoil layers and decreased regularly with depth. The analysis of green leaves of *T. diversifolia* and *C. odorata* used for the experiments indicated that *C. odorata* had higher values of moisture content, N, P, K, Ca and lower C:N ratio compared with *C. odorata*. The organic C content in *T. diversifolia* was also comparable to *C. odorata*, while *T. diversifolia* and *C. odorata* were low in Mg.

The experiment consisted of 2 × 5 factorial combinations of two mulch materials (Siam weed: *C. odorata* and Mexican sunflower: *T. diversifolia*) and five rates of application of the mulch materials (0.0, 5.0, 7.5, 10.0 and 12.5 t ha^{-1}).

Table 1. Mean ± standard deviation of soil physical and chemical properties of the experimental site before planting in 2006 and chemical composition of *Chromolaena* and *Tithonia* mulch materials used.

Soil property	0–20 cm depth	20–40 cm depth	40–60 cm depth
Sand (g kg^{-1})	683 ± 5.5	670 ± 5.8	665 ± 6.4
Silt (g kg^{-1})	155 ± 3.4	153 ± 3.6	141 ± 5.8
Clay (g kg^{-1})	162 ± 3.9	177 ± 4.1	194 ± 4.6
Textural class	Sandy loam	Sandy loam	Sandy loam
pH (H_2O)	5.9 ± 0.4	5.8 ± 0.2	5.7 ± 0.3
Bulk density (Mg m^{-3})	1.58 ± 0.05	1.63 ± 0.03	1.68 ± 0.04
Organic matter (%)	2.76 ± 0.04	2.59 ± 0.05	2.46 ± 0.06
Total N (%)	0.19 ± 0.02	0.17 ± 0.01	0.15 ± 0.02
Available P (mg kg^{-1})	10.6 ± 0.3	10.2 ± 0.4	9.9 ± 0.3
Exchangeable K (cmol kg^{-1})	0.14 ± 0.01	0.12 ± 0.01	0.11 ± 0.01
Exchangeable Ca (cmol kg^{-1})	1.30 ± 0.04	1.26 ± 0.06	1.23 ± 0.03
Exchangeable Mg (cmol kg^{-1})	0.51 ± 0.02	0.48 ± 0.03	0.44 ± 0.02

	Organic C	N	P	K	Ca	Mg	C:N	Moisture content (%)
	(%)							
Chromolaena	33.5a	2.41b	0.44b	1.03b	2.30b	0.04a	13.9	22.3b
Tithonia	31.7a	3.30a	0.53a	3.89a	3.41a	0.04a	9.6	27.5a

Note: Values followed by the same letters in the same column are not significantly different at $p \leq 0.05$ according to Duncan's multiple range test (DMRT).

The treatments were as follows:

(1) no application of *C. odorata* mulch at 0.0 t ha^{-1},
(2) application of *C. odorata* mulch at 5.0 t ha^{-1},
(3) application of *C. odorata* mulch at 7.5 t ha^{-1},
(4) application of *C. odorata* mulch at 10.0 t ha^{-1},
(5) application of *C. odorata* mulch at 12.5 t ha^{-1},
(6) no application of *T. diversifolia* mulch at 0.0 t ha^{-1},
(7) application of *T. diversifolia* mulch at 5.0 t ha^{-1},
(8) application of *T. diversifolia* mulch at 7.5 t ha^{-1},
(9) application of *T. diversifolia* mulch at 10.0 t ha^{-1},
(10) application of *T. diversifolia* mulch at 12.5 t ha^{-1}.

The 10 treatments were arranged in a randomised complete block design with three replications. The size of the site used for the experiment was 763 m^2. Each block comprised 10 plots, each of which measured 5 × 4 m^2. Blocks were 1 m apart, and the plots were 0.5 m apart. The same treatment was allotted to each plot for the 2 years of study.

Planting of yam and application of mulch

After manual clearing, mounding was done manually at 1 m × 1 m spacing in November 2006 and 2007. Each mound was approximately 1 m wide at the base and about 0.75 m high. Mounds were prepared by piling the soil surface layer using the traditional hoe after cleared weeds were removed from the plots of 20 m^2 size each. Planting was done immediately after mound construction in November each year. One seedyam, weighing about 0.4 kg of white yam (*Dioscorea rotundata* cv. Gambari) was planted per mound. Fresh Siam weed (*Chromolaena odorata*) and Mexican sunflower (*T. diversifolia*) were collected from a nearby farm and hedge containing green tender stems and the leaves equivalent to 0.0, 5.0, 7.5, 10.0 and 12.5 t ha^{-1} were applied to cover the mounds (in December each year) 1 month after planting. Staking was done after sprouting. Weeding was done manually with a hoe four times throughout the cropping period in each experiment.

Determination of soil properties

Two months after mulching yam, determination of certain soil physical properties in all plots commenced and this was done at 2-month intervals on four occasions for each year. Six undisturbed samples (4 cm diameter, 10 cm high) were collected at 0–10 cm depth from each plot on top of mound using steel core samplers and were used for the determination of bulk density and gravimetric moisture content after oven drying of samples at 100°C for 24 h. Soil temperature was determined at 15:00 h with a soil thermometer inserted to 10 cm depth. Six readings were made per plot at each sampling time at 2-month intervals and mean computed.

Disturbed soil samples were collected randomly at 0–20 cm depth from the mound top and mound side of each plot at harvest in 2007 and 2008 with a soil auger and analysed for chemical properties as described by Carter (1993). Soil organic carbon was determined by the procedure of Walkley and Black using the dichromate wet oxidation method (Nelson & Sommers 1996). Organic matter was deduced by multiplying C by 1.724. The total N was determined by micro-Kjeldahl digestion and distillation techniques (Bremner 1996), available P was extracted using Bray-1 solution and determined by molybdenum blue colorimetry

(Frank et al. 1998). Exchangeable K, Ca and Mg were extracted using 1 N ammonium acetate. Thereafter, K was determined using a flame photometer and Ca and Mg by the EDTA titration method (Hendershot & Lalande 1993). Soil pH was determined by using a soil-water medium at a ratio of 1:2 using digital electronic pH meter (Ibitoye 2006).

Analysis of yam leaves

Five months after planting in each year, yam leaf samples were collected randomly from each plot, oven-dried for 24 h at 80°C and ground in a Willey mill. These samples were analysed for leaf N, P, K, Ca and Mg as described by Tel and Hagarty (1984). Leaf N was determined by the micro-Kjeldahl digestion method. Ground samples were digested with nitric-perchloric-sulphuric acid mixture for the determination of P, K, Ca and Mg. Phosphorus was determined colorimetrically using the vanadomolybdate method, K was determined using a flame photometer and Ca and Mg were determined by the EDTA titration method (Horwitz 1997).

Growth and yield parameters

Ten plants were selected randomly for the determination of leaf area at 7 months after planting using graphical method (i.e. by placing the leaf on graph sheet for area determination). Vine length was measured by meter rule at harvest in August each year. Tuber weight was also determined at harvest by recording the weight of fresh tubers from 10 plants selected randomly from each plot using a top loading balance to determine their weights and tuber yield per hectare was computed.

Statistical analysis

Data collected from each experiment were subjected to analysis of variance (ANOVA) using the Genstat statistical package (GENSTAT 1993) to determine the effects of treatments on soil physical and chemical properties, leaf nutrient concentrations, growth and yield of yam. The standard error of difference between means (s. e. d.) was used to compare the treatment means. Mention of statistical significance refers to $p \leq 0.05$ unless otherwise stated. Economics of yam production under the different mulch materials and rates were also determined.

Results

Soil physical properties

In both the years, *C. odorata* and *T. diversifolia* mulches reduced soil bulk density compared with the control, but the reduction was only significant at 12.5 t ha^{-1} (Table 2). There were no significant differences ($p \leq 0.05$) of bulk densities between the same rates of *C. odorata* mulch and *T. diversifolia* mulch. Similarly, mulching increased soil moisture content compared with the control. However, the values were only statistically different for mulch treatments 10.0 t ha^{-1} rates. There were also no significant differences ($p \leq 0.05$) between the same rate of *C. odorata* mulch and *T. diversifolia* mulch for soil moisture content. Although there were no significant differences between the same rate of *C. odorata* mulch and *T. diversifolia* mulch with reference to soil temperature, both mulch materials produced significant differences

Table 2. Effect of *Chromolaena* and *Tithonia* mulch materials on soil physical properties (0–10 cm depth) when averaged across four sampling periods (2, 4, 6 and 8 months after planting) in 2007 and 2008 cropping seasons.

Year	Mulch material	Mulch rate (t ha^{-1})	Bulk density (Mg m^{-3})	Moisture content (%)	Temperature (°C)
2007	*Chromolaena*	0.0	1.31	12.6	36.5
		5.0	1.29	13.1	32.5
		7.5	1.24	13.4	29.3
		10.0	1.20	13.8	26.1
		12.5	1.16	14.9	24.4
	Tithonia	0.0	1.30	12.7	36.0
		5.0	1.28	13.1	32.5
		7.5	1.24	13.5	29.1
		10.0	1.19	13.9	26.3
		12.5	1.16	14.8	24.3
2008	*Chromolaena*	0.0	1.32	13.5	32.9
		5.0	1.29	13.9	29.9
		7.5	1.23	14.4	27.2
		10.0	1.20	14.8	25.0
		12.5	1.13	15.6	22.1
	Tithonia	0.0	1.31	13.6	32.6
		5.0	1.28	13.9	29.7
		7.5	1.24	14.5	27.5
		10.0	1.17	14.8	24.9
		12.5	1.12	15.7	22.3
		SE±	0.02	1.04	0.65
Year (Y)			NS	*	*
Mulch material (M)			NS	NS	NS
Mulch rate (R)			*	NS	*
Y × M			NS	NS	NS
Y × R			NS	NS	NS
M × R			NS	NS	NS
Y × M × R			NS	NS	NS

Note: NS, not significant; *$p \leq 0.05$.

($p \leq 0.05$) between mulch and no mulch plots. Soil temperatures reduced as the rate of both the *C. odorata* and *T. diversifolia* mulches increased from 0.0 to 12.5 t ha^{-1}.

Years (Y) when considered as an individual factor influenced soil moisture content and temperature significantly ($p \leq 0.05$), but had no significant influence on soil bulk density (Table 2). Mulch materials (M) when studied as an individual factor had no significant effect on soil bulk density, moisture content and temperature. Whereas mulch rates (R) when considered as individual factor were significant for soil bulk density and temperature, but had no significant influence on soil moisture content. The interactions Y × M, Y × R and M × R were neither significant, nor was Y × M × R significant.

Soil chemical properties

In both the *C. odorata* and *T. diversifolia* treatments, mulching increased soil organic matter (SOM), total N, available P, exchangeable K, Ca and Mg concentrations compared with the control (Table 3). Increasing the rates of mulch with both mulching materials increased the values of SOM, N and P from 0.0 to 12.5 t ha^{-1}. However, exchangeable K, Ca and Mg only

Table 3. Effect of *Chromolaena* and *Tithonia* mulch materials on soil chemical properties (0–20 cm depth) in 2007 and 2008 cropping seasons.

Year	Mulch material	Mulch rate (t ha^{-1})	SOM (%)	Total N (%)	Available P (mg kg^{-1})	Exch. K (cmol kg^{-1})	Exch. Ca (cmol kg^{-1})	Exch. Mg (cmol kg^{-1})
2007	*Chromolaena*	0.0	2.62	0.18	4.6	0.13	1.10	0.38
		5.0	2.90	0.20	5.7	0.17	1.31	0.41
		7.5	3.67	0.25	7.6	0.24	1.81	0.49
		10.0	4.45	0.31	10.7	0.27	2.51	0.61
		12.5	5.73	0.36	14.9	0.27	2.50	0.62
	Tithonia	0.0	2.59	0.19	4.8	0.13	1.10	0.38
		5.0	3.24	0.23	6.1	0.20	1.51	0.46
		7.5	4.01	0.29	9.1	0.27	2.72	0.89
		10.0	5.10	0.35	13.7	0.28	2.73	0.78
		12.5	6.30	0.41	18.1	0.28	2.76	0.74
2008	*Chromolaena*	0.0	2.41	0.16	5.6	0.12	1.00	0.35
		5.0	2.62	0.19	6.6	0.14	1.30	0.40
		7.5	3.20	0.21	9.1	0.19	1.74	0.46
		10.0	4.00	0.25	15.3	0.22	2.44	0.71
		12.5	4.90	0.29	26.2	0.22	2.49	0.71
	Tithonia	0.0	2.43	0.16	5.7	0.11	1.03	0.34
		5.0	2.88	0.21	7.8	0.16	1.47	0.49
		7.5	3.60	0.24	10.9	0.24	2.17	0.81
		10.0	4.40	0.30	21.1	0.24	2.68	0.82
		12.5	5.51	0.36	29.1	0.25	2.71	0.79
		SE±	0.06	0.01	0.25	0.01	0.04	0.01
Year (Y)			*	*	*	*	*	*
Mulch material (M)			*	*	*	*	*	*
Mulch rate (R)			*	*	*	*	*	*
Y × M			NS	NS	*	NS	*	*
Y × R			*	*	*	NS	*	*
M × R			*	*	*	*	*	*
Y × M × R			*	NS	*	NS	*	*

Note: NS, not significant; *$p \leq 0.05$.

increased with *C. odorata* mulch up to 10.0 t ha^{-1} and *T. diversifolia* mulch up to 7.5 t ha^{-1}. In all cases in both the years, considering the same rate of mulch, *T. diversifolia* mulch significantly ($p \leq 0.05$) produced higher values of SOM, total N, available P, exchangeable K, Ca and Mg concentrations compared with *C. odorata* mulch. When considered as single factors, years (Y), mulch materials (M) and mulch rates (R) significantly ($p \leq 0.05$) influenced soil chemical properties (Table 3). The interactive effects of Y × M were significant for soil P, Ca and Mg, but not significant for SOM, N and K. The interactions Y × R and M × R were significant for SOM, total N, available P, exchangeable Ca and Mg. However, Y × R interaction was not significant for exchangeable K, but significant under M × R interaction. The interactive effects of Y × M × R were significant for SOM, available P, exchangeable Ca and Mg, but not significant for total N and exchangeable K.

Leaf nutrient concentrations of yam

In both the years, the *C. odorata* and *T. diversifolia* mulches increased leaf N, P, K, Ca and Mg concentrations of yam compared with the control (Table 4). The values of leaf N and P concentrations of yam increase with increasing mulch rate in both the mulch materials. *C.*

Table 4. Effect of *Chromolaena* and *Tithonia* mulch materials on leaf nutrient concentrations of yam in 2007 and 2008 cropping seasons.

Year	Mulch material	Mulch rate (t ha^{-1})	N	P	K	Ca	Mg
			(%)				
2007	*Chromolaena*	0.0	2.01	0.30	1.30	0.60	0.45
		5.0	2.22	0.36	1.51	0.68	0.50
		7.5	2.69	0.49	1.99	0.85	0.62
		10.0	3.34	0.62	2.20	0.97	0.72
		12.5	4.01	0.78	2.22	0.99	0.72
	Tithonia	0.0	2.07	0.31	1.30	0.58	0.45
		5.0	2.44	0.41	1.79	0.78	0.56
		7.5	2.98	0.56	2.20	0.96	0.70
		10.0	3.74	0.69	2.26	1.00	0.73
		12.5	4.51	0.86	2.24	1.01	0.73
2008	*Chromolaena*	0.0	1.98	0.29	1.27	0.59	0.43
		5.0	2.20	0.34	1.51	0.66	0.51
		7.5	2.51	0.46	1.97	0.84	0.62
		10.0	3.21	0.62	2.20	0.97	0.70
		12.5	3.96	0.76	2.21	0.97	0.71
	Tithonia	0.0	2.01	0.29	1.28	0.58	0.44
		5.0	2.40	0.41	1.78	0.78	0.56
		7.5	2.90	0.55	2.20	0.98	0.69
		10.0	3.69	0.68	2.23	0.98	0.74
		12.5	4.46	0.85	2.22	0.99	0.73
		SE±	0.14	0.20	0.03	0.03	0.02
Year (Y)			NS	NS	NS	NS	NS
Mulch material (M)			*	*	*	*	*
Mulch rate (R)			*	*	*	*	*
Y × M			NS	NS	NS	NS	NS
Y × R			NS	NS	NS	NS	NS
M × R			NS	NS	NS	NS	NS
Y × M × R			NS	NS	NS	NS	NS

Note: NS, not significant; *$p \leq 0.05$.

odorata mulch only increased leaf K, Ca and Mg concentrations of yam up to 10.0 t ha^{-1}. There were no significant differences ($p \leq 0.05$) between 10.0 and 12.5 t ha^{-1}. *T. diversifolia* mulch increased leaf K, Ca and Mg concentrations of yam up to 7.5 t ha^{-1}. There were no significant differences between 7.5, 10.0 and 12.5 t ha^{-1} rates of mulch. At the same rate of 5.0, 7.5, 10.0 and 12.5 t ha^{-1} *C. odorata* and *T. diversifolia* mulches, *T. diversifolia* mulch significantly ($p \leq 0.05$) produced higher values of leaf N, P, K, Ca and Mg concentrations of yam compared with *C. odorata* mulch. Years (Y) when considered as an individual factor had no significant influence on leaf nutrient concentrations of yam (N, P, K, Ca and Mg) (Table 4). Whereas, mulch materials (M) and mulch rates (R) when studied as individual factors had significant effect on leaf nutrient concentrations of yam (N, P, K, Ca and Mg). However, the interactive effects of Y × M, Y × R and M × R and when all the three factors were considered together (Y × M × R) were not significant.

Crop growth parameters and tuber yield of yam

In both the years, the *C. odorata* and *T. diversifolia* mulches produced significant different ($p \leq 0.05$) values vine length, leaf area (Table 5) and tuber yield of yam (Table 5,

Table 5. Effect of *Chromolaena* and *Tithonia* mulch materials on growth and tuber yield of yam in 2007 and 2008 cropping seasons.

Year	Mulch material	Mulch rate (t ha^{-1})	Vine length (m)	Leaf area (m^2)	Tuber yield (t ha^{-1})
2007	*Chromolaena*	0.0	2.70	1.91	25.1
		5.0	3.01	2.19	28.5
		7.5	3.41	2.45	32.4
		10.0	3.81	2.80	36.1
		12.5	3.90	2.89	36.9
	Tithonia	0.0	2.63	1.87	24.2
		5.0	3.40	2.51	31.6
		7.5	4.10	3.17	41.3
		10.0	4.22	3.21	43.0
		12.5	4.30	3.33	43.6
2008	*Chromolaena*	0.0	2.59	1.59	21.3
		5.0	2.90	2.01	23.5
		7.5	3.34	2.35	29.1
		10.0	3.69	2.71	33.1
		12.5	3.73	2.80	33.9
	Tithonia	0.0	2.55	1.61	20.9
		5.0	3.31	2.31	26.7
		7.5	3.91	2.90	37.1
		10.0	4.01	2.99	37.9
		12.5	4.09	3.12	38.6
		SE±	0.05	0.04	0.4
Year (Y)			*	*	*
Mulch material (M)			*	*	*
Mulch rate (R)			*	*	*
Y × M			NS	*	*
Y × R			NS	NS	NS
M × R			*	*	*
Y × M × R			NS	NS	NS

Note: NS, not significant; *$p \leq 0.05$.

Figure 1) compared with the control. With *C. odorata* mulch, vine length, leaf area and tuber yield of yam increased with increasing mulch rate up to 12.5 t ha^{-1}. The values for growth and yield parameters were not significantly different at 10.0 and 12.5 t ha^{-1} *C. odorata* mulch. Likewise, *T. diversifolia* mulch increased yam vine length, leaf area and tuber yield with increasing mulch rate. However, there were no significant differences between 7.5, 10.0 and 12.5 t ha^{-1} rates of mulch. Using the same rate of mulch, *T. diversifolia* mulch produced higher values of vine length, leaf area and tuber yield of yam compared with *C. odorata* mulch. Using the mean of the 2 years, 5.0, 7.5, 10.0 and 12.5 t ha^{-1} *C. odorata* mulch increased tuber yield of yam by 12%, 33%, 49% and 53%, respectively and 5.0, 7.5, 10.0 and 12.5 t ha^{-1} *T. diversifolia* mulch increased yam tuber yield by 29%, 73%, 79% and 82%, respectively, compared with the control. Using the mean of the rates of mulch materials, *T. diversifolia* mulch increased yam tuber yield by 19% in 2007 and 18% in 2008. When considered as single factors, years (Y), mulch materials (M) and mulch rates (R) significantly ($p \leq 0.05$) influenced vine length, leaf area and tuber yield of yam (Table 5). The interactive effects of Y × M were significant for leaf area and tuber yield of yam, but not significant for vine length. The interaction Y × R were not significant for vine length, leaf area and tuber yield of yam. However, the interactive effects of M × R were significant for vine length, leaf area and tuber yield of yam. The interactive effects of Y × M × R were not significant for vine length, leaf area and tuber yield of yam.

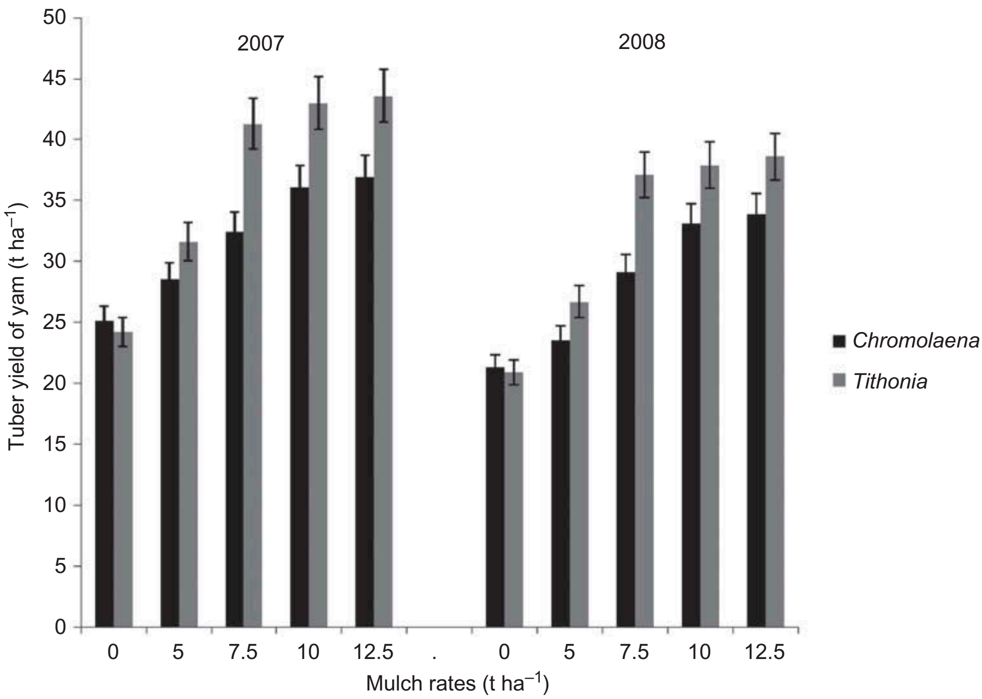

Figure 1. Effect of mulch plant materials and rates of application on tuber yield of yam in 2007 and 2008 cropping seasons. Vertical bars show standard errors of paired comparisons.

Economics of yam production under the different mulch rates of C. odorata *and* T. diversifolia

The cost of cutting and transportation of *C. odorata* and *T. diversifolia* biomass increased with increasing rate of mulches (Table 6). The economic returns and net benefits in treatments receiving *C. odorata* and *T. diversifolia* were higher than the control. The economic returns increased with increasing rate of *C. odorata* and *T. diversifolia* mulches, the highest (1,128,750 ₦ ha^{-1}) being obtained from *T. diversifolia* mulch applied at 12.5 t ha^{-1}, closely followed by *T. diversifolia* mulch applied at 10.0 and 7.5 t ha^{-1}, respectively, and *C. odorata* applied at 12.5 and 10.0 t ha^{-1}. Economically, *T. diversifolia* applied at rate of 7.5 t ha^{-1} and *C. odorata* applied at 10.0 t ha^{-1} proved to be more cost-effective and profitable than all other rates, as shown by their high return rates or value–cost ratios of 62:1 and 31:1, respectively, for the two rates. Based on the objective function of profit maximization, the optimum returns were recorded at a mulch application rate of 7.5 t ha^{-1} under *T. diversifolia* with a net return of (1,021,000 ₦ ha^{-1}) and a value–cost ratio of 62:1. Under the *C. odorata,* optimum rate of mulch application was 10.0 t ha^{-1} with a net return of 690,500 ₦ ha^{-1} and a benefit–cost ratio of 31:1. This shows that farmers stand in a better position to make more profit from yam production through these application rates than other rates recorded in this study.

Discussion

The findings that soil nutrients were higher at the surface (0–20 cm depth) than at subsoil layers (20–40 and 40–60 cm depths) could be attributed to higher concentration of organic matter in the upper soil layers than the subsoil layers. This was due to the fact that more

Table 6. Economics of producing yam under *Chromolaena* and *Tithonia* mulches tested for year 2007–2008.

Mulch material	Mulch rate (t ha^{-1})	Monetary gain (₦ ha^{-1})	Production increase value	Production increase (%)	Cost of cutting and transporting of mulches (₦ ha^{-1})	Net return over each mulch material	Return rate or benefit/cost ratio of each mulch
Chromolaena	0.0	1,450,000	–	–	–	–	–
	5.0	1,625,000	175,000	12	11,000	164,000	15
	7.5	1,925,000	475,000	33	16,500	458,500	28
	10.0	2,162,500	712,500	49	22,000	690,500	31
	12.5	2,212,500	762,500	53	27,500	735,000	27
Tithonia	0.0	1,412,500	–	–	–	–	–
	5.0	1,825,000	412,500	29	11,000	401,500	37
	7.5	2,450,000	1,037,500	73	16,500	1,021,000	62
	10.0	2,531,250	1,118,750	79	22,000	1,096,750	50
	12.5	2,568,750	1,156,250	82	27,500	1,128,750	41

Notes: In 2007, the price of yam tuber was 56.25 ₦ kg^{-1}, while it was 68.75 ₦ kg^{-1} in 2008. 120.00 ₦ is equivalent to 1.00 US$ in 2007; 138.00 ₦ is equivalent to 1.00 US$ in 2008.

decomposition occurred on the upper layers of soil profile because more organic matter was added through litter fall. The findings that soil bulk density increased with depth was adduced to the large sand fraction, lower concentration of organic matter at subsoil layers, less aggregation, less root penetration and compaction caused by the weight of the overlying layers (Brady & Weil 1999; Agbede 2010).

Effect of **C. odorata** *and* **T. diversifolia** *mulches on soil physical properties*

It was observed that both *C. odorata* and *T. diversifolia* mulches increased soil moisture content, reduced bulk density and temperature. The higher moisture content and lower temperature associated with mulch could be ascribed to reduction of evaporation losses (Agele et al. 1999a, 1999b). Opara-Nadi and Lal (1987) found that surface applied mulch at 4 to 6 t ha^{-1} created more favourable soil moisture and temperature regimes than did low mulch rates or buried mulch treatments on an Alfisol of southwest Nigeria. The reduction of soil bulk density observed in both *C. odorata* and *T. diversifolia* mulched plots compared with unmulched plots (control) could be attributed to increase in SOM resulted from the degraded organic residues by soil microorganisms. Organic matter is known to improve soil structure, aeration, reduce soil bulk density and enhance water infiltration and retention (Hsieh & Hsieh 1990). The presence of vegetative surface mulches should have increased activities of beneficial soil fauna in organic matter decomposition which led to enhancement of soil porosity and reduction of soil bulk density. Also by protecting the soil, the mulch should have stabilized the soil structure against raindrop impact and thereby preventing soil erosion, soil compaction and crusting.

Effect of **C. odorata** *and* **T. diversifolia** *mulches on soil chemical properties*

The results that both *C. odorata* and *T. diversifolia* mulches increased SOM, total N, available P, exchangeable K, Ca and Mg concentrations compared with the control attested to the fact that the treatments are rich in these nutrients and affirmed that these nutrients are released into the soil by decomposed mulches. Other works conducted in other parts of Nigeria also proved that *C. odorata* and *T. diversifolia* mulch decomposed to enhance SOM and nutrient concentrations (Obatolu & Agboola 1993; Olabode et al. 2007). The higher values of SOM, total N, available P, exchangeable K, Ca and Mg concentrations beneath *T. diversifolia* mulch plots compared with *C. odorata* mulch plots could be adduced to the initial analysis recorded for the leaves of the two mulch materials. The increase in the values of soil nutrients with applied rate of mulch from *C. odorata* and *T. diversifolia* could be due to increase in organic matter. It was found that values of soil exchangeable K, Ca and Mg concentrations increased up to 10.0 and 7.5 t ha^{-1} in *C. odorata* and *T. diversifolia* mulch plots, respectively. This could be due to leaching of excess cations and fixations by soil colloids especially clay (Akanbi & Ojeniyi 2007).

Effect of **C. odorata** *and* **T. diversifolia** *mulches on leaf nutrient concentrations of yam*

The increase in leaf N, P, K, Ca and Mg concentrations of yam due to application of *C. odorata* and *T. diversifolia* mulches was attributable to increased availability of nutrients in the soil by application of mulch leading to increased uptake by yam, indicating that soil fertility influenced nutrient uptake by yam. The results that *C. odorata* up to 10.0 ha^{-1} and *T. diversifolia* mulches up to 7.5 t ha^{-1} increased leaf K, Ca and Mg concentrations, was consistent with the values of soil chemical properties recorded for those treatments.

Response of yam yield to C. odorata *and* T. diversifolia *mulches*

The increase in performance of yam due to mulch application could be due to reduced soil temperature and increased availability of SOM, total N, available P, exchangeable K, Ca and Mg concentrations due to the mulches. Variation in soil moisture content between 10–30% and soil temperature between 25–30°C were found suitable for yam growth (Ohiri 1995). Also, Ohiri and Nwokoye (1984) reported that the optimum soil bulk density for yam is 1.10–1.36 Mg m^{-3} meaning that the soil temperature and nutrients are limiting factors between mulched and unmulched plots in this study. Similar effects of mulch on soil temperature had been reported for the northern guinea savanna zone of Nigeria (Adeoye 1984). This author found that 5 t ha^{-1} of grass mulch reduced soil temperature by about 7°C at 5 cm depth and 5°C at 10 cm depth. The increase in growth and yield of yam as a result of increases in rates of *C. odorata* and *T. diversifolia* mulches could be due to increased availability of organic matter, total N, available P, exchangeable K, Ca and Mg in the soil. The results that 10.0 t ha^{-1} *C. odorata* mulch and 7.5 t ha^{-1} *T. diversifolia* mulch gave the highest values of growth and yield could be due to the maximum presence of K, Ca and Mg in the soil and leaf of yam at that mulch rate. Yam performance is known to be strongly influenced by K (Obigbesan 1981, 1999). K availability would enhance starch formation. There were no significant differences in tuber yield produced by *C. odorata* treatments at 10.0 and 12.5 t ha^{-1} applications and *T. diversifolia* mulch produced at 7.5, 10.0 and 12.5 t ha^{-1} applications. *C. odorata* mulch applied at 10.0 t ha^{-1} and *T. diversifolia* mulch at 7.5 t ha^{-1} are adequate for yam production. These rates of mulches are recommended for yam. The findings that at the same rate of mulch, *T. diversifolia* mulch produced significantly higher growth and tuber yield compared with *C. odorata* mulch could be adduced to the analysis recorded for the two mulch materials. *T. diversifolia* had higher nutrient status and low C:N ratio compared with *C. odorata*. The higher nutrient status and low C:N ratio of *T. diversifolia* in this study should have increased decomposition and nutrient release for yam uptake. This was in agreement with the findings of Nziguheba et al. (1998) that *T. diversifolia* is a high-quality organic source in term of nutrient release and supplying capacity.

Sustainability of C. odorata *and* T. diversifolia *mulches as sources of nutrients*

The use of *C. odorata* and *T. diversifolia* mulches as sources of nutrients is highly sustainable. This is because *C. odorata* and *T. diversifolia* had been observed to be widely spread in Nigeria and other tropical countries where they are found growing on abandoned waste lands, along major roads and waterways and on cultivated farmlands (Akanbi & Ojeniyi 2007; Olabode et al. 2007). Furthermore, the abundance and adaptability of this weed species to various environments coupled with its rapid growth rate and very high vegetative matter turnover makes them to candidate species for soil rejuvenation (Obatolu & Agboola 1993).

Social or technical constraints in the use of mulches

The major constraint to the use of *C. odorata* and *T. diversifolia* for mulches is the labour cost required for cutting and transportation of *C. odorata* and *T. diversifolia* biomass. This agreed with the findings of Jama et al. (2000) who reported that considerable labour is required for cutting and transporting biomass to fields, especially if the *C. odorata* or *T. diversifolia* is far from the homestead. Based on this, *C. odorata* and *T. diversifolia* biomass can be particularly well suited for high-valued crops like yam that can generate income, which can then be used to defray/compensate for money spent on labour. For example, economic analysis for application of *T. diversifolia* biomass to maize and kale (*Brassica oleracea*) under farmer-management conditions in western Kenya revealed that *T. diversifolia* biomass was not profitable for low-valued maize at mean application rate of 19 t ha^{-1} (fresh weight). On the other hand, *T. diversifolia* biomass was very profitable with kale (*Brassica oleracea* cv acephala) – a high-valued green vegetable at mean application rate of 14 t ha^{-1} (fresh weight) (ICRAF 1997). Therefore, the use of *T. diversifolia* biomass was found to be economically more attractive with high-than low-valued crops (ICRAF 1997). Some other constraints that will also likely limit the wide-scale use of *Chromolaena* and *Tithonia* for mulches are their little awareness by farmers of their potential as nutrient sources to improve soil fertility and crop yields, the large amount required to supply nutrients to soil, their potential to become weeds in crop fields, especially if uncontrolled, and thereby increasing labour for weeding, and the prioritization of use of mulches in local farmland systems other than soil fertility improvement (Jama et al. 2000; Meertens 2003; Chianu & Tsujii 2005).

Conclusions

C. odorata and *T. diversifolia* mulches reduced soil temperature, bulk density and increased moisture content, SOM, total N, available P, exchangeable K, Ca and Mg, leaf N, P, K, Ca and Mg concentrations and growth and tuber yield of yam compared with the control. Results revealed that *T. diversifolia* mulch produced significantly higher yield compared with *C. odorata* mulch. The higher yield was adduced to higher N, P, K, Ca supply and low C:N produced by *T. diversifolia* mulch compared with *C. odorata* mulch. *C. odorata* mulch and *T. diversifolia* mulch applied at 10.0 and 7.5 t ha^{-1}, respectively, were found to be suitable for yam production in tropical Alfisol.

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