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Soil properties and yam yield under different tillage systems in a tropical Alfisol

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In Nigeria, information is lacking regarding the most suitable tillage method in extensive yam production. Hence, five tillage methods were compared at two sites in 2008–2010 with reference to their effects on soil physical and chemical properties, leaf nutrient concentrations, growth and tuber yield of yam (*Dioscorea rotundata* Poir) on Alfisols at Owo (site A) and Akure (site B), south-west Nigeria. The tillage methods were: zero tillage (ZT), manual ridging (MR), manual mounding (MM), ploughing + harrowing (P + H) and ploughing + harrowing + ridging (P + H + R). P + H + R had lower soil bulk density than other tillage methods and resulted in higher leaf N, P, K, Ca and Mg and yam tuber yield. In ZT, bulk density, soil moisture content, soil organic C, N, P, K, Ca and Mg were significantly higher and temperature lower than other tillage methods. Results of multiple regressions revealed that bulk density significantly influenced the yield of yam rather than soil chemical properties. Compared with MR, MM, P + H and ZT, and averaged across years, P + H + R increased yam tuber yield by 12.3, 12.8, 34.9 and 50.7%, respectively, in site A and 12.9, 13.5, 25.2 and 44.5%, respectively, in site B. P + H + R was found to be most advantageous and is therefore recommended for yam cultivation.

Keywords: tillage; soil properties; leaf nutrient concentrations; yam; bulk density

Introduction

Yam (*Dioscorea rotundata* Poir) belongs to the Dioscoreaceae family and is the staple food and major source of calories for about one-third of the world's population. In 2004, global yam production was almost 47 million metric tonnes, 96% of this production was in Africa and Nigeria alone accounts for ~70% of world production (Consultative Group on International Agricultural Research 2004). People consume yams, sweet in flavour, as a cooked vegetable. In West Africa, it is often pounded into a thick paste after boiling and is eaten with soup. Yams are also processed into flour, which is used in the preparation of the paste. Virtually all production is used for human food. Yam is a preferred food and a food security crop in some sub-Saharan Africa countries. Unlike cassava (*Manihot esculenta* Crantz), sweet potato (*Ipomoea batatas* L.) and aroids (*Colocasia esculenta* and *Xanthosoma sagittifolium*), yam tubers can be stored for periods of up to 4 or even 6 months at

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ambient temperatures. This characteristic helps sustain the food supply, especially during the difficult (food scarce) period at the onset of the wet season.

Yam is the second most important and cultivated tropical tuber crop after cassava (Howeler et al. 1993). To date, the actual yield and tillage requirements of yam have not been well documented. Most of the crop produced is consumed locally. The global average gross yield for yam tubers is just 10 Mg ha^{-1} (Consultative Group on International Agricultural Research 2004). This means that there is a dire need to raise the production level in order to meet demand. The tillage system might be important in enhancing yam yield in tropical regions, but limited research has been done to test this hypothesis. Soil tillage is one cultural practice that affects soil physical and chemical properties, as well as crop yield.

Tillage operations are known to influence both the release and conservation of soil nutrients. Tillage practices modify the soil structure by changing physical properties such as soil bulk density, soil penetration resistance and soil water content. According to Khan et al. (2001), annual disturbance and pulverizing caused by continuous tillage produced a finer loose soil structure compared with conservation and no-tillage methods, which leave the soil intact. The latter methods result in a change in the number, shape, continuity and size distribution of the pore network that controls the ability of a soil to store and transmit air, water and agricultural chemicals, and improve the porosity and water-holding capacity of the soil. This consequently leads to a favourable environment for crop growth, nutrient release and use.

The response of crop yield to non-tillage, conventional and intensive farming systems is well documented for temperate regions. However, limited information is available on tillage practices for yam; published results show that tillage methods for yam vary with soil type, soil depth, microclimate and topography. Tillage studies mainly compared the effects of either minimum/reduced tillage or conventional tillage systems on yam yields. The few studies carried out largely neglected the combination of no-tillage, minimum/reduced tillage systems and conventional tillage systems and their effects on soil physical and chemical properties, nutrient uptake, growth and yam yield. The few studies undertaken in Nigeria and other tropical countries gave inconclusive and contradicting results under the different tillage practices compared (Hulugalle et al. 1985). On the sandy soils of Nigeria, Maduakor et al. (1984) observed no significant difference in yam tuber yield when planted on ridges, mounds or on the flat. A study carried out on Ultisols of south-east Nigeria indicated that yam yields in no-tilled plots were greater than in ploughed plots (Opara-Nadi and Lal 1987). However, Hulugalle et al. (1985) found that no-tillage reduced yam yield. In large plantations in Barbados and Jamaica, yam production is mainly mechanized and yams are planted on ridges (Jeffer 1990). In Leyte, Philippines, Villanueva (1986) found that planting yam on mounds produced a higher yield than planting on ridges, on the flat or in furrows.

No study has compared zero tillage with reduced tillage and conventional tillage practices for yam production on an Alfisol under a forest–savanna transition zone with humid tropical conditions. Hence, there is a need to study soil conditions that promote yam production in different ecological zones and soil types. These soil conditions are influenced by tillage, which is performed differently in different ecologies, depending on the location, environment and soil type. The objective of this study was to find a tillage method that maximizes yam performance on Alfisols located in the forest–savanna transition zone of south-west Nigeria. The relative effect of zero tillage, manual mounding, manual ridging, ploughing plus harrowing and ploughing plus harrowing followed by mechanized ridging was studied in relation to soil physical and chemical properties, leaf nutrient concentrations and yield of yam.

Materials and methods

Site description and tillage treatments

Field experiments were conducted during the 2008, 2009 and 2010 cropping seasons at Owo (latitude 7°12′N, longitude 5°32′E), site A, and Akure (latitude 7°15 ′ N, longitude 5°15′E), site B, in the forest–savanna transition zone of south-west Nigeria with yam as the test crop. The soils at the two sites were both Alfisols. The soil at site A (Owo) is Oxic Tropuldalf (USDA 2010) or Luvisol (FAO 1998) derived from quartzite, gneiss and schist. The soil at site B (Akure) is Oxic Paleustalf (USDA 2010) or Luvisol (FAO 1998). The top of the soil at both sites was sandy loam. The total annual rainfalls for 2008, 2009 and 2010 were 1346, 1547 and 1456 mm, respectively. There are two rainy seasons, one from March to July and the other from mid-August to November, with temperatures ranging from 24 to 32°C. The experimental sites had been under bush fallow for 3 years after arable cropping. The predominant weeds at Owo (site A) were Siam weed (*Chromolaena odorata* L. King and Robinson), water leaf (*Talinum triangulare* Jacq. Wild) and coffee senna (*Senna occidentalis* L. Link), interspersed with shrubs. At Akure (site B) the weeds included Guinea grass (*Panicum maximum* Jacq.), haemorrhage plant (*Aspilia africana* Pers. Adams) and broomweed (*Sida acuta* Burm), interspersed with shrubs.

Each year, the experiments consisted of five tillage methods, which were compared at the two sites. The tillage treatments were:

(1) Zero tillage (ZT): manual clearing with a 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 2 weeks before planting on the flat with hoe in the killed sod without primary or secondary tillage operations.
(2) Manual ridging (MR): the ridge was prepared by heaping the soil surface layer using the traditional hoe after cleared weeds had been removed from the plots.
(3) Manual mounding (MM): the mound was prepared by heaping the soil surface layer using the traditional hoe after cleared weeds had been removed from the plots.
(4) Ploughing plus harrowing (P + H): soil was ploughed and harrowed to 0.20 m depth once using a tractor-mounted disc plough and harrow.
(5) Ploughing plus harrowing plus ridging (P + H + R): soil was ploughed and harrowed to 0.20 m depth once using a tractor-mounted disc plough and harrow followed by mechanized ridging with tractor-mounted disc ridger.

The tractor used was a Steyer 768 and its weight was 4500 kg. There was an initial clearing of the plots before tillage operations for treatments P + H and P + H + R. The experiment was laid out in a randomized complete block design with three replications. Each plot size was 12 × 10 m. To minimize interference, blocks were 4 m apart, and plots were 3 m apart. Tillage treatments were carried out in April each year.

Treatments 2 and 3 are the types of seedbed practices most widely used by farmers in the tropics. They are compared with conventional tillage systems and the introduced zero tillage with mulch. The same tillage method was maintained on each plot at each site for the three years of the experiment.

Crop establishment

On 4 April 2008, 6 April 2009 and 8 April 2010, 2 weeks after tillage, treatments were performed in each site; one seedyam weighing 0.4 kg was planted per hill at a spacing of 1×1 m to give a plant population of 10 000 plants ha^{-1}. In each cropping season at each site, a field recommended chemical fertilizer NPK 15–15–15 was applied at 400 kg ha^{-1} in ring form in two equal doses (round each crop in a circle form $\sim$10–15 cm away and 5 cm deep). The first dose was applied 1 month after vine emergence, while the second dose was applied 8 weeks later when tuber expansion, rapid stem and leaf development were in progress. At sprouting, staking was done. Weeding was carried out manually with a hoe at 6, 12 and 18 weeks after planting.

Soil sampling and analysis

Prior to the commencement of the experiment in 2008, soil samples were collected from 0–0.20, 0.20–0.40 and 0.40–0.60 m depths of a profile pit dug in each of the 10 points selected randomly from each site. Undisturbed samples were collected from the centre of the depth intervals using steel coring tubes (0.04 m diameter, 0.10 m high) and were put in an oven set at 100°C for 24 h for determination of bulk density. Particle-size analysis was done using the hydrometer method (Sheldrick and Hand Wang 1993), with 50 g of soil in 100 mL sodium hexametaphosphate as the dispersing agent. Hydrometer readings were taken at 40 s and at 2 h. Textural class was determined using a textural triangle. Before tillage, composite soil samples were collected from the three depths and analysed for chemical properties. Disturbed soil samples were also collected per plot at harvest of yam from 0 to 0.20 m depth in 2008, 2009 and 2010 and similarly analysed for chemical properties as described by Carter (1993). The soil samples were mixed, air-dried and passed through a 2-mm sieve before determinations. Soil organic C was determined by Walkley and Black sulfuric acid–dichromate digestion followed by back titration with ferrous ammonium sulfate (Nelson and Sommers 1996). Total N was determined by digesting 0.3 g of the soil sample in a mixture of Se, $LiSO_4$, H_2O_2 and concentrated H_2SO_4 (Anderson and Ingram 1993). The N content in the digests was determined colorimetrically. Available P was determined by the Olsen method as described by Okalebo et al. (2002). The basic cations (K, Ca and Mg) were extracted by leaching 5 g of soil sample with 50 mL ammonium acetate at pH 7 (Anderson and Ingram 1993). The exchangeable K in the extract was determined with a flame photometer, and exchangeable Ca and Mg were determined using a absorption spectrophotometer. Soil pH was determined using a glass pH meter at a 1:2 soil/water ratio.

Determination of soil physical properties

Two months after establishing tillage treatments, determination of selected soil physical properties in all plots at both sites commenced and this was carried out at 2-month intervals on four occasions for each year. Five undisturbed samples were collected at 0–0.10 m depth from each plot using a steel coring tube and were used to evaluate bulk density and gravimetric moisture content, as described above (Campbell and Henshall 1991). Soil temperature was determined at 15:00 h with a soil thermometer inserted to 0.1 m depth. Five readings were made per plot at each sampling time and the mean computed.

Nutrient content of leaves

In each cropping season (2008, 2009 and 2010), 2–3-week-old yam leaves were collected at 5 months after planting from five plants per plot at each site for chemical analysis. The leaf samples were oven-dried at 80°C for 48 h before grinding in a Willey-mill. Leaf N was determined by micro-Kjedahl digestion method (Bremner 1996). Samples were dry-ashed at 500°C for 6 h in a furnance and extracted using a nitric/perchloric/sulfuric acid mixture for determination of P, K, Ca and Mg (Horwitz 1997). Leaf P was determined colorimetrically by the vanadomolybdate method, K with a flame photometer, and Ca and Mg were determined with a spectrophotometer (Okalebo et al. 2002).

Leaf area and tuber weight

Ten plants selected randomly per plot were used to determine leaf area (by graphical method) at 5 months after planting (MAP) when the yam plants reached their full canopy formation. At harvest (8 months after planting), tuber weight (using top loading balance) was determined from 10 plants selected randomly.

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 (SED) was used to compare the treatment means. Mention of statistical significance refers to $p = 0.05$, unless stated otherwise.

Results

Initial soil fertility status of sites

The surface soils at both sites were sandy loam in texture. The clay contents at both sites increased progressively down the profiles, whereas the silt and sand contents of the soils decreased with depth. The soils at both sites were low in organic C, N, P and Ca, whereas exchangeable K and Mg were adequate (Akinrinde and Obigbesan 2000). Also at both sites, the value of pH, soil organic C, N, P, K, Ca and Mg at the surface declined with depth. Site A had higher sand and lower silt and clay content, bulk density and higher nutrient concentrations compared with site B (Table 1).

Response of soil physical properties to years, sites and tillage methods

The response of soil physical properties to years, sites and tillage methods is shown in Table 2. Years (Y), sites (S) and tillage methods (T), when studied as individual

Table 1. Physical and chemical properties (0–0.60 m depth) of the study sites prior to experimentation.

	Site A			Site B		
Property	0–0.20 m depth	0.20–0.40 m depth	0.40–0.60 m depth	0–0.20 m depth	0.20–0.40 m depth	0.40–0.60 m depth
Sand (g kg^{-1})	685	676	668	600	595	586
Silt (g kg^{-1})	150	144	141	222	217	211
Clay (g kg^{-1})	165	180	191	178	188	203
Textural class	Sandy loam	Sandy loam	Sandy loam	Sandy loam	Sandy loam	Sandy loam
pH (water)	6.4	6.3	6.2	5.8	5.6	5.5
Bulk density (Mg m^{-3})	1.58	1.63	1.66	1.61	1.65	1.69
Organic C (g 100 g^{-1})	2.89	2.66	2.51	2.81	2.61	2.49
Total N (g 100 g^{-1})	0.17	0.15	0.13	0.16	0.14	0.13
Available P (mg kg^{-1})	9.1	8.8	8.5	8.9	8.6	8.1
Exchangeable K (cmol kg^{-1})	0.18	0.15	0.12	0.16	0.13	0.11
Exchangeable Ca (cmol kg^{-1})	1.56	1.51	1.46	1.51	1.47	1.41
Exchangeable Mg (cmol kg^{-1})	0.42	0.38	0.34	0.40	0.36	0.32

factors, influenced soil bulk density, moisture content and soil temperature significantly. However, the sites have no significant influence on soil temperature. In the first, second and third years at both sites, bulk density increased in the order P + H + R < MM and MR < P + H < ZT. With all tillage methods and sites, bulk density increased over the years. In the three years, ZT produced the highest moisture content and least soil temperature while P + H + R had lowest moisture content and highest soil temperature. The interactive effect of Y × S, Y × T, S × T and all three factors together (Y × S × T) were not significant.

Response of soil chemical properties to years, sites and tillage methods

Data containing the response of soil chemical properties to years, sites and tillage methods are shown in Table 3. When considered as single factors, Y, S and T significantly influenced soil chemical properties. In the three years at both sites, ZT produced the highest values of soil chemical properties and P + H produced the least. The decreasing order of soil chemical properties at both sites were ZT > P + H + R > MR and MM > P + H. MR and MM had similar values. Also at both sites, the values of soil organic C, N, P, K, Ca and Mg decreased over the years. Soil chemical properties were higher at site A than at site B. The interactive effects of Y × S, Y × T, S × T and Y × S × T were not significant. However, the interactive effect of S × T was significant for potassium.

Table 2. Soil physical properties – dependence on years, sites and tillage methods.

Year	Site	Tillage method	Bulk density (Mg m^{-3})	Moisture content (g kg^{-1})	Temperature (°C)
2008	A	ZT	1.58	155	28.4
		MR	1.26	126	33.2
		MM	1.27	127	32.7
		P + H	1.38	132	31.6
		P + H + R	1.13	120	34.1
	B	ZT	1.61	132	29.1
		MR	1.31	108	32.7
		MM	1.31	108	32.2
		P + H	1.45	118	31.2
		P + H + R	1.16	101	33.8
2009	A	ZT	1.59	151	28.2
		MR	1.27	121	32.6
		MM	1.28	122	31.9
		P + H	1.41	129	30.7
		P + H + R	1.15	116	33.5
	B	ZT	1.63	130	28.7
		MR	1.32	105	31.8
		MM	1.33	108	31.4
		P + H	1.47	117	30.7
		P + H + R	1.18	99	33.5
2010	A	ZT	1.63	169	28.2
		MR	1.29	141	31.6
		MM	1.29	143	31.9
		P + H	1.42	150	30.1
		P + H + R	1.16	132	33.6
	B	ZT	1.65	146	27.6
		MR	1.34	125	30.2
		MM	1.35	126	30.5
		P + H	1.49	131	29.2
		P + H + R	1.19	120	31.9
Year (Y)			*	*	*
Site (S)			*	*	n.s
Tillage (T)			*	*	*
Y × S			n.s	n.s	n.s
Y × T			n.s	n.s	n.s
T × S			n.s	n.s	n.s
T × Y × S			n.s	n.s	n.s

Note: *Significant difference at $p = 0.05$; n.s., not significant at 0.05. ZT, zero tillage; MR, manual ridging; MM, manual mounding; P + H, ploughing + harrowing; P + H + R, ploughing + harrowing + ridging.

Response of leaf nutrient concentrations of yam to years, sites and tillage methods

Table 4 contains data on the response of leaf nutrient concentrations of yam to years, sites and tillage methods. Y, S and T when considered as individual factors were significant for leaf N, P, K, Ca and Mg. At both sites in the three years, P + H + R produced the highest values of leaf N, P, K, Ca and Mg concentrations and ZT produced the least. The decreasing order of leaf nutrient concentrations were P + H + R > MM and MR > P + H > ZT. MM and MR had similar values. Leaf nutrient concentrations of yam decreased with year at both sites and were significantly higher in site A compared with site B. The interactions Y × S, Y × T,

Table 3. Soil chemical properties – dependence on years, sites and tillage methods.

Year	Site	Tillage method	SOC (g 100 g^{-1})	N (g 100 g^{-1})	P (mg kg^{-1})	K (cmol kg^{-1})	Ca (cmol kg^{-1})	Mg (cmol kg^{-1})
2008	A	ZT	2.61	0.15	8.8	0.14	1.45	0.34
		MR	2.25	0.11	7.2	0.10	1.20	0.28
		MM	2.25	0.11	7.1	0.10	1.21	0.29
		P + H	2.11	0.11	6.4	0.10	1.17	0.27
		P + H + R	2.42	0.13	7.9	0.12	1.32	0.31
	B	ZT	2.38	0.14	8.1	0.12	1.31	0.32
		MR	2.04	0.10	6.8	0.09	1.06	0.26
		MM	2.05	0.10	6.7	0.09	1.05	0.25
		P + H	1.88	0.09	5.9	0.08	1.00	0.23
		P + H + R	2.20	0.12	7.6	0.10	1.17	0.29
2009	A	ZT	2.46	0.14	8.6	0.13	1.39	0.33
		MR	2.15	0.10	7.1	0.09	1.17	0.27
		MM	2.14	0.10	7.0	0.09	1.17	0.28
		P + H	2.02	0.09	6.3	0.09	1.16	0.26
		P + H + R	2.31	0.12	7.8	0.11	1.30	0.30
	B	ZT	2.24	0.13	7.9	0.11	1.30	0.31
		MR	1.92	0.09	6.7	0.08	1.05	0.26
		MM	1.92	0.09	6.6	0.08	1.04	0.24
		P + H	1.76	0.08	5.7	0.07	0.90	0.22
		P + H + R	2.03	0.11	7.5	0.09	1.10	0.28
2010	A	ZT	2.34	0.12	8.4	0.12	1.30	0.31
		MR	2.03	0.09	7.0	0.09	1.14	0.26
		MM	2.01	0.09	6.8	0.09	1.13	0.26
		P + H	1.94	0.09	6.2	0.07	1.15	0.25
		P + H + R	2.19	0.11	7.6	0.11	1.29	0.28
	B	ZT	2.15	0.11	7.7	0.10	1.28	0.30
		MR	1.84	0.08	6.6	0.08	1.03	0.25
		MM	1.85	0.08	6.5	0.08	1.02	0.23
		P + H	1.73	0.08	5.6	0.07	0.90	0.20
		P + H + R	1.99	0.10	7.3	0.08	1.09	0.26
Year (Y)			*	*	*	*	*	*
Site (S)			*	*	*	*	*	*
Tillage(T)			*	*	*	*	*	*
Y × S			n.s	n.s	n.s	n.s	n.s	n.s
Y × T			n.s	n.s	n.s	n.s	n.s	n.s
T × S			n.s	n.s	n.s	*	n.s	n.s
T × Y × S			n.s	n.s	n.s	n.s	n.s	n.s

Note: *Significant difference at $p = 0.05$; n.s., not significant at 0.05. ZT, zero tillage; MR, manual ridging; MM, manual mounding; P + H, ploughing + harrowing; P + H + R, ploughing + harrowing + ridging; SOC, soil organic carbon; N, total nitrogen; P, available phosphorous; K, exchangeable potassium; Ca, exchangeable calcium; Mg, exchangeable magnesium.

S × T and Y × S × T were not significant. However, the interaction S × T was significant for potassium.

Response of leaf area and tuber yield of yam according to years, sites and tillage methods

The responses of leaf area and tuber yield of yam to years, sites and tillage methods are shown in Table 5. When considered as individual factors, Y, S and T were

Table 4. Leaf nutrient concentrations of yam - dependence on years, sites and tillage methods.

Year	Site	Tillage method	N	P	K ($g\ 100\ g^{-1}$)	Ca	Mg
2008	A	ZT	2.31	0.26	1.59	0.62	0.53
		MR	2.91	0.34	1.97	0.83	0.68
		MM	2.89	0.34	1.98	0.85	0.68
		P + H	2.64	0.31	1.75	0.72	0.61
		P + H + R	3.32	0.38	2.31	0.96	0.77
	B	ZT	2.18	0.22	1.38	0.55	0.47
		MR	2.63	0.27	1.81	0.71	0.64
		MM	2.59	0.28	1.79	0.71	0.65
		P + H	2.41	0.24	1.56	0.62	0.54
		P + H + R	2.97	0.31	2.24	0.84	0.72
2009	A	ZT	2.26	0.25	1.45	0.60	0.52
		MR	2.81	0.32	1.81	0.81	0.59
		MM	2.81	0.32	1.82	0.81	0.58
		P + H	2.54	0.29	1.71	0.66	0.56
		P + H + R	3.22	0.36	2.17	0.91	0.75
	B	ZT	2.10	0.21	1.22	0.49	0.45
		MR	2.56	0.26	1.69	0.65	0.63
		MM	2.55	0.26	1.71	0.64	0.61
		P + H	2.32	0.23	1.45	0.58	0.59
		P + H + R	2.87	0.29	2.12	0.79	0.68
2010	A	ZT	2.19	0.24	1.37	0.56	0.51
		MR	2.69	0.31	1.61	0.75	0.57
		MM	2.68	0.31	1.63	0.75	0.57
		P + H	2.49	0.27	1.58	0.62	0.52
		P + H + R	3.11	0.34	2.10	0.84	0.73
	B	ZT	2.01	0.20	1.17	0.45	0.42
		MR	2.41	0.24	1.59	0.57	0.51
		MM	2.43	0.23	1.58	0.57	0.51
		P + H	2.16	0.21	1.34	0.52	0.48
		P + H + R	2.62	0.28	1.96	0.72	0.64
Year (Y)			*	*	*	*	*
Site (S)			*	*	*	*	*
Tillage(T)			*	*	*	*	*
Y × S			n.s	n.s	n.s	n.s	n.s
Y × T			n.s	n.s	n.s	n.s	n.s
T × S			n.s	n.s	*	n.s	n.s
T × Y × S			n.s	n.s	n.s	n.s	n.s

Note: *Significant difference at $p = 0.05$; n.s., not significant at 0.05. ZT, zero tillage; MR, manual ridging; MM, manual mounding; P + H, ploughing + harrowing; P + H + R, ploughing + harrowing + ridging; N, leaf nitrogen; P, leaf phosphorous; K, leaf potassium; Ca, leaf calcium; Mg, leaf magnesium.

significant for leaf area and tuber yield of yam. The interactions Y × S, Y × T, S × T and Y × S × T were not significant. At both sites and all years, P + H + R had significantly higher leaf area and tuber yield compared with other tillage methods. ZT produced the least values of leaf area and tuber yield. The order of decreasing values of leaf area and tuber yield of yam at the two sites were P + H + R > MM and MR > P + H > ZT. The values for MM and MR were similar. Leaf area and tuber yield decreased over the years. Leaf area and tuber yield were significantly higher at site A than at site B. Compared with MR, MM, P + H

Table 5. Leaf area and tuber yield of yam – dependence on years, sites and tillage methods.

Year	Site	Tillage method	Leaf area (m^2)	Tuber yield (Mg ha^{-1})
2008	A	ZT	1.54	19.5
		MR	2.26	26.2
		MM	2.23	25.9
		P + H	1.96	22.6
		P + H + R	2.64	29.1
	B	ZT	1.46	18.9
		MR	2.19	23.8
		MM	2.17	23.6
		P + H	1.87	21.9
		P + H + R	2.39	26.7
2009	A	ZT	1.44	18.1
		MR	2.18	24.3
		MM	2.21	24.1
		P + H	1.76	19.9
		P + H + R	2.58	27.6
	B	ZT	1.34	18.2
		MR	2.07	22.9
		MM	2.04	22.6
		P + H	1.69	20.1
		P + H + R	2.31	25.4
2010	A	ZT	1.21	16.9
		MR	1.93	22.8
		MM	1.94	23.0
		P + H	1.58	18.4
		P + H + R	2.29	25.5
	B	ZT	1.26	15.3
		MR	1.88	20.4
		MM	1.84	20.6
		P + H	1.65	18.5
		P + H + R	2.18	23.8
Year (Y)			*	*
Site (S)			*	*
Tillage (T)			*	*
Y × S			n.s	n.s
Y × T			n.s	n.s
T × S			n.s	n.s
T × Y × S			n.s	n.s

Note: *Significant difference at $p = 0.05$; n.s., not significant at 0.05. ZT, zero tillage; MR, manual ridging; MM, manual mounding; P + H, ploughing + harrowing; P + H + R, ploughing + harrowing + ridging.

and ZT, and averaged across years, P + H + R increased yam yield by 12.3, 12.8, 34.9 and 50.7%, respectively, in site A, and by 12.9, 13.5, 25.2 and 44.5%, respectively, in site B. Also using the average across years, site A produced 0.7, 2.0, 2.0, 0.1 and 2.1 Mg ha^{-1} higher tuber yield compared with site B for ZT, MR, MM, P + H and P + H + R, respectively.

When soil physical properties (bulk density, moisture content and soil temperature) were regressed as independent variables with yam leaf area and tuber yield as the dependent variable (Table 6), the coefficient of determination (R^2) for leaf area and tuber yield were 0.752 and 0.658, respectively. The multiple regressions revealed that soil bulk density significantly influenced the performance of yam. Moisture content and soil temperature had no effect.

Table 7 shows data on the regression of soil chemical properties (soil organic C, N, P, K, Ca and Mg) against leaf area and tuber yield of yam. The R^2 values for leaf area and tuber yield were 0.181 and 0.154, respectively. Soil chemical properties were not significant. When leaf nutrient concentrations of yam (N, P, K, Ca and Mg) were regressed as the independent variable (Table 8, the R^2 values for leaf area and tuber yield were 0.755 and 0.834, respectively. The leaf nutrient concentrations significantly influenced the performance of yam.

Discussion

The increase in clay content of the experimental soils down the profiles is attributable to lithological discontinuities and neo-formation (Wambeke 1992). The decrease in silt values with depth indicated a stratified deposit, which is in conformity with the alluvial origin of the profiles. The high sand content of site A may be caused by the geology of the sand area (Soil Survey Staff 1998). The reduction of pH, soil organic C (SOC), N, P, K, Ca and Mg with depth was attributed to the fact that more

Table 6. Multiple regressions of leaf area and tuber yield using soil physical properties.

Yield component	R^{2*}	Soil physical properties	p
Leaf area	0.752	Bulk density, moisture content, soil temperature	> 0.000, > 0.933, > 0.241
Tuber yield	0.658	Bulk density, moisture content, soil temperature	> 0.000, > 0.334, > 0.513

Note: *Significant at $p = 0.05$.

Table 7. Multiple regressions of leaf area and tuber yield using soil chemical properties.

Yield component	R^2*	Soil chemical properties	p
Leaf area	0.181	SOC, N, P, K, Ca, Mg	> 0.372, > 0.293, > 0.136, > 0.127, > 0.412, > 0.101
Tuber yield	0.154	SOC, N, P, K, Ca, Mg	> 0.615, > 0.174, > 0.227, > 0.353, > 0.994, > 0.114

Note: *Significant at $p = 0.05$. SOC, soil organic carbon; N, total nitrogen; P, available phosphorous (Olsen-P); K, exchangeable potassium; Ca, exchangeable calcium; Mg, exchangeable magnesium.

Table 8. Multiple regressions of leaf area and tuber yield using leaf nutrient concentrations of yam.

Yield component	R^2*	Leaf nutrient concentrations	p
Leaf area	0.775	N, P, K, Ca, Mg	> 0.000, > 0.005, > 0.035, > 0.008, > 0.044
Tuber yield	0.834	N, P, K, Ca, Mg	> 0.000, > 0.019, > 0.035 > 0.006, > 0.032

Note: *Significant at $p = 0.05$.

decomposition occurs on the upper layers of soil profile because more organic matter was added through litter fall. The differences in the physical and chemical properties of soils of the two sites were related to the inherent heterogeneity in the parent material, differences in physiograhy and previous cultural practices carried out on the soils.

The low soil bulk densities of tilled soils (P + H + R, P + H, MR and MM) compared with ZT might be explained by loosening effects of tillage (Agbede 2008). The low soil bulk density of P + H + R compared with other tilled treatments could be attributed to better pulverization of soil by ridging implement after ploughing plus harrowing operations, which produced finer and loose structure. The high soil bulk density recorded for zero tillage could be caused by non-tillage and compaction (Hulugalle et al. 1985; Adekiya and Ojeniyi 2002). Zero tillage had higher moisture content and lower temperature compared with tilled soils. This could be related to the presence of organic matter on the surface of the soil, which acted as mulch to reduce temperature and evaporation loss of water. The low moisture content of tilled soils, especially P + H + R, was induced by the resultant increase of turbulent movement of atmospheric air into the soil, which enhanced water evaporation (Agbede 2010). Zero tillage has lower temperature compared with tilled soils because the unporous nature of untilled soil increased heat conduction into the soil during the day and consequently reduced water evaporation.

Untilled zero tillage had higher SOC, N, P, K, Ca and Mg at both sites and years compared with tilled soils. The best fertility status of zero tillage can be attributed to the presence of mulch on the surface due to decomposed plant residues, which led to enhanced soil organic matter status and associated availability of nutrients (Agbede 2008). The least values of SOC, N, P, K, Ca and Mg recorded by tilled soils compared with ZT could be due to inversion of top soil during soil preparation, which brought less fertile subsoil to the surface in addition to possible leaching (Ali et al. 2006). The higher values of soil nutrients produced by P + H + R compared with other tilled soils could have led to possible increase in oxidation and mineralization of organic matter and consequent release of nutrients. Rapid mineralization has been previously reported for tropical Alfisol (Mueller-Harvey et al. 1985; Adekiya et al. 2009). The significant difference in the soil chemical properties of the two sites was related to the initial soil fertility status of the sites. The decrease in SOC, N, P, K, Ca and Mg from the first to third year indicates a degradation of soil fertility over time. Most of the soils available for crop production in the tropics are fragile and can rapidly decline in fertility after 2–3 years of cultivation (Godo and Yeboua 1990; Agbede and Ojeniyi 2009).

Tillage had a significant effect on leaf nutrient concentrations at both sites and all years of the study, with ZT having the least values. The lower leaf nutrient concentrations of yam grown on ZT soil was related to its higher soil bulk density, which may have reduced nutrient uptake. The correlations (r) between soil bulk density and leaf N, P, K, Ca and Mg were -0.77, -0.57, -0.76, -0.73 and -0.74, respectively. Yams grown on P + H + R had higher values of leaf area and tuber yield compared with other tillage methods. This could also be caused by reduced soil bulk density. Yam on untilled soils at both sites had lower leaf N, P, K, Ca and Mg concentrations, leaf area and tuber yield compared with yam grown on tilled soils. Lower leaf nutrient concentrations and performance of yam on untilled soils could be explained by higher bulk density, which adversely affected nutrient uptake, easy penetration and tuberization (swelling of yam tubers). Similarly, the lower leaf nutrient concentrations, growth and tuber yield of yam on P + H compared with P + H + R, MR and MM could be attributed to mechanical impedance to root and tuber growth, and lack of effective soil depth for tuber formation as a result of its high bulk density. Multiple regressions revealed that performance of yam was not related to soil chemical properties. In fact, zero tillage that gave higher soil fertility had lower yam yield. Therefore, the effect of soil bulk density on yam performance was more prominent in this study. Increase in soil bulk density is known to reduce root elongation at low water contents (Adekiya and Ojeniyi 2002). Although the untilled zero tillage had a higher water content and lower temperature, these did not positively influence yam growth and yield. Differences in soil bulk density caused differences in yam growth, yield and nutrient status between the various tillage methods. The mean bulk density recorded for zero tillage (1.58- 1.65 Mg m^{-3}) was clearly above the optimum required (1.10- 1.36 Mg m^{-3}) for yam production (Ohiri and Nwokoye 1984). Therefore, yam grown on Alfisol of humid tropics requires tillage for reducing soil bulk density and enhancing root growth, nutrient uptake and tuber yield.

Yield of yam was reduced with each year between 2008 and 2010, irrespective of tillage methods and sites, indicating loss of soil fertility with time. The possible impact of nematodes in the system, mainly in the second and third years of the experiment, might also explain yield reduction (in addition to nutrients depletion). This result was also consistent with an increase in bulk density from the first to third year of the experiment. Yam yield had been reported to reduce with small increase in bulk density (Ferguson and Gumbs 1976). The better performance of yam at site A compared with site B could be attributed to better initial soil properties (i.e. reduced soil bulk density, and higher soil organic C, N, P, K, Ca and Mg) at site A compared with site B (Table 1).

Conclusions

This study showed that tillage was necessary for yam cultivation in tropical Alfisols. When measured soil chemical properties (SOC, N, P, K, Ca, and Mg) were compared with soil physical properties (bulk density, moisture content and soil temperature), it was soil bulk density that dictated the growth and tuber yield of yam. Ploughing plus harrowing plus ridging (P + H + R) reduced soil bulk density and led to enhanced nutrient uptake, growth and tuber yield of yam. Zero tillage (ZT) had high soil bulk density and could not be substituted for tilled soils especially P + H + R due to significant loss in yield of yam. Although ZT had highest soil nutrient concentrations and organic matter status, but these did not contribute to higher yield due to higher bulk density. Bulk density increased while soil chemical properties, leaf nutrient concentrations and yield of yam tended to reduce with each year 2008, 2009 and 2010, indicating that tillage degrades soil qualities with time.

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