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Effect of Tillage Systems and *Tithonia diversifolia* Mulch on Soil Physical and Chemical Properties, Growth and Cocoyam Yield in a Tropical Alfisol

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Authors' contributions

This work was carried out in collaboration between both authors. Author TMA designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript and managed literature searches. Authors TMA and JOO managed the analyses of the study and literature searches. Both authors read and approved the final manuscript.

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ABSTRACT

Field experiments were carried out during 2012 and 2013 cropping seasons on an Alfisol (Oxic Tropuldalf) at Owo in the forest–savanna transition zone of southwest Nigeria to evaluate the effect of different tillage systems (zero tillage (ZT), ploughing plus harrowing (P+H) and ploughing plus harrowing twice (P+2H), and with or without *Tithonia diversifolia* mulch (TM) on soil properties, growth and yield of cocoyam. The experiment was laid out in a randomized complete block design in a factorial combination of six treatments that were replicated three times. Among the tillage systems, zero tillage had the highest soil moisture content (12.3%), lowest soil temperature (31.8°C) and lower soil bulk density (1.36 Mg m^{-3}) and higher total porosity (48.7%) that was similar to P+H. ZT also produced the best values of soil chemical properties, growth and yield of cocoyam compared with P+H and P+2H. P+2H had the highest soil bulk density (1.56 Mg m^{-3}) and temperature (34.6ºC) and lowest soil moisture (9.6%) and total porosity (41.1%) and also produced

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the least soil chemical properties and hence poor growth and yield compared with ZT and P+H. ZT increased cocoyam corm yield by 15 and 33% over the P+H and P+2H respectively. The corresponding increases in cormel yield were 12 and 28%, respectively. Application of 7.5 t ha^{-1} tithonia mulch in combination with tillage system significantly reduced soil bulk density and temperature, increased soil moisture content and total porosity, soil organic matter, N, P, K, Ca and Mg, growth and cocoyam yield than their sole tillage systems. Among the tillage – tithonia mulch combinations, the most satisfactorily corm yield (9.1 t ha^{-1}) and cormel yield (13.3 t ha^{-1}) was produced by zero tillage plus tithonia mulch (ZT+TM) while the lowest corm yield (7.2 t ha^{-1}) and cormel yield (11.1 t ha^{-1}) was produced by ploughing plus harrowing twice plus tithonia mulch (P+2H+TM).

Keywords: Alfisol; cocoyam; Tithonia mulch; soil properties; tillage.

1. INTRODUCTION

Cocoyam (*Xanthosoma sagittifolium* (L.) Schott) belongs to the family Araceae and it is one of the six most important root and tuber crops worldwide. The corms and cormels of the plant are an important source of carbohydrate for human nutrition, animal feed and cash income for farmers. Occasionally, young leaves and petioles are also used for food [1]. It contains easily digestible starch as well as vitamin C, riboflavin and thiamine. It has many therapeutic values in treatment of gastrointestinal disorder and diabetics [2]. Cocoyam ranks third in importance after cassava and yam among the root and tuber crops cultivated and consumed in Nigeria [3]. The crop is mainly cultivated by small-scale farmers in Africa, Asia and Latin America, with Nigeria featuring as the world's leading producer of cocoyam, accounting for up to 11 million metric tonnes annually [4]. In spite of its importance as a staple food in many countries, cocoyam has received very little research attention and the full potentials of crop production have not yet been achieved.

The major production problems responsible for its low yield are continuous decline in soil fertility and lack of soil management required for cocoyam cultivation. Research recommendations with respect to tillage requirements are scarce for different ecological zones. Tillage affects soil properties, nutrient availability, loss and production of organic matter [5]. Cocoyam like any other root and tuber crops is a heavy feeder, exploiting a greater (large) volume of soil for nutrients and water [6]. Tillage is an important cultural practice that can be used to increase the yield of cocoyam. In the humid tropics where most farmers are poor and fertilizer is expensive, soil working and tillage systems can temporarily serve as an alternative to fertilizer application [7]. Higher concentrations of organic C, N, P, K and Mg have been observed in surface soil of zero tillage with mulch than tilled plots [8].

One of the agronomic measures adopted by farmers to ensure adequate soil moisture content and subsequent optimum crop yield in some communities and soil types is the adoption of appropriate tillage practice [9]. Tillage induces nutrient release, decomposition of organic materials and mineralization of organic nutrients. However, intensive or repetitive tillage causes rapid degradation of soil physical, chemical and biological qualities especially in case of Alflsol of southwest Nigeria [6]. Use of excessive and unnecessary tillage operations is often harmful to soil. Therefore, currently there is a significant interest and emphasis on the shift to the conservation and zero tillage (no-tillage) methods for the purpose of controlling erosion process, conserving soil and water, mitigating drought, reducing tillage costs, increasing soil organic matter, boosting crop productivity and reducing net CO_2 emissions which contribute to global warming attenuation [5]. Hence, there is need to examine the potential of growing cocoyam using zero tillage and conventional practices and their effect on soil properties and cocoyam performance.

Tillage systems and residue management practices are beneficial in Nigeria, where the bulk of the potential arable land, consisting of Alfisols, Ultisols and Oxisols, have low-activity clay and low inherent fertility, various nutrient imbalances, poor structural stability, low water-holding capacity and high susceptibility of the soils to erosion [10,11,12]. These soil management practices are being used to improve the quality and productivity of the soils, maintain the diversity and stability of the ecosystem, and increase crop growth and yield [10].

Mulching maintains a good soil physical condition by conserving soil moisture and enhancing water infiltration and stabilizing soil structure. Mulching improves biotic activity and adds nutrients to soil thereby improving soil fertility through decomposition [13]. Mulch materials were reported to 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 [14,15]. Residue mulch is also reported to reduce soil particle detachment and transport [16], improve organic matter content and soil fertility, soil water storage capacity and infiltration rate and increase crop growth and yield [17,18]. The type of material used as mulch determines its impact on soil physical and chemical properties and crop yield [19], and this is due to differences in biochemical quality of plant materials. According to [13], 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.

Mexican sunflower (*Tithonia diversifolia*) is a shrub which belongs to the family of 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 [20]. It is an aggressive annual weed growing along major roads, paths and abandoned farm lands in southwest Nigeria [13]. *Tithonia diversifolia* has aroused research interest because of the relatively 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 [21]. According to [22], the high N concentration and rapid decomposition of green *Tithonia diversifolia* biomass make it an effective source of N for crops. *Tithonia diversifolia* has been used successfully to improve soil fertility and crop yield in Kenya [21], Malawi [23], Rwanda [24] and Zimbabwe [25]. It has the potential of being a mulch material and nutrient source for cocoyam. *Tithonia diversifolia* has received less research attention in the tropics compared with *Chromolaena odorata* (Asteraceae) as to its effect on soil properties and crop productivity [13]. Mulching is a traditional practice in cocoyam cultivation aimed at controlling heat scorching and soil temperature, and to improve soil fertility and yield, but the majority of traditional cocoyam farmers in Nigeria and other African countries use different types of mulch materials which range from dry grasses, weeds, palm fronds to wood shavings. However, research information on the use of *Tithonia diversifolia* as a mulch material for cocoyam production on an Alfisol of the humid tropics has not been documented when compared with *Chromolaena odorata* mulch for yam [26].

Research information on tillage requirements of cocoyam in the forest-savanna transition zone of southwest Nigeria and the implication of tillage – tithonia mulch combination for the production of cocoyam is yet to receive research attention on tropical Afisols because previous tillage studies in the tropics on cocoyam have concentrated on acidic Ultisols [27,28]. Zero tillage was found to reduce yield of cocoyam compared with ploughing [27]. The author observed that tillage reduced soil bulk density, but that soil infiltration increases only when tillage and mulch were combined. Also [28], in an experiment on an Ultisol in southeast Nigeria, evaluated the effects of two tillage systems (tilled and clear plastic-film mulch) on the performance of cocoyam. At harvest, corm yield (29.1 t ha^{-1}) obtained in tilled black mulch plots was significantly higher (P = .05) than yields obtained in no-till no mulch plot by 72%. The objective of this work was to evaluate the effects of tillage systems and tithonia mulch on soil physical and chemical properties, growth and fresh corm and cormel yields of cocoyam in southwest Nigeria.

2. MATERIALS AND METHODS

2.1 Site Description

The experiments were carried out in 2012 and 2013 cropping seasons at the Teaching and Research Farm of Rufus Giwa Polytechnic, Owo on latitude 7º12`N, longitude 5º35`E within the forest-savanna transition zone of southwest Nigeria. Available climatic data indicate that the annual rainfall totals were 1428 and 1356 mm, for 2012 and 2013, respectively. The rainfall pattern is bimodal with peaks in the months of July and September. The rainy season commences in March, lasting till October, while the dry season is between November and February with mean monthly temperature ranging between 24ºC and 32ºC. The soil of the experimental site belongs to an Afisol classified as Oxic Tropuldalf [29] or Luvisol [30] derived from quartzite, gneiss and schist [31]. The site had been under bush fallow for four years after arable cropping to a variety of crops such as yam (*Dioscorea rotundata* Poir), maize (*Zea mays* L.), cowpea (*Vigna unguiculata* Walp), cassava

(*Manihot esculenta* Crantz), groundnut (*Arachis hypogaea* L.), melon (*Colosynthis citrullus* L.) etc.

2.2 Field Experiments and Treatments

The experiment was laid out in a 3 x 2 factorial combinations of tillage (seedbed type) and application of *Tithonia diversifolia* mulch (0, 7.5 t ha^{-1}). The treatments compared at the site were (a) zero tillage without application of tithonia mulch (ZT), (b) zero tillage with application of 7.5 t ha^{-1} tithonia mulch (ZT+7.5 t ha^{-1} TM), (c) ploughing followed by harrowing without application of tithonia mulch (P+H), (d) ploughing followed by harrowing with application of 7.5 t ha^{-1} tithonia mulch (P+H+7.5 t ha^{-1} TM), (e) ploughing followed by harrowing twice without application of tithonia mulch (P+2H) and (f) ploughing followed by harrowing twice with application of 7.5 t ha^{-1} tithonia mulch (P+2H+7.5 t ha^{-1} TM). For the zero tillage treatments, the land was cleared with cutlass followed by treatment with paraquat (1, 1- dimethyl - 4, 4 - bipyridilium dichloride at the rate of 2.5 kg ha^{-1} a.i. sprayed two weeks before planting on flat in the killed sod. For ploughing and harrowing treatment, soil was ploughed and harrowed to a 20 cm depth once with tractor-mounted disc plough and harrow, while for ploughing followed by harrowing twice treatment, soil was ploughed to a 20 cm depth once with a tractor-mounted disc plough followed by harrowing twice to a 20 cm depth with a tractor – mounted disc harrow. The six treatments were factorially arranged in a randomized complete block design and with three replications.

2.3 Crop Establishment and Management

The experimental plot size in each trial was 12 m x 10 m. Blocks were 4 m apart, and plots were 3 m apart. Tillage treatments were carried out in mid-March each year. Cocoyam (*Xanthosoma sagittifolium* cv. Owo local) cormels weighing approximately 150 g were planted on 5 April 2012 and 9 April 2013, respectively. One cocoyam cormel was planted per hole at a spacing of 1 m x 1 m. Fresh Mexican sunflower (*Tithonia diversifolia*) were collected from a nearby farm and hedge containing green tender stems and the leaves were applied at the rate of 7.5 t ha^{-1} to cover the stands (apart from the controls) 2 weeks after planting. Weeding was done manually with a hoe three times throughout the cropping period in each experiment.

2.4 Determination of Soil Properties

Two months after application of treatments, the determination of certain soil physical properties in all plots commenced and this was done at 2-month intervals on four occasions for each year. Five undisturbed core samples were collected at 0-20 cm depth from each plot on the top of cocoyam stand using steel core samplers (4 cm diameter, 20 cm high) and were used for the determination of bulk density and gravimetric moisture content after oven drying of samples at 100ºC for 24 h. Soil temperature was determined at 15.00 h with a soil thermometer inserted to 20 cm depth. Five readings were made per plot at each sampling time at 2-month intervals and mean computed.

Surface soil (0-20 cm) samples were collected at experimental site before commencement of the study and those collected per plot basis at harvest in 2013 (second crop) under no mulch and mulch layer were bulked, air-dried and sieved for chemical analysis as described by [32]. Particle size analysis was done using hydrometer method [33]. Soil pH was determined in soil-water (1:2) suspension using the digital electronic pH meter. Soil organic carbon was determined by the procedure of Walkley and Black using the dichromate wet oxidation method [34]. Organic matter (OM) was deduced by multiplying organic carbon by 1.724. Total N was determined by the micro-Kjeldahl digestion and distillation techniques [35], available P was determined by Bray – 1 extraction followed by molybdenum blue colorimetry [36]. Exchangeable K, Ca and Mg were extracted with a 1M NH4OAC, pH 7 solution. Thereafter, K was analysed with a flame photometer and Ca and Mg were determined with an atomic absorption spectrophotometer [37]. Samples from Tithonia used for the experiments (mulching) were also analysed for organic C, N, P, K, Ca and Mg to determine its nutrient composition.

2.5 Crop Growth and Yield Parameters

Ten plants were selected per plot for the determination of plant height and leaf area per plant at 168 days after planting (DAP) when the cocoyam plant reached its peak growth [1,6]. Plant height was measured by a ruler from the ground level to the shoot apex and leaf area was estimated using the mathematical model developed by [38] between linear measurements of leaves. It relates leaf area (Y) to the product of length (L) and breadth (B).

$$Y = k\ (LB) \quad (1)$$

where the constant, k = 0.927

The corm and cormel yields were determined by harvesting ten cocoyam plants per plot and separated them into corms and cormels. They were washed and cleaned to remove traces of sand before weighing on a top loading balance to determine their fresh weights.

2.6 Statistical Analysis

Data collected were subjected to the analysis of variance (ANOVA) using the Genstat Statistical package [39]. The Duncan's multiple range test (DMRT) at *P* = .05 was used to compare the treatment means.

3. RESULTS AND DISCUSSION

3.1 Initial Soil Fertility Status and Chemical Composition of Tithonia Mulch

The results of the experimental site prior to experimentation in 2012 showed that the surface and subsoil layers were sandy loam in texture and slightly acidic with pH of 5.8 (Table 1). At 0-20 cm depth, bulk density was 1.36 Mg m^{-3} and increase with depth. The sand content tended to reduce, while clay and silt contents increased with depth. The values of soil organic matter and total N were low, while available P, exchangeable K, Ca and Mg were adequate, according to the threshold levels of 3.0% OM, 0.20% N, 10.0 mg kg^{-1} P, 0.16-0.20 cmol kg^{-1} K, 2.0 cmol kg^{-1} Ca and 0.40 cmol kg^{-1} Mg recommended for crop production [40]. The values of soil OM, N, P, K, Ca and Mg were higher statistically at the surface (0-20 cm depth) than at subsoil layer (20-40 cm depth). This could be attributed to higher concentration of organic matter in the upper soil layer than the subsoil layer. 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 tithonia mulching material contained higher amount of organic C, N, P, K and Ca with C:N ratio of 9.6 and 78% moisture content (Table 2). The soil is expected to benefit from organic matter and nutrients to be released from tithonia weed mulch.

3.2 Effect of Tillage Systems and Tithonia Mulch on Soil Physical Properties

Among the tillage systems, zero tillage (ZT) and ploughing plus harrowing (P+H) treatments had lower bulk density and higher total porosity compared with ploughing plus harrowing twice (P+2H) treatment (0-20 cm depth) (Table 3). ZT produced relatively higher soil moisture content and lower temperature compared to other tillage systems. The P+2H treatment produced the lowest total porosity, moisture content, and highest bulk density and temperature. The lower bulk density and higher porosity of zero tilled plots compared with P+2H was attributed to high organic matter. Compared with P+H and P+2H, ZT had highest moisture content and lowest temperature. This is because ZT is protected by plant residue mulch that is left on the soil surface after herbicide treatment that reduces evaporation losses. On the other hand, tilled soils are exposed to radiation and increased evaporation loss of soil water. The higher bulk density of P+2H compared with ZT and P+H was attributed to wheel traffic of tractor and implement passes that compact the soil. Repetitive tillage degrades soil quality and causes rapid collapse of soil structure especially under tropical conditions [6]. A compacted layer may also be formed just below the surface leading to reduction in infiltration rate, ponding and attendant anaerobic conditions. Therefore, Alfisols have a coarse texture surface horizon overlaying a clayey sub-surface layer which are weak in structure and highly susceptible to crusting, compaction and accelerated erosion [6]. Irrespective of any tillage system, application of 7.5 t ha^{-1} tithonia mulch significantly increased (*P* = .05) soil moisture content and total porosity; and reduced soil bulk density and temperature (Table 3). The higher moisture content and lower temperature associated with mulch could be adduced to reduction of evaporation of moisture from the soil [41,42]. The reduction of soil bulk density observed in mulched plots compared with un-mulched plots could be attributed to increase in soil organic matter resulted from the degraded organic residues by soil microorganisms. Mulches generate the organic matter that binds soil particles and stabilize aggregate, reduce the kinetic energy of the impacting raindrops, and soil compaction and aggregate disintegration [12]. Organic matter is known to improve soil structure, aeration, soil moisture content, reduce soil bulk density, soil temperature and enhance water infiltration and retention [13]. The presence of vegetative surface mulch should have increased activities of beneficial soil fauna in organic matter decomposition which led to enhancement of soil moisture, soil porosity and reduction of soil bulk density and temperature. 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.

3.3 Effect of Tillage Systems and Tithonia Mulch on Soil Chemical Properties at Harvest in 2013 Cropping Season

Zero tillage produced significantly higher values of soil organic matter (SOM), N, K, Ca and Mg for surface soil (0-20 cm) compared with other tillage systems (Table 4). The effect of tillage on soil pH and P were not statistically significant. The soil fertility after harvest in 2013 (second cropping season) tended to decrease in the order: ZT > P+H > P+2H. The best fertility status of zero tillage compared with other tillage systems could be attributed to presence of organic matter. This affirmed the conservation of soil organic matter and nutrient concentrations by zero tillage as opposed to conventional tillage systems which destroys soil chemical properties [43,44]. In all cases, P+2H gave the lowest values of soil organic matter, N, P, K, Ca and Mg concentrations compared to other tillage systems. The decline in the nutrient reserves of tilled soils especially P+2H could be attributed to a number of processes such as leaching, increased biological activity and oxidation, and high destruction of the soil structure by mechanical tillage during land preparation which encourages soil erosion that preferentially removes colloidal fraction with high "enrichment ratio" [44], resulting in a progressive depletion of its nutrient reserves. [45] reported rapid mineralization of soil organic C, N, S and P for Alfisols in Nigeria due to forest clearance. Therefore, it is confirmed that tillage degrades the quality of Alfisol while cultivation generally increases the depletion of soil organic matter and other soil nutrients and the degree of degradation of these fertility properties depends on the degree of soil manipulation imposed by the tillage system.

Application of 7.5 t ha^{-1} tithonia mulch in combination with tillage systems significantly increased soil organic matter (SOM), N, P, K, Ca and Mg (Table 4). However, the tithonia mulch did not increase soil pH. The findings that tithonia mulch increased SOM, N, P, K, Ca and Mg concentrations compared with unmulch attested to the fact that tithonia is rich in these nutrients and affirmed that these nutrients are released into the soil by decomposed tithonia mulch. Other works carried out in other parts of Nigeria and Africa also proved that tithonia mulch

Table 1. Mean ± standard deviation of soil physical and chemical properties of the experimental site prior to experimentation in 2012

Soil property	0-20 cm depth	20-40 cm depth
Sand (g kg^{-1})	685±8.6	648±6.5
Silt (g kg^{-1})	147±6.4	160±4.7
Clay (g kg^{-1})	168±5.7	192±8.2
Textural class	Sandy loam	Sandy loam
pH (water)	5.8±0.2	5.8±0.1
Bulk density (Mg m^{-3})	1.36±0.04	1.38±0.05
Total porosity (%, v/v)	48.7±0.3	47.9±0.4
Organic matter (%)	2.86±0.07	1.79±0.03
Total N (%)	0.17±0.01	0.13±0.02
Available P (mg kg^{-1})	10.3±0.5	8.8±0.3
Exchangeable K (cmol kg^{-1})	0.18±0.01	0.13±0.01
Exchangeable Ca (cmol kg^{-1})	2.56±0.03	2.12±0.05
Exchangeable Mg (cmol kg^{-1})	0.60±0.02	0.46±0.02

Table 2. Chemical composition of the tithonia mulch used in the study

Organic/mulching material	Organic C (%)	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	C : N	Moisture content (%)
Tithonia	31.6	3.3	0.37	4.1	3.4	0.21	9.6	78

decomposed to enhance SOM and nutrient concentrations [21,23]. The higher values of SOM, N, P, K, Ca and Mg concentrations on tithonia mulched plots compared with unmulched plots could be ascribed to its nutrient contents (Table 2). Hence, those nutrients were released into the soil after decomposition leading to increased uptake by cocoyam. This agreed with the findings of [46] that tithonia is a high quality organic source in terms of nutrients release and supply capacity. The lower C/N ratio of tithonia (9.6) indicates a faster decomposition. [47] also listed high N and P contents and high soluble fraction and moderate lignin content resulting in high bio-degradation as the strong points of tithonia as source of organic matter.

3.4 Effect of Tillage Systems and Tithonia Mulch on Growth and Yield of Cocoyam in 2012 and 2013 Cropping Seasons

Among the tillage systems, zero tillage produced the highest mean values of plant height (Fig. 1), leaf area (Fig. 2), corm and cormel yields of cocoyam (Fig. 3) in 2012 and 2013 cropping seasons compared with other tillage systems while P+2H gave the lowest mean values. Zero tillage increased corm yield of cocoyam by 15 and 33% compared with P+H and P+2H, respectively, while the corresponding increase in cormel yield were 12 and 28%, respectively. The highest performance of cocoyam under zero tillage followed by P+H was adduced to better soil conditions resulting from this treatment. These were associated with reduced soil bulk density and temperature, higher moisture content, total porosity, soil organic matter and soil nutrients compared with P+2H. For example, the soil bulk density (1.36 Mg m^{-3}) given by ZT was not limiting to growth and development of cocoyam and is less than the value of 1.40 Mg m^{-3} which was found quite suitable for cocoyam [48] and for crop production in the tropics [49]. These findings agreed with study carried out by [50] who found that zero tillage with mulch suppressed weed growth, retained moisture in the soil, provided nutrients and improved soil structure. The least growth and yield of cocoyam under P+2H was due to high soil bulk density and temperature, reduced soil moisture and total porosity and deterioration of soil quality resulting from repeated passage of implement and low soil organic matter and other soil nutrients.

In the two cropping seasons, application of tithonia mulch in combination with tillage systems gave significantly higher (*P* = .05) plant height (Fig. 1), leaf area (Fig. 2), corm and cormel yields of cocoyam (Fig. 3) than their sole tillage systems. Among tillage plus tithonia mulch treatments, zero tillage plus 7.5 t ha^{-1} tithonia mulch (ZT+7.5 t ha^{-1} TM) gave the highest plant height, leaf area, corm and cormel yields of cocoyam and these were significantly higher (*P* = .05) than ploughing plus harrowing plus 7.5 t ha^{-1} tithonia mulch (P+H+7.5 t ha^{-1} TM). Among the tillage - tithonia mulch combinations, ploughing plus harrowing twice plus 7.5 t ha^{-1} tithonia mulch (P+2H+7.5 t ha^{-1} TM) gave the lowest growth and yield parameters of cocoyam. The growth and yield of cocoyam in tillage plus tithonia mulch regime treatments/combinations increased over time, whereas that under various tillage regime treatments declined over time. The increase in growth and yield of cocoyam over time in the tillage plus tithonia mulch combinations/ treatments could be attributed to improvement in soil physical and chemical properties. These were associated with increased availability of soil moisture and higher porosity, reduced soil bulk density and soil temperature, and increased availability of soil organic matter, N, P, K, Ca and Mg due to mulching with tithonia and their residual effects on soil properties. All these parameters are known to enhance cocoyam productivity. Whereas the decrease in growth and yield of cocoyam over time in the various tillage treatments was related to the fact that tillage degrades soil properties with time and the degradation depends on the frequency or intensity of tillage imposed on soil [8].

Among all treatments, the mean fresh corm yield over 2 years at the experimental site for ZT, ZT+TM, P+H, P+H+TM, P+2H and P+2H+TM were 6.9, 9.1, 6.0, 8.1, 5.2 and 7.2, respectively and the corresponding values for cormel yield were 10.2, 13.3, 9.1, 12.2, 8.0 and 11.1, respectively (Fig. 3). ZT+TM increased fresh corm and cormel yields of cocoyam by 32% and 30%, respectively relative to ZT alone. Relative to P+H, P+H+TM increased fresh corm and cormel yield of cocoyam by 35% and 34%, respectively. P+2H+TM increased fresh corm and cormel of cocoyam by 38% and 39%, respectively compared with P+2H alone. These results confirmed that application of tithonia mulch in combination with tillage improved growth and yield of cocoyam, relative to tillage alone. Compared with the unmulched plots (control), tithonia mulched plots significantly increased (*P* = .05) growth and yield of cocoyam in the two years. This is expected because tithonia mulch made available nutrients, especially N and K that are essential for tuber crops which eventually led to increased plant height, leaf area, corm and cormel yields of cocoyam. Cocoyam performance is known to be strongly influenced by K [51]. Adequate soil water and N would also aid corm and cormel expansion, whereas K availability would enhance starch formation. [52,6] found that adequate soil water significantly influenced the yield of cocoyam. In a field experiment conducted in forest-savanna transition zone of southwest Nigeria, [13] found that tithonia mulch applied at 7.5 t ha^{-1} significantly increased yield of yam compared with control. Similar result was found in a field experiment conducted on an Ultisol of eastern Nigeria for yam and cocoyam [27].

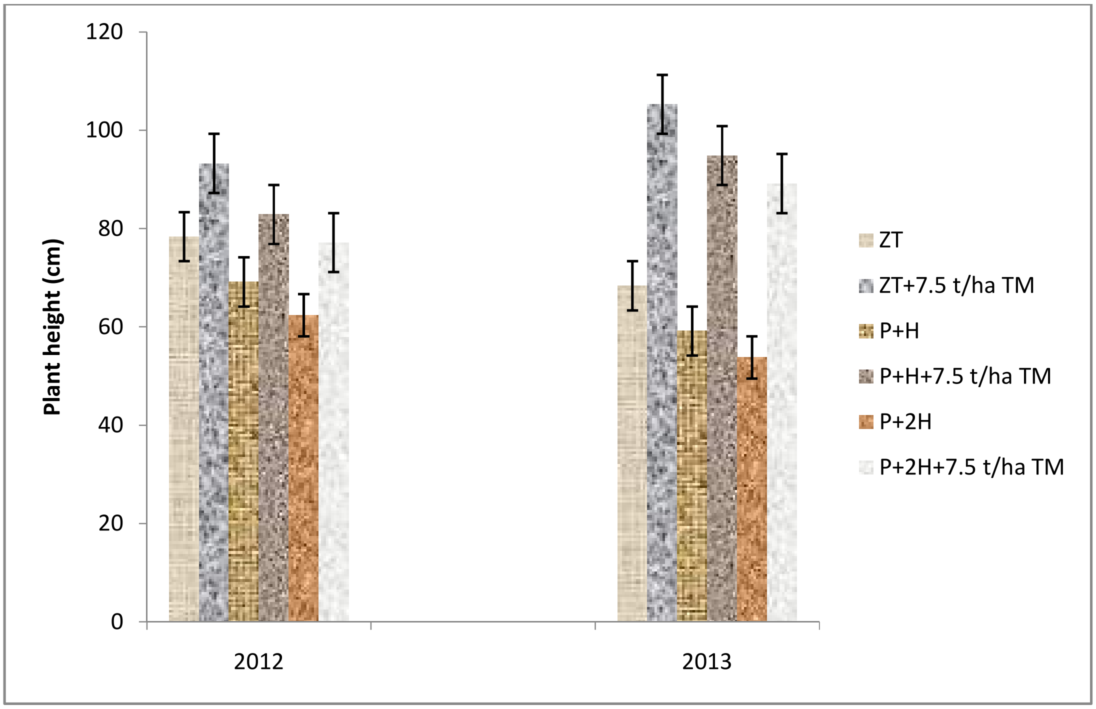

Fig. 1. Plant height of cocoyam in 2012 and 2013 cropping seasons as influenced by tillage systems and tithonia mulch. Vertical bars show standard errors of paired comparisons. ZT: Zero tillage, P+H: Ploughing plus harrowing, P+2H: Ploughing plus harrowing twice, TM: Tithonia mulch

Table 3. Mean Effect of tillage systems and tithonia mulch on soil physical properties (0-20 cm depth) at 2, 4, 6 and 8 months after planting

Treatment	Bulk density (Mg m^{-3})	Total porosity (%, v/v)	Moisture content (%)	Temperature (ºC)
ZT	1.36bc	48.7bc	12.3c	31.8b
ZT+7.5 t ha^{-1} TM	1.21d	54.3a	15.9a	27.9c
P+H	1.36bc	48.7bc	10.7d	33.3a
P+H+7.5 t ha^{-1} TM	1.22d	54.0a	14.2b	30.1b
P+2H	1.56a	41.1d	9.6e	34.6a
P+2H+7.5 t ha^{-1} TM	1.41b	46.8c	12.7c	31.2b

Note: Mean values followed by the same alphabets in the same column are not significantly different at, P = .05 according to Duncan's multiple range test (DMRT). ZT: Zero tillage, P+H: Ploughing plus harrowing, P+2H: Ploughing plus harrowing twice, TM: Tithonia mulch

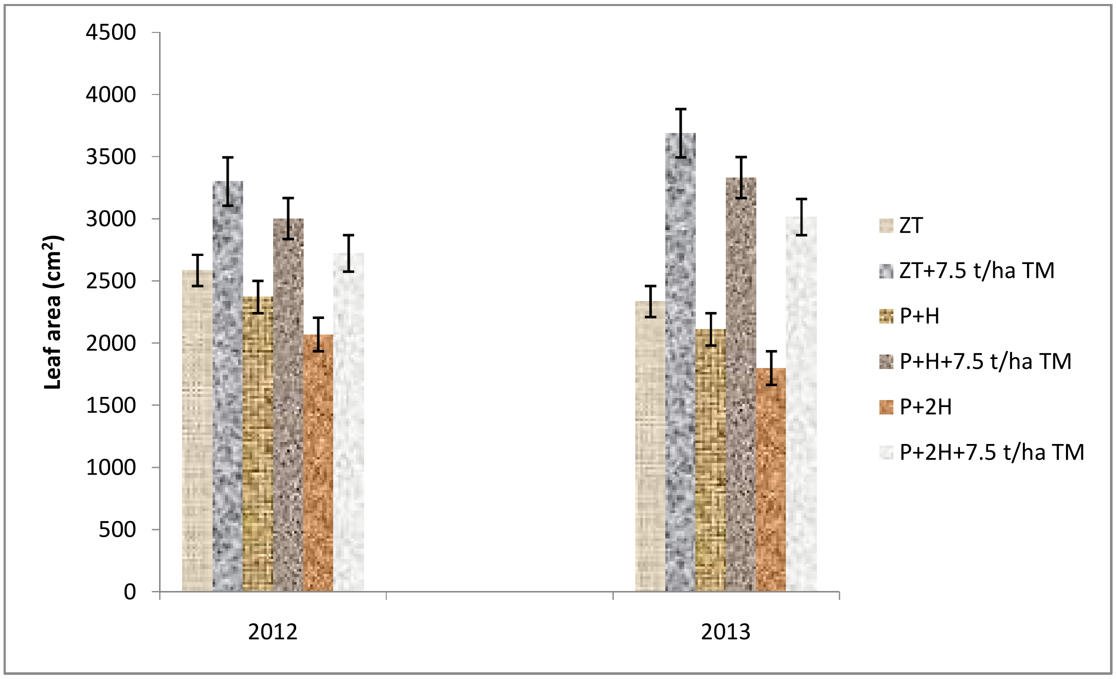

Fig. 2. Leaf area of cocoyam in 2012 and 2013 cropping seasons as influenced by tillage systems and tithonia mulch. Vertical bars show standard errors of paired comparisons, ZT: Zero tillage, P+H: Ploughing plus harrowing, P+2H: Ploughing plus harrowing twice, TM: Tithonia mulch

Table 4. Effect of tillage systems and tithonia mulch on soil chemical properties (0-20 cm depth) at harvest in 2013 cropping season

Treatment	pH (water)	OM (%)	Total N	P (mg kg^{-1})	K	Ca (cmol kg^{-1})	Mg
ZT	5.8a	2.35d	0.14d	8.7b	0.15c	2.2c	0.49d
ZT+7.5 t ha^{-1} TM	6.2a	3.08a	0.20a	12.4a	0.28a	3.1a	0.74a
P+H	5.7a	2.13c	0.12e	8.4b	0.12d	1.9d	0.41e
P+H+7.5 t ha^{-1} TM	6.1a	2.80b	0.18b	12.1a	0.23b	2.5b	0.62b
P+2H	5.6a	1.92f	0.10f	8.2b	0.10e	1.6e	0.35f
P+2H+7.5 t ha^{-1} TM	6.0a	2.58c	0.16c	11.8a	0.19b	2.3c	0.56c

Note: Mean values followed by the same alphabets in the same column are not significantly different at, P = .05 according to Duncan's multiple range test (DMRT). ZT: Zero tillage, P+H: Ploughing plus harrowing, P+2H: Ploughing plus harrowing twice, TM: Tithonia mulch

In comparing zero tillage with ploughing plus harrowing, corm and cormel yields reduced by 13 and 11%, respectively, while ploughing plus harrowing twice reduced the corm and cormel yields by 25 and 22%, respectively. The mean fresh corm yield of cocoyam for unmulched and mulched were 6.0 and 8.1 t ha^{-1}, respectively, while the corresponding mean values for cormel yield were 9.1 and 12.2 t ha^{-1} respectively. Hence, tithonia mulch application in combination with tillage increased fresh corm and cormel yields of cocoyam by 35 and 34%, respectively compared with tillage alone. The ZT+TM increased fresh corm yield of cocoyam by 12 and 26% compared with P+H+TM and P+2H+TM, respectively. The corresponding increases in cormel yields of cocoyam were 9 and 20%, respectively. The ZT+TM gave the highest growth, and fresh corm and cormel yields of cocoyam crops. This might be due to favourable physical and chemical properties resulting from this treatment that helps in better establishment and growth of cocoyam. It is affirmed that adequate soil moisture, reduced bulk density and

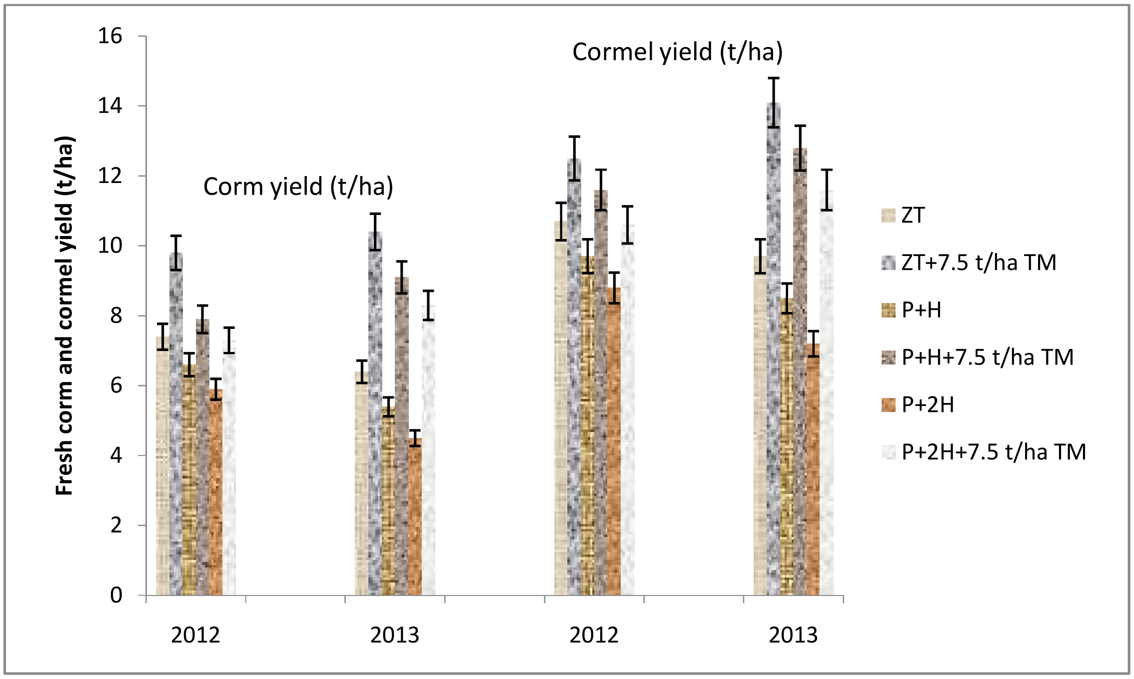

Fig. 3. Fresh corm and cormel yields of cocoyam in 2012 and 2013 cropping seasons as influenced by tillage systems and tithonia mulch. Vertical bars show standard errors of paired comparisons. ZT: Zero tillage, P+H: Ploughing plus harrowing, P+2H: Ploughing plus harrowing twice, TM: Tithonia mulch

temperature, and nutrient availability dictated the performance of cocoyam on an Alfisol of forest-savanna transition zone of southwest Nigeria. In the two years of study, very high correlation coefficients were recorded between soil physical properties and corm and cormel yields (Table 5). High negative correlation coefficients were recorded between soil bulk density and corm and cormel yields and between soil temperature and corm and cormel yields while soil total porosity and soil moisture were positively correlated with corm and cormel yields. Soil OM, N, P, K, Ca and Mg were generally highly and positively correlated with corm and cormel yields (Table 6).

Table 5. Correlation coefficients between soil physical properties and corm and cormel yield of cocoyam in 2012 and 2013 cropping seasons

Soil physical properties	Corm yield	Cormel yield
Bulk density	-0.8583*	-0.8805*
Porosity	0.8511*	0.8739*
Moisture content	0.9912*	0.9930*
Temperature	-0.9920*	-0.9908*

**Significant at P = .05*

Table 6. Correlation coefficients between soil chemical properties and corm and cormel yield of cocoyam in 2013 cropping season

Soil chemical properties	Corm yield	Cormel yield
Organic matter	0.9995*	0.9988*
Total nitrogen	0.9988*	0.9996*
Available phosphorus	0.9275*	0.9197*
Exchangeable potassium	0.9841*	0.9798*
Exchangeable calcium	0.9800*	0.9769*
Exchangeable magnesium	0.9978*	0.9947*

**Significant at P = .05*

4. CONCLUSION

Cocoyam performance was favoured by zero tillage followed by ploughing plus harrowing as opposed to repetitive tillage involving ploughing followed by two passes of harrow. Conventional tillage degrades soil properties and reduced cocoyam productivity and is therefore not recommended for cocoyam cultivation on an Alfisol of forest-savanna transition zone of southwest Nigeria. The application of tithonia mulch at the rate of 7.5 t ha^{-1} each to any tillage treatment significantly increased soil moisture content and total porosity, reduced soil bulk density and temperature and improved soil fertility status, growth and yield of cocoyam. However, zero tillage in combination with 7.5 t ha^{-1} tithonia mulch gave the best production technology of cocoyam cultivation because the combination (ZT+7.5 t ha^{-1} TM) improved soil properties and yield of cocoyam than other tillage - tithonia mulch combinations. Therefore, zero tillage in combination with 7.5 t ha^{-1} tithonia mulch is recommended for cocoyam cultivation on an Alfisol of southwest Nigeria for soil conservation and crop sustainability.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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