Effects of *Chromolaena* and *Tithonia* Mulches on Soil Properties, Leaf Nutrient Composition, Growth and Yam Yield

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Abstract

Plant materials differ in their chemical composition, rate of decomposition and suitability as mulch materials. Experiments were conducted on an Oxic Tropuldalf of southwestern Nigeria at Owo to study the effect of *Chromolaena* and *Tithonia* 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*hromolaena* and *Tithonia* mulches reduced soil bulk density and temperature. They also increased concentrations of organic matter, N, P, K, Ca and Mg in the soil, and N, P, K, Ca and Mg in the leaves. The mulches also increased growth and yield of yam compared with the control. The values of soil organic matter, N and P, and leaf N and P concentrations increased with increasing mulch rate. *Chromolaena* mulch and *Tithonia* mulch applied at 10.0 and 7.5 t ha^{-1}, respectively, were found to be suitable for yam production. *Tithonia* mulch compared with *Chromolaena* mulch produced higher values of soil chemical properties, leaf nutrient concentrations, growth and yield of yam. *Tithonia* mulch produced 19% and 18% higher tuber yield compared with *Chromolaena* mulch in the first and second cropping seasons, respectively.

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. 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 (Awodun & Ojeniyi, 1999; Ojeniyi & Adetoro, 1993). The type of material used as mulch determines its impact on soil physical and chemical properties, and crop yield (Awodun & Ojeniyi, 1999). This is due to differences in biochemical quality of plant materials. The key factors determining quality of the mulching materials are the nutrient value, texture, rate of decomposition, availability, cost, growth rate and vegetative matter turn over. The nutritional effect of mulches on plants depends on residue quality. High quality materials improve plant nutrition by releasing nutrients. Low quality residues have relatively weak direct nutritional effect.

Siam weed (*Chromolaena odorata*) is widespread throughout the humid forest zone of West Africa. In southwest Nigeria, it grows luxuriantly and rejuvenates the soil. Its effectiveness in yam mulching had been reported (Akanbi & Ojeniyi, 2007). Mexican sunflower (*Tithonia diversifolia*) is an aggressive annual weed growing along major roads, paths and on abandoned farm lands in southwest Nigeria. According to Jama *et al*. (2000), *Tithonia* has aroused research interest because of the relatively high nutrient concentrations that are found in its biomass, and because of its ability to extract relatively high amount of nutrients from the soil. 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.

Tithonia has received less research attention in the tropics compared with siam weed 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 majority of the traditional yam farmers in Nigeria, Cameroon, Togo and Ghana use different types of mulch materials which range from dry grass, palm fronds to wood shavings. However, research information on the use of *Tithonia* as a mulch material for yam production on an Alfisol of the humid tropics has not been documented.

The actual rate of *Tithonia* on the performance of yam does not exist in the tropics. There is the need to ascertain the extent to which this weed species could be used as mulch for soil improvement and performance of yam to determine the best rate of application of the weed species. There is scarcity of research information on comparison of *Chromolaena* and *Tithonia* as to their relative effects on soil properties, growth and yield of yam. It is hypothesized that *Chromolaena* and *Tithonia* would enhance soil fertility and performance of yam. Therefore, the study was carried out to compare the impact of *Chromolaena* and *Tithonia* 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 cropping seasons at Owo, Nigeria. Owo is located at latitude 7^0 12’ N and longitude 5^0 35’ E within the forest-savanna transition zone of southwest Nigeria. The average rainfall varies from 1000-1240 mm. This forest savanna 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 from September to November. The site was previously left to fallow for 2 years. It was manually cleared before the experiment was laid out. The soil derived from this site had been classified as Oxic Tropuldalf (USDA, 1999) or Luvisol (FAO, 1998) derived from quartzite, gneiss and schist (Agbede, 2006).

The experiment consisted of 2×5 factorial combinations of two mulch materials (Siam weed: *Chromolaena odorata* and Mexican sunflower: *Tithonia diversifolia*) and five rates of application of the mulch materials (0.0, 5.0, 7.5, 10.0 and 12.5 t ha^{-1}). The treatments were (a) no application of *Chromolaena* mulch at 0.0 t ha^{-1}, (b) application of *Chromolaena* mulch at 5.0 t ha^{-1}, (c) application of *Chromolaena* mulch at 7.5 t ha^{-1}, (d) application of *Chromolaena* mulch at 10.0 t ha^{-1}, (e) application of *Chromolaena* mulch at 12.5 t ha^{-1}, (f) no application of *Tithonia* mulch at 0.0 t ha^{-1}, (g) application of *Tithonia* mulch at 5.0 t ha^{-1}, (h) application of *Tithonia* mulch at 7.5 t ha^{-1}, (i) application of *Tithonia* mulch at 10.0 t ha^{-1}, (j) application of *Tithonia* mulch at 12.5 t ha^{-1}. The 10 treatments were arranged in a randomised complete block design with three replications. The same site was used in the two years of the experiment.

Planting of yam and application of mulch

After manual clearing, heaping was done manually at 1 m $\times$ 1 m spacing in 2006 and 2007. Each heap was approximately 1 m wide at the base and about 0.75 m high. Heaps were prepared by piling the soil surface layer using the traditional hoe after cleared weeds were removed from the plots. Each plot was 20 m^2. Planting was done immediately after heap construction each year. One seed yam of white yam (*Dioscorea rotundata* cv. Gambari), weighing about 0.4 kg was planted per heap. Fresh Siam weed (*Chromolaena odorata*) and Mexican sunflower (*Tithonia diversifolia*) were collected from a nearby farm and hedge containing pure stands and the leaves equivalent to 0.0, 5.0, 7.5, 10.0 and 12.5 t ha^{-1} were applied to cover the heaps one month after planting. Staking was done after sprouting. Weeding was manual with a hoe four times 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 heap using steel core samplers and were used for the determination of bulk density, and gravimetric moisture content after oven drying of samples at 100 ^{0}C for 24 h. Soil temperature was determined at 15:00 h with a soil thermometer inserted to 10 cm depth. Six readings were taken 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 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 & Black using the dichromate wet oxidation method (Nelson & Sommers, 1996). Organic matter was deduced by multiplying soil organic carbon with a factor of 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 ammonium acetate. Thereafter, K was determined using a flame photometer and Ca and Mg by the EDTA titration method (Hendershot & Lalande, 1993). Soil *p*H was determined by using a soil-water medium at a ratio of 1:2 using digital electronic *p*H 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 ^{0}C and ground in a Willey-mill. These samples were analysed for leaf N, P, K, Ca and Mg as described by Tel & Hagarty (1984). Leaf N was determined by the micro-Kjeldahl digestion method. Ground samples were digested with nitric-perchloric-sulphuric acid mixture (AOAC, 1997) for the determination of P, K, Ca and Mg. Phosphorus was determined colorimetrically by the vanadomolybdate method, K was determined using a flame photometer and Ca and Mg determined by EDTA titration method.

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 a meter rule at harvest 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. Statistical significance was at $P = 0.05$ unless otherwise stated.

Results

Soil physical properties

The physical and chemical properties of the soils at the site before planting in 2006 and chemical composition of *Chromolaena* and *Tithonia* 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

TABLE 1
Soil physical and chemical properties of the experimental site before planting

Soil properties	*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*
*p*H (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 matter before the commencement of the experiment was partly attributed to its fairly high bulk density (Adekiya *et al.*, 2011). The site was low 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 *Tithonia* and *Chromoloaena* used for the experiments are presented in Table 2. Results indicated that *Tithonia* had higher values of moisture content, N, P, K, Ca and lower C : N ratio compared with *Chromolaena*. The organic C content in *Tithonia* was also comparable to *Chromolaena*. However, *Tithonia* and *Chromoloaena* were low in Mg.

TABLE 2

Chemical composition of Chromolaena *and* Tithonia *mulch materials used*

Organic	*C (%)*	*N (%)*	*P (%)*	*K (%)*	*Ca (%)*	*Mg (%)*	*C:N*	*Moisture content (%)*
Chromolaena	15.6a	1.21b	0.61b	1.03b	2.30b	0.004a	12.9	22.3b
Tithonia	14.8a	1.88a	0.79a	3.89a	3.41a	0.004a	7.8	27.5a

Values followed by the same letters in the same column are not significantly different at $P = 0.05$ according to Duncan's multiple range test (DMRT)

Soil physical properties

In both years, *Chromolaena* and *Tithonia* mulches reduced soil bulk density compared with the control, but the reduction was only significant at 12.5 t ha^{-1} (Table 3). Similarly, mulching increased soil moisture content compared with the control. However, the values were only statistically different for both the *Chromolaena* mulch and *Tithonia* mulch at 10.0 and 12.5 t ha^{-1} mulch rates (Table 3). Both mulch materials at 10,0–12.5 t ha^{-1} multh rates produced significant differences ($P = 0.05$) between mulch and no mulch plots. Soil temperatures reduced as the rate of *Chromolaena* and *Tithonia* mulches increases from 0.0 to 12.5 t ha^{-1} (Table 3b, Fig. 3).

Considering years (Y) as individual factor, there was influence on soil moisture content and temperature significantly ($P = 0.05$), had no significant influence on soil bulk density (Table 3).

Mulch materials (M), when studied also as individual factor, have 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 has 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 *Chromolaena* and *Tithonia* treatments, mulching increased soil organic matter (SOM), N, P, K, Ca and Mg concentrations compared with the control (Table 4). However, K, Ca and Mg only

TABLE 3

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 (^0C)*
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
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

NS = Not significant; *P = 0.05

increased with *Chromolaena* mulch up to 10.0 t ha^{-1} and *Tithonia* mulch increased to 7.5 t ha^{-1}. In all cases in both years, considering the same rate of mulch, *Tithonia* mulch significantly (P = 0.05) produced higher values of SOM, N, P, K, Ca and Mg concentrations compared with *Chromolaena* mulch. When considered as single factors, years (Y), mulch materials (M) and mulch rates (R) significantly (P = 0.05) influenced soil chemical properties (Table 4). 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, N, P, Ca and Mg. However, Y × R interaction was not significant for K, but significant for K under M × R interaction. The interaction of Y × M × R were significant for SOM, P, Ca and Mg, but not significant for N and K.

TABLE 4

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 ($g\ 100g^{-1}$)*	*N ($g\ 100g^{-1}$)*	*P ($mg\ kg^{-1}$)*	*K ($cmol\ kg^{-1}$)*	*Ca ($cmol\ kg^{-1}$)*	*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
Year (Y)			*	*	*	*	*	*
Mulch material (M)			*	*	*	*	*	*
Mulch rate (R)			*	*	*	*	*	*
Y × M			NS	NS	*	NS	*	*
Y × R			*	*	*	NS	*	*
M × R			*	*	*	*	*	*
Y × M × R			*	NS	*	NS	*	*

NS = Not significant; *P = 0.05

Leaf nutrient concentrations of yam

In both years, the *Chromolaena* and *Tithonia* mulches increased leaf N, P, K, Ca and Mg concentrations of yam compared with the control (Table 5). The values of leaf N and P concentrations of yam increased with increasing mulch rate in both mulch materials. *Chromolaena* mulch only increased leaf K, Ca and Mg concentrations of yam up to 10.0 t ha^{-1}. There were no significant differences (P = 0.05) between 10.0 and 12.5 t ha^{-1}. *Tithonia* 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} *Chromolaena* and *Tithonia* mulches, *Tithonia* mulch significantly (P = 0.05) produced higher values of leaf N, P, K, Ca and Mg concentrations of yam compared with *Chromolaena* mulch.

Years (Y), when considered as individual factor, have no significant influence on leaf nutrient concentrations of yam (N, P, K, Ca and Mg) (Table 5). Whereas mulch materials (M) and mulch rates (R), when studied as individual factors, have 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.

TABLE 5

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 (g 100g^{-1})*	*P (mg kg-^{1})*	*K (cmol kg^{-1})*	*Ca (cmol kg^{-1})*	*Mg (cmol kg^{-1})*
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
Year (Y)		NS	NS	NS	NS	NS	NS
Mulch material (M)		*	*	*	*	*	*
Mulch rate (R)		*	*	*	*	*	*
Y × M		NS	NS	NS	NS	NS	NS
Y × R		NS	NS	NS	NS	NS	NS
M × R		NS	NS	NS	NS	NS	NS
Y × M × R		NS	NS	NS	NS	NS	NS

NS = Not significant; *P = 0.05

Crop growth parameters and tuber yield of yam

In both years, the *Chromolaena* and *Tithonia* mulches produced significant (P = 0.05) values of yam vine length, leaf area (Table 6) and tuber yield of yam (Table 6 and Fig. 1) compared with the control. With *Chromolaena* 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} *Chromolaena* mulch.

Likewise, *Tithonia* 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, *Tithonia* mulch produced higher values of vine length, leaf area and tuber yield of yam compared with *Chromolaena* mulch. Using the mean of the

TABLE 6

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
Year (Y)			*	*	*
Mulch material (M)			*	*	*
Mulch rate (R)			*	*	*
Y × M			NS	*	*
Y × R			NS	NS	NS
M × R			*	*	*
Y × M × R			NS	NS	NS

NS = Not significant; *P = 0.05

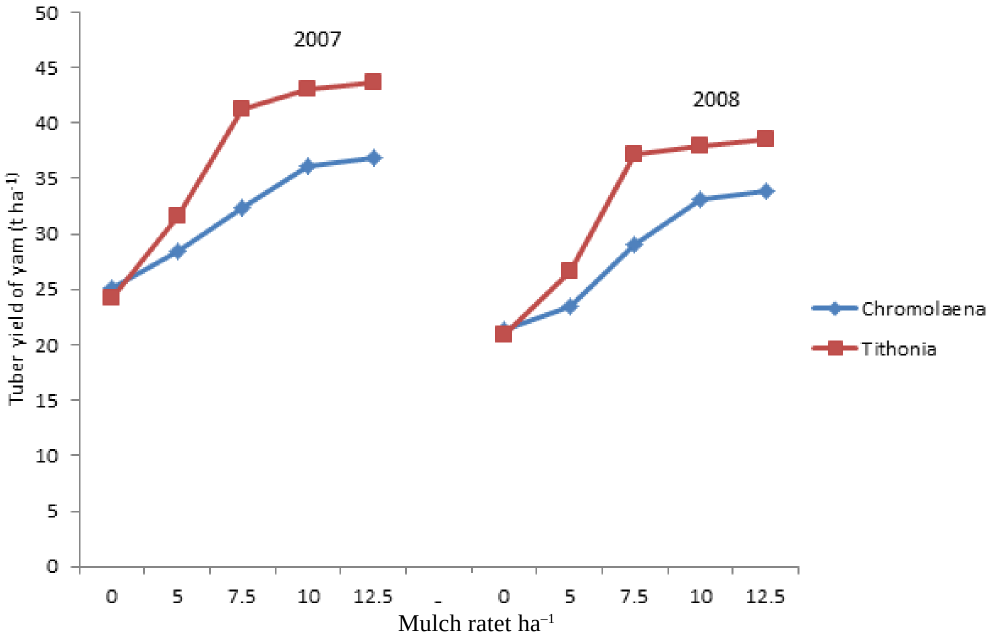

Fig. 1. Effect of different rates of mulch materials on tuber yield of yam in 2007 and 2008 cropping seasons

2 years, 5.0, 7.5, 10.0 and 12.5 t ha^{-1} *Chromolaena* 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} *Tithonia* 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, *Tithonia* 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 ($P = 0.05$) influenced vine length, leaf area and tuber yield of yam (Table 6). 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.

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 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 Chromolaena *and* Tithonia *mulches on soil physical properties*

It was observed that both *Chromolaena* and *Tithonia* 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 & Lal (1987) found that surface applied mulch at 4–6 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 *Chromolaena* and *Tithonia* mulched plots compared with unmulched plots (control) could be attributed to increase in soil organic matter which 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, the mulch by protecting the soil, it should have stabilized the soil structure against raindrop impact and, thereby, preventing soil erosion, soil compaction and crusting.

Effect of Chromolaena *and* Tithonia *mulches on soil chemical properties*

Chromolaena and *Tithonia* mulches increased soil organic matter, N, P, 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 the decomposed mulches. Other works (Obatolu & Agboola, 1993; Olabode *et al.*, 2007) conducted in other parts of Nigeria also proved that *Chromolaena* and *Tithonia* mulches decomposed to enhance soil organic matter and nutrient concentrations. The higher values of soil organic matter, N, P, K, Ca and Mg concentrations under *Tithonia* mulch plots compared with *Chromolaena* 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 rate of mulch from *Chromolaena* and *Tithonia* could be due to increase in organic matter. It was found that values of soil K, Ca and Mg concentrations increased up to 10.0 t ha^{-1} and 7.5 t ha^{-1} in *Chromolaena* and *Tithonia* mulch plots, respectively. This could be due to leaching of excess cations and fixations by soil colloids, especially clay (Akanbi & Ojeniyi, 2007).

Effect of Chromolaena and Tithonia mulches on leaf nutrient concentrations of yam

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

Response of yam yield to Chromolaena *and* Tithonia *mulches*

The increase in performance of yam due to mulch application could be due to reduced soil temperature and increased availability of SOM, N, P, K, Ca and Mg concentrations due to the mulches. Variation in soil moisture content between 10–30% and soil temperature between 25–30 ^{0}C were found suitable for yam growth (Ohiri, 1995). Also Ohiri & 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). He found out that 5 t ha^{-1} of grass mulch reduced soil temperature by about 7 ^{0}C at 5 cm depth and 5 ^{0}C at 10 cm depth. The increase in growth and yield of yam as a result of increases in rates of *Chromolaena* and *Tithonia* mulches could be due to increased in availability of organic matter, N, P, K, Ca and Mg in the soil.

The results that 10.0 t ha^{-1} *Chromolaena* mulch and 7.5 t ha^{-1} *Tithonia* 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 *Chromolaena* treatments at 10.0 and 12.5 t ha^{-1} applications and *Tithonia* mulch produced at 7.5, 10.0 and 12.5 t ha^{-1} applications. *Chromolaena* mulch applied at 10.0 t ha^{-1} and *Tithonia* 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, *Tithonia* mulch produced significantly higher growth and tuber yield compared with *Chromolaena* mulch could be adduced to the analysis recorded for the two mulch materials. *Tithonia* has higher nutrient status and low C : N ratio compared with *Chromolaena*. The higher nutrient status and low C : N ratio of *Tithonia* 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 *Tithonia* is a high quality organic source in term of nutrient release and supplying capacity.

Sustainability of Chromolanena and Tithonia *mulches as sources of nutrients*

The use of *Chromolanena* and *Tithonia* mulches as sources of nutrients is highly sustainable. This is because *Chromolanena* and *Tithonia* 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 (Olabode *et al*., 2007; Akanbi & Ojeniyi, 2007). Furthermore, the abundance and adaptability of these weed species to various environments, coupled with its rapid growth rate and very high vegetative matter turnover, makes it candidate species for soil rejuvenation (Obatolu & Agboola, 1993).

Social or technical constraints in the use of mulches

The major constraint to the use of *Chromolaena* and *Tithonia* for mulches is the labour cost required for collection, transportation and application of

Chromolaena and *Tithonia* mulches. Despite this cost, the economic returns and net benefits in treatments receiving *Chromolaena* and *Tithonia* were higher than the control (data not shown). The economic returns and net benefits increased with increasing rate of *Chromolaena* and *Tithonia* mulches, the highest being obtained from *Tithonia* mulch applied at 7.5 t ha^{-1} followed by *Chromolaena* applied at 10.0 t ha^{-1}. Other important constraints limiting the use of *mulches* are the large amount required to supply nutrients to soil, leaching of nutrients due to erosion, lack of supportive institutions, harsh climatic conditions and prioritization of use of mulches in local farmland systems other than soil fertility improvement (Meertens, 2003; Chianu & Tsujii, 2005).

Conclusion

Chromolaena and *Tithonia* mulches reduced soil temperature, bulk density and increased moisture content, soil organic matter, N, P, 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 *Tithonia* mulch produced significantly higher yield of yam compared with *Chromolaena* mulch. The higher yield was adduced to higher N, P, K, Ca and low C:N produced by *Tithonia* mulch compared with *Chromolaena* mulch. *Chromolaena* mulch and *Tithonia* mulch applied at 10.0 and 7.5 t ha^{-1}, respectively, was found to be suitable for yam production in tropical Alfisol.

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