# The Effect of Tillage on Soil Physical and Chemical Properties and Yield of Ginger

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**Summary**

Five tillage methods were compared during the seasons of 2014–2016 with reference to their effects on soil physical and chemical properties and fresh rhizome yield of ginger (*Zingiber officinale* Roscoe) on an Alfisol at Owo, southwest Nigeria. The tillage methods were: zero tillage (ZT), manual ridging (MR), manual mounding (MM), ploughing plus harrowing (P + H) and ploughing plus harrowing twice (P + 2H). P + 2H had higher soil bulk density than other tillage methods and resulted in lower soil OM, N, P, K, Ca and Mg and rhizome yield of ginger. ZT improved soil bulk density, moisture content, temperature, soil OM, N, P, K, Ca and Mg better than other tillage methods and resulted in higher plant height and rhizome yield of ginger compared with other tillage treatments. Results of multiple regressions revealed that bulk density and moisture content significantly influenced the yield of ginger. Compared with MR, MM, P + H and P + 2H, and averaged across years, ZT increased rhizome yield of ginger by 10.9, 11.5, 4.9 and 26.8%, respectively. P + 2H degraded soil quality and reduced rhizome yield of ginger significantly. ZT was found to be the most suitable for soil health and optimum yield and is therefore recommended for ginger cultivation.

**Key words**

tillage, soil properties, ginger, bulk density, moisture content

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## Introduction

Ginger (*Zingiber officinale* Roscoe) belongs to the Zingiberaceae family and it is an important commercial crop grown for its aromatic rhizomes which are consumed as delicacy, medicine, spices and as special vegetable in daily diets worldwide. The medicinal values of these great ancient spices are widely recognized across the continents. It contains a number of unique organic phytochemical ingredients that can take care of some human ailments such as enterotoxin induced diarrhea, diabetic, nephropathy, nausea, plasma antioxidant, vomiting, high cholesterol, high blood pressure and inflammation. To date, the actual yield and tillage requirements of ginger have not been well documented. Most of the crop produced is consumed locally. The average yield in Nigeria for fresh ginger rhizomes is low, being estimated at about 12-15 t $ha^{-1}$ (NRCRI, 2009). 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 ginger 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. 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 ginger; published results show that tillage methods for ginger 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 ginger yields. The few studies carried out largely neglected the combination of zero tillage, minimum/reduced tillage systems and conventional tillage systems and their effects on soil physical and chemical properties and ginger yield. The few studies undertaken in Nigeria and other tropical countries gave inconclusive and contradicting results under the different tillage practices compared. In Kaduna State, Nigeria, Sati and Bala (2017) found that the flatbed tillage method produced the highest yield of ginger, followed by ridges and mounds, respectively. A study conducted at the Hill Agricultural Research Station, Khagrachari, Bangladesh indicated that ginger yields in zero tillage plots were greater than in furrow and conventional plots (Zaman et al., 2002). In the hills, ginger is usually planted in furrow with subsequent ridging. As most of the land in the hilly area is sloppy, conventional tillage operation is very much detrimental as it accelerates soil erosion. Research work carried out on the ginger crop in the hill slope, revealed that zero tillage gave higher yield than conventional tillage (Rahman et al., 1988).

Appropriate tillage method for ginger cultivation has not been documented in the study area, and since no study has compared zero tillage with reduced tillage and conventional tillage practices for ginger production in an Alfisol under a forest–savanna transition zone with humid tropical conditions. Hence, there is a need to study soil conditions that promote ginger 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 ginger performance on an Alfisol located in the forest–savanna transition zone of southwest Nigeria. The relative effect of zero tillage, manual mounding, manual ridging, ploughing plus harrowing and ploughing plus harrowing twice was studied in relation to soil physical and chemical properties and yield of ginger.

## Materials and methods

### Site description and tillage treatments

Field experiments were conducted during the 2014, 2015 and 2016 cropping seasons at Owo (latitude 7°12'N, longitude 5°32'E), in the forest–savanna transition zone of southwest Nigeria with ginger as the test crop. The soil at the study site was an Alfisol. The soil at Owo is Oxic Tropuldalf (Soil Survey Staff, 2014) or Luvisol (FAO, 1998) derived from quartzite, gneiss and schist. Owo has gently undulating plains. The top of the soil at the experimental site was sandy loam. The average rainfall varied from 1000 to 1500 mm. 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 site had been under bush fallow for three years after arable cropping. The predominant weeds at the study site 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.

Each year, the experiments consisted of five tillage methods, which were compared for three years. 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 two 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 twice (P + 2H): soil was ploughed to 0.20 m depth once using a tractor-mounted disc plough and harrowed to 0.20 m depth twice using a tractor-mounted disc harrow.

There was an initial land clearing of the plots before tillage operations for treatments P + H and P + 2H. The experiment was laid out in a randomized complete block design with three replications. Each plot size was 12 x 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 (Agbede, 2008; Agbede and Adekiya, 2013). The same tillage method was maintained on each plot at the study site for the three years of the experiment.

### Crop establishment

Two weeks after tillage treatments were performed on the study site: mature ginger rhizomes (Tafin Giwa cv.) were cut into seed-pieces weighing about 45 g. The seed-pieces were treated with a seed-dressing fungicide (Benlate) against seed-borne or soil-borne pathogens before planting by hoe to a depth of 10 cm at a spacing of 20 cm x 20 cm on 4 April 2014, 6 April 2015 and 8 April 2016, respectively, for the first, second and third trials, giving a plant population of 250,000 plants $ha^{-1}$. In each cropping season, a field recommended chemical fertilizer NPK 15–15–15 was applied at 300 kg $ha^{-1}$ in ring form twice (round each crop in a circle form 10-15 cm away and 5 cm deep). The first dose was applied at the rate of four bags per hectare about 20 days after planting, while the second application was about 40 days after the first application at the rate of two bags per hectare. Weeding was manual with a hoe at four and eight weeks after planting.

### Soil sampling and analysis

Prior to the commencement of the experiment in 2014, soil samples were collected from 0–15, 15–30 and 30–45 cm depths of a profile pit dug in the 10 points selected randomly from the study site. Undisturbed samples were collected from the center of the depth intervals using steel coring tubes (4 cm diameter, 15 cm high) and were put in an oven set at 100°C for 24 h for determination of bulk density (Campbell and Henshall, 1991). Particle-size analysis was done using the hydrometer method (Gee and Or, 2002). Textural class was determined using a textural triangle (*Hunt and Gilkes, 1992; Brady and Weil, 1999*). Before tillage, composite soil samples were collected from the three depths and analyzed for chemical properties. Disturbed soil samples were also collected per plot at harvest of ginger from 0 to 15 cm depth in 2014, 2015 and 2016 and similarly analyzed for chemical properties as described by Carter and Gregorich (2007). The soil samples were mixed, air-dried and passed through a 2-mm sieve before determinations. Soil organic carbon was determined by the procedure of Walkley and Black using the dichromate wet oxidation method (Nelson and Sommers, 1996). Organic matter was calculated by multiplying C by 1.724. Total N was determined by the micro-Kjeldahl digestion method (Bremner, 1996). Available P was determined by Bray-1 extraction followed by molybdenum blue colorimetry (Frank et al., 1998). Exchangeable K, Ca and Mg were extracted using 1 M ammonium acetate (Van Reeuwijk, 2002). K level was determined with a Jenway PFP7 flame photometer, and Ca and Mg were determined by EDTA titration method (Hendershot et al., 2008). Soil pH was determined using a glass pH meter at a 1:2 soil/water ratio (Ibitoye, 2006).

### Determination of soil physical properties

Two months after establishing tillage treatments, determination of selected soil physical properties in all plots at the study site commenced and this was carried out at two month intervals on four occasions for each year. Five undisturbed samples were collected from 0–15 cm 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 measured at two month intervals on four occasions for each year at 15:00 h with a soil thermometer inserted to 15 cm depth. Five readings were made per plot at each sampling time and the mean was computed.

### Plant height and ginger yield

Ten plants selected randomly per plot were used to determine plant height at 150 days after planting (DAP) when the ginger plants reached their full canopy formation. Harvesting was done at 9 months after planting for the determination of ginger yield.

### Statistical analysis

Data collected from each experiment were subjected to analysis of variance (ANOVA) using the Genstat statistical package (GENSTAT, 2005) to determine the effects of treatments on soil physical and chemical properties, plant height and yield of ginger. 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 the experimental site

The physical characteristics and chemical status of the initial soil are shown in Table 1. The textural class at the surface of the experimental site was sandy loam. The clay content at the site increased progressively down the profiles, whereas the silt and sand contents of the soil decreased with depth. The soil at the study site was low in organic matter, N, P and Ca, whereas exchangeable K and Mg were adequate (Akinrinde and Obigbesan, 2000). Also at the study site, the value of soil pH, organic matter, N, P, K, Ca and Mg at the surface decreased with depth. At 0-45 cm where ginger tubers are formed, bulk density was moderate (Agbede, 2008) and increased with depth (Table 1).

**Table 1.** Physical and chemical properties (0-45 cm depth) of the study site prior to experimentation

| Property | Depth 0-15 cm | 15-30 cm | 30-45 cm |
|---|---|---|---|
| Sand (g $kg^{-1}$) | 680 | 676 | 668 |
| Silt (g $kg^{-1}$) | 155 | 146 | 141 |
| Clay (g $kg^{-1}$) | 165 | 178 | 191 |
| Textural class | Sandy loam | Sandy loam | Sandy loam |
| $pH_{H2O}$ | 6.5 | 6.4 | 6.3 |
| Bulk density (Mg $m^{-3}$) | 1.35 | 1.43 | 1.56 |
| Organic matter (%) | 2.63 | 2.46 | 2.31 |
| Total N (%) | 0.18 | 0.15 | 0.13 |
| Available P (mg $kg^{-1}$) | 9.3 | 8.9 | 8.4 |
| Exchangeable K ($cmol^{+}$ $kg^{-1}$) | 0.16 | 0.14 | 0.12 |
| Exchangeable Ca ($cmol^{+}$ $kg^{-1}$) | 1.57 | 1.51 | 1.47 |
| Exchangeable Mg ($cmol^{+}$ $kg^{-1}$) | 0.45 | 0.39 | 0.35 |

### Effect of years and tillage methods on soil physical properties

The effect of years and tillage methods on soil physical properties is shown in Table 2. Years (Y) and tillage methods (T), when studied as individual factors, influenced soil bulk density, moisture content and soil temperature significantly. In the first year at the study site, bulk density increased in the order P + H < MR, MM and ZT < P + 2H; in the second year, bulk density increased in the order P + H, ZT, MR and MM < P + 2H, while the order was ZT < MM and MR < P +H < P+2H in the third year. In each investigated year, but also in average of three-year period, the highest moisture content and least soil temperature were recorded with ZT method in comparison to other methods. Moisture content was in the decreasing order of ZT > MM and MR > P +H and P+2H in the third year. Although MM and MR had the highest soil temperature in the three years considered, the values for all tilled treatments were similar. The interactive effect of Y x T for soil bulk density, moisture content and temperature were significant.

**Table 2.** Effect of years and tillage methods on soil physical properties

| Year | Tillage method | Bulk density (Mg m$^{-3}$) | Moisture content (%) | Temperature (°C) |
|---|---|---|---|---|
| 2014 | ZT | 1.35 | 18.8 | 28.2 |
| | MR | 1.28 | 14.1 | 33.4 |
| | MM | 1.29 | 13.9 | 33.7 |
| | P + H | 1.21 | 14.6 | 32.6 |
| | P + 2H | 1.45 | 16.5 | 32.8 |
| 2015 | ZT | 1.29 | 15.5 | 27.4 |
| | MR | 1.29 | 12.8 | 31.0 |
| | MM | 1.30 | 12.6 | 31.4 |
| | P + H | 1.26 | 13.0 | 30.2 |
| | P + 2H | 1.52 | 14.1 | 30.8 |
| 2016 | ZT | 1.24 | 17.8 | 29.2 |
| | MR | 1.42 | 14.2 | 33.4 |
| | MM | 1.41 | 13.9 | 33.7 |
| | P + H | 1.53 | 11.3 | 32.5 |
| | P + 2H | 1.68 | 10.9 | 32.9 |
| Year (Y) | | * | * | * |
| Tillage (T) | | * | * | * |
| Y x T | | * | * | * |

Note: *significant difference at p = 0.05; ZT, zero tillage; MR, manual ridging; MM, manual mounding; P + H, ploughing + harrowing; P + 2H, ploughing + harrowing twice.

**Table 4.** Effect of years and tillage methods on plant height and ginger yield

| Year | Tillage method | Plant height (cm) | Ginger yield (t ha$^{-1}$) |
|---|---|---|---|
| 2014 | ZT | 84.6 | 20.5 |
| | MR | 72.2 | 18.4 |
| | MM | 71.9 | 18.2 |
| | P + H | 75.5 | 19.9 |
| | P + 2H | 64.3 | 16.3 |
| 2015 | ZT | 80.4 | 19.4 |
| | MR | 67.8 | 17.5 |
| | MM | 66.5 | 17.3 |
| | P + H | 71.6 | 18.6 |
| | P + 2H | 60.2 | 15.2 |
| 2016 | ZT | 79.2 | 18.3 |
| | MR | 66.6 | 16.7 |
| | MM | 67.0 | 16.6 |
| | P + H | 70.4 | 17.1 |
| | P + 2H | 58.5 | 14.4 |
| Year (Y) | | * | * |
| Tillage (T) | | * | * |
| Y x T | | * | * |

Note: *significant difference at p = 0.05; ZT, zero tillage; MR, manual ridging; MM, manual mounding; P + H, ploughing + harrowing; P + 2H, ploughing + harrowing twice.

### Effect of years and tillage methods on soil chemical properties

Data containing the effect of years and tillage methods on soil chemical properties are presented in Table 3. When considered as single factors, years and tillage methods significantly influenced soil chemical properties. In each investigated year, but also in average of three year period, the highest values of soil chemical properties were recorded on ZT method and the lowest values were recorded on P + 2H method in comparison to other methods. The decreasing order of soil chemical properties at the site were ZT > P + H > MR and MM > P + 2H. MR and MM had similar values. Also at the study site, the values of soil organic matter, N, P, K, Ca and Mg decreased over the years. The interactive effects of Y x T for soil chemical properties were not significant.

### Effect of years and tillage methods on plant height and yield of ginger

The effect of years and tillage methods on plant height and yield of ginger are shown in Table 4. When considered as individual factors, years (Y) and tillage methods (T) were significant for plant height and yield of ginger. The interactions Y x T were significant.

**Table 3.** Effect of years and tillage methods on soil chemical properties

| Year | Tillage method | OM (%) | N (%) | P (mg kg$^{-1}$) | K (cmol$^+$ kg$^{-1}$) | Ca (cmol$^+$ kg$^{-1}$) | Mg (cmol$^+$ kg$^{-1}$) |
|---|---|---|---|---|---|---|---|
| 2014 | ZT | 2.59 | 0.16 | 8.9 | 0.14 | 1.56 | 0.36 |
| | MR | 2.23 | 0.14 | 7.4 | 0.12 | 1.31 | 0.29 |
| | MM | 2.21 | 0.14 | 7.2 | 0.12 | 1.32 | 0.30 |
| | P + H | 2.31 | 0.14 | 7.5 | 0.12 | 1.28 | 0.27 |
| | P + 2H | 2.14 | 0.12 | 6.6 | 0.11 | 1.16 | 0.25 |
| 2015 | ZT | 2.44 | 0.15 | 8.7 | 0.13 | 1.42 | 0.32 |
| | MR | 2.16 | 0.13 | 7.2 | 0.11 | 1.17 | 0.26 |
| | MM | 2.15 | 0.13 | 7.1 | 0.11 | 1.15 | 0.25 |
| | P + H | 2.18 | 0.10 | 7.3 | 0.10 | 1.12 | 0.24 |
| | P + 2H | 2.03 | 0.13 | 6.4 | 0.09 | 1.11 | 0.21 |
| 2016 | ZT | 2.26 | 0.13 | 8.5 | 0.12 | 1.39 | 0.30 |
| | MR | 2.03 | 0.11 | 7.0 | 0.09 | 1.08 | 0.24 |
| | MM | 2.01 | 0.11 | 6.9 | 0.09 | 1.07 | 0.24 |
| | P + H | 2.05 | 0.11 | 7.2 | 0.09 | 1.03 | 0.23 |
| | P + 2H | 1.95 | 0.09 | 6.1 | 0.08 | 1.01 | 0.19 |
| Year (Y) | | * | * | * | * | * | * |
| Tillage (T) | | * | * | * | * | * | * |
| Y x T | | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. |

Note: *significant difference at p = 0.05; n.s., not significant; ZT, zero tillage; MR, manual ridging; MM, manual mounding; P + H, ploughing + harrowing; P + 2H, ploughing + harrowing twice; OM, organic matter; N, total nitrogen; P, available phosphorous; K, exchangeable potassium; Ca, exchangeable calcium; Mg, exchangeable magnesium.

**Table 5.** Effect of multiple regressions of plant height and ginger yield using soil physical properties

| Plant height and ginger yield | $R^{2*}$ | Soil physical properties | p-value |
|---|---|---|---|
| Plant height | 0.682 | BD, MC, ST | > 0.012 > 0.042 > 0.285 |
| Ginger yield | 0.643 | BD, MC, ST | > 0.004 > 0.025 > 0.573 |

Note: *significant at p = 0.05 level; BD, bulk density; MC, moisture content; ST, soil temperature.

**Table 6.** Effect of multiple regressions of plant height and ginger yield using soil chemical properties

| Plant height and ginger yield | $R^{2*}$ | Soil chemical properties | p-value |
|---|---|---|---|
| Plant height | 0.957 | OM, N, P, K, Ca, Mg | > 0.529 > 0.789 > 0.058 > 0.670 > 0.709 > 0.379 |
| Ginger yield | 0.883 | OM, N, P, K, Ca, Mg | > 0.142 > 0.485 > 0.095 > 0.176 > 0.229 > 0.590 |

Note: *significant at p = 0.05 level; OM, organic matter; N, total nitrogen; P, available phosphorus (Olsen-P); K, exchangeable potassium; Ca, exchangeable calcium; Mg, exchangeable magnesium.

In 2014, 2015 and 2016, ZT had significantly higher plant height and rhizome yield of ginger compared with MM, MR and P + 2H. P + 2H produced the least values of plant height and ginger yield. The order of decreasing values of plant height and yield of ginger were ZT and P + H > MM and MR > P + 2H. The values for MM and MR were similar. Plant height and ginger yield decreased over the years. Compared with P + H, MR, MM and P + 2H, and averaged across years, ZT increased ginger yield by 4.9, 10.9, 11.5 and 26.8%, respectively.

When soil physical properties (bulk density, moisture content and soil temperature) were regressed as independent variables with ginger plant height and ginger yield as the dependent variable (Table 5), the coefficient of determination ($R^2$) for plant height and ginger yield were 0.682 and 0.643, respectively. The multiple regressions revealed that soil bulk density and moisture content significantly influenced the performance of ginger. Soil temperature had no effect. Table 6 shows data on the regression of soil chemical properties (soil organic matter, N, P, K, Ca and Mg) against plant height and ginger yield. The $R^2$ values for plant height and ginger yield were 0.957 and 0.883, respectively. The multiple regressions revealed that the soil chemical properties were not significant.

## Discussion

The increase in clay content of the experimental soil down the profiles is attributable to clay lessivation at the soil surface. The lowest bulk density obtained at the soil surface could be partially due to high accumulation of dead materials at the surface, which reflected as high organic matter content. The reduction of pH, soil organic matter (OM), N, P, K, Ca and Mg with depth was attributed to the fact that more decomposition occurs on the upper layers of soil profile because more organic matter was added through litter fall.

The low soil bulk densities of tilled soils (P + H, MR and MM) compared with P + 2H might be explained by loosening effects of tillage (Agbede, 2008). The low soil bulk density of P + H compared with other tilled treatments could be attributed to better pulverization of soil by harrowing implement after ploughing operation, which produced finer and loose structure. The high soil bulk density recorded for P + 2H could be adduced to wheel traffic of tractor and implement passes that compact the soil. Zero tillage had lower bulk density, 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 MM, MR and P + H, was induced by the resultant increase of turbulent movement of atmospheric air into the soil, which enhanced water evaporation. The fact that interactive effect of Y x T for soil bulk density, moisture content and temperature were significant corroborates the findings of Adekiya et al. (2011) who reported that interaction of Y x T for soil bulk density, moisture content and temperature were significant.

ZT had higher soil OM, N, P, K, Ca and Mg in the three 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 soil OM, 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 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 decrease in soil OM, 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.

Gingers grown on ZT had higher values of plant height and ginger yield compared with other tillage methods. This could also be caused by reduced soil bulk density and high moisture content. Multiple regressions revealed that performance of ginger was related to soil physical and not chemical properties. Therefore, the effect of soil bulk density and moisture content on ginger performance was more prominent in this study. Decrease in soil bulk density is known to increase root elongation and therefore nutrient and water uptake (Adekiya and Ojeniyi, 2002). The higher moisture content of the ZT would have also enhanced root development and nutrient uptake which favoured rhizome expansion and formation. The zero tillage had lower mean of bulk density and higher mean of water content and these positively influenced ginger growth and yield. The mean bulk density recorded for zero tillage (1.29 Mg $m^{-3}$) and initial bulk density of value of 1.35 Mg $m^{-3}$ recorded for the study site was not limiting to growth and development of ginger. A soil bulk density of 1.40 Mg $m^{-3}$ was recommended as optimum required for efficient crop production in the tropics (Ohiri and Nwokoye, 1984; Villanueva, 1986; Arshad et al., 2009). Therefore, ginger can be grown on zero tillage on an Alfisol of humid tropics for good soil quality and crop productivity.

## Conclusions

This study showed that tillage was not necessary for ginger cultivation in tropical Alfisol especially if the initial soil bulk density is low. When measured soil chemical properties (soil OM, N, P, K, Ca, and Mg) were compared with soil physical properties (bulk density, moisture content and soil temperature), it was soil bulk density and moisture content that dictated the growth and yield of ginger. P + 2H increased soil bulk density and led to degradation of soil properties, reduced growth and yield of ginger. ZT had low soil bulk density and could be substituted for tilled soils especially P + 2H due to significant increase in yield of ginger. Bulk density in tillage methods increased with each year except that of ZT, while soil chemical properties and yield of ginger in all tillage treatments tended to reduce with each year (2014, 2015 and 2016), indicating that tillage degrades soil qualities with time.

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