



## Research article

## Soil productivity improvement under different fallow types on Alfisol of a derived savanna ecology of Nigeria



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## ABSTRACT

Fallowing is considered an important management strategy for the restoration of soil productivity. Therefore, a three-year fallow of pigeon pea (*Cajanus cajan*), mexican sunflower (*Tithonia diversifolia*) and elephant grass (*Pennisetum purpureum*) was established at Landmark University, Nigeria between 2016 – 2019. Leaf nutrient concentrations of maize (*Zea mays*) planted with soils taken from each fallowed plots after three years were also determined. The experimental design was a randomized complete block design with three replications. Soil samples were collected from each fallow plots for physical and chemical analysis (bulk density, porosity, moisture content, particle size, dispersion ratio, soil erosion loss, soil organic matter (SOM), total N, available P, exchangeable K, Ca, Mg, CEC and pH.) before and at the end of the experiment. Means of data collected were separated using Tukey's HSD test at  $p = 0.05$ . *Tithonia* fallow improved soil properties and leaf nutrient concentration of maize compared with *Pennisetum* and *Cajanus* fallows. The order was *Tithonia* > *Pennisetum* > *Cajanus*. This was added to the regular return of plant residues to the soil in *Tithonia* fallow which resulted in high SOM (*Tithonia* increased SOM by about 23%, 7.5%, and 20%, respectively, compared with the initial soil, *Pennisetum* and *Cajanus* fallows) and increases soil N, P, K, Ca, Mg, CEC and pH and also stabilized soil structure by increasing porosity, moisture content and reducing bulk density, dispersion ratio, and soil loss. Therefore, plant species of high nutrient contents and high return of biomass to the soil are necessary for quick restoration of soil productivity in a derived savanna ecology.

## 1. Introduction

In Nigeria's agro-ecological zone, the derived savanna ecological zone is the zone that evolved from the rain forest by human activities such as regular fire, deforestation, and farming (Adekiya et al., 2018). Only a few fire-tolerant trees are found and the area can advance to the forest if communal burning is stopped (Adegbite et al., 2020). Among other crops, legumes like groundnut (*Arachis hypogaea*), soybean (*Glycine max*), cowpea (*Vigna unguiculata*) and bambara groundnut (*Voandzeia subterranean*), and pigeon pea (*Cajanus cajan*) are common. Also, mexican sunflower (*Tithonia diversifolia*) and elephant grass (*Pennisetum purpureum*)

are common weed species. The soils of this region like the soils of savanna are mostly Alfisols which are characterized by low activity clays, low organic matter content, and high sand content, thus these soils are physically fragile and susceptible to degradation (Salako et al., 2001). The inherently low fertility status of the soil and the continuous cropping of farmers in this zone left the soil nutrient-depleted after about 2–3 years of cropping. Chemical fertilizers had been used for improving soil fertility and crop yield, but their use especially in Nigeria is limited by scarcity and cost. Other problems associated with the use of chemical fertilizers are acidity, nutrient imbalance (Agbede et al., 2018), and the inability to improve aggregate stability by increasing soil organic matter.

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Fallowing is considered an important management strategy for the restoration of soil productivity. Fallowing replenishes nutrients removed by crops, reduces erosion and leaching, and maintains better soil physical and biological conditions (Barrios and Cobo, 2004; Tian et al., 2005). However, due to population growth and alternative demand for land other than agriculture, the period of fallow has drastically reduced (Dania Ogbe and Bamidele, 2007). The fallow period is now too short to adequately restore soil fertility. Therefore, there is a dire need to research on fast-growing crop/weed species that produce a large amount of high-quality biomass during a growth period of one to three years which can add reasonable nutrient and organic matter to the soil (Agbede and Afolabi, 2014). Numerous crop is planted by farmers and some weed species grow on or near smallholder farms, some have relatively high nutrient concentrations, but little is known about their potential at the restoration of degraded soil. Among these crop/plant species are; pigeon pea (*Cajanus cajan* (L.) Millsp.), mexican sunflower (*Tithonia diversifolia* (Hemsley) A. Gray), and elephant grass (*Pennisetum purpureum* (Schum).

Pigeon pea is an erect, short-lived perennial leguminous shrub of the family Fabaceae (Heuzé et al., 2017). Due to its tap-root system and high biomass production, it is able to recycle nutrients and improve the soil fertility status of degraded lands (Ong and Daniel, 1990). The extensive root system also improves soil structure by breaking plow pans and enhancing the water holding capacity of the soil (Crop Trust 2014; Mallikarjuna et al., 2011).

Mexican sunflower (*Tithonia diversifolia*) is a shrub belonging to the family Asteraceae. *Tithonia* has aroused research interest because of the relatively nutrient concentrations (N, P, and K) that are found in its massive biomass. The abundance and adaptation of this weed species to various environments coupled with its rapid growth rate and very high vegetative matter turnover makes it a candidate species for soil rejuvenation (Olabode et al., 2007).

Elephant grass is a very important forage in the tropics due to its high productivity. The literature on the use of elephant grass as a fallow crop is very scarce. Majorly the use of elephant grass has been in the areas of runoff and erosion (Adimassu et al., 2013; Mandal et al., 2017). In Nigeria, elephant grass has been used as mulch (25 cm layer) for weed control, for water storage, and to reduce soil losses on slopes (Adekalu et al., 2007; Francis, 2004).

The type of plant material used as fallow may influence the physical, chemical, and biological properties of the soil and crop yield at the end of the fallow period. This is due to the morphological and biochemical qualities of each fallow crop. There is therefore the need to research into different weed species (*Tithonia* and *Pennisetum*) and crop (*Cajanus*) will affect soil properties. More so, there is a scarcity of information on the use of *Pennisetum* and *Tithonia* as fallow crops. Therefore, the objectives of this study were to compare the effects of elephant grass (*Pennisetum purpureum* (Schum), mexican sunflower (*Tithonia diversifolia* (Hemsley) A. Gray) and pigeon pea (*Cajanus cajan* (L.) Millsp.) used as fallow crops on soil physico-chemical properties and leaf nutrient concentrations of maize planted with their soils after three years. Based on these objectives we hypothesized that soil physico-chemical properties and leaf nutrient concentrations of maize will behave differently under *Pennisetum*, *Tithonia*, and *Cajanus* fallows.

## 2. Materials and methods

### 2.1. The experimental site

A three-year fallow of pigeon pea (*Cajanus cajan*), mexican sunflower (*Tithonia diversifolia*) and elephant grass (*Pennisetum purpureum*) was established at the Teaching and Research Farm, Landmark University, Omu –Aran, Kwara State, Nigeria between 2016 – 2019. Omu-Aran lies between Latitude 8°9'N and Longitude 5° 61'E. The soil was

an Alfisol or Luvisol (Adekiya et al., 2018). Annual rainfall is about 1300 mm and the temperature is about 32°C. The first raining season starts from March to July with a short dry spell in August called “August break”, followed by the second raining season between September and November. Findings of the land use of the land reveal heavy presence of anthropogenic activities which range from extensive opening of land for arable cropping to bush burning. The site used for the experiment had earlier been put to continuous cultivation for five years and recently cropped for two years with maize and maize cassava crop mixture before the trial was initiated.

The landscape is highly undulating with varying slope lengths. The topography is generally rolling. The slope aspects are gentler on the northern portion while the southern portion is steeper.

The experimental design was a randomized complete block design with three replications. The experiment consisted of three treatments/fallow lands; (i) pigeon pea (*Cajanus cajan*), (ii) mexican sunflower (*Tithonia diversifolia*) and (iii) elephant grass (*Pennisetum purpureum*).

### 2.2. Establishment of fallow land

Land preparation was done by ploughing and harrowing of the entire land area in May 2016 when rains become steady in the area. One (1) ha each was marked for the establishment of each crop. Stem cuttings of *Pennisetum* were placed underground at a 10 cm depth at a distance of 1 m × 1 m. No harvesting of any kind was done on the established *Pennisetum* that year. Suckers of the *Pennisetum* sprouted and regrowth at the onset of rains the second year. Manual weeding was done for the *Pennisetum* plot. *Cajanus* seeds were sown with two seeds per stand at a distance of 1 m × 1 m while the *Tithonia* seed was broadcasted. Harvesting was done on the *Cajanus* the first year after which the plant remains to grow into the second and third year. The *Tithonia* plant at the end of the first and second year completed its lifecycle and died, but the seeds germinated again the next season for the continuation of life.

### 2.3. Soil sampling and analysis

Immediately after land preparation in 2016, before the start of the experiment, soil samples from topsoil (0–15 cm and 15–30 cm) were taken from ten spots in the study area and were bulked together separately to form a composite samples. Five undisturbed samples (4 cm diameter, 15 cm high) were also collected at 0–15 cm and 15–30 cm depth from ten positions using core steel sampler. The samples were used to evaluate bulk density and gravimetric moisture content after oven-drying at 100 °C for 24 h (Adekiya, 2019). Total porosity was calculated from the bulk density by using particle density value of 2.65 g cm<sup>-3</sup>. Collected composite soil samples were air-dried and sieved using a 2-mm sieve ready for analysis. The textural class of the soils was determined using the Bouyoucos (1951) hydrometer method as described by (Gee and Or, 2002) which measures density of liquids involving a dry sample of soil treated with sodium hexametaphosphate to separate soil particles was employed. A dispersing agent (sodium hexametaphosphate) was mixed in distilled water until it completely dissolved. Dried soil sample weighing 50 g was poured into a 250 ml beaker and 100 ml of distilled water and 50 ml of 5.0% sodium hexametaphosphate were added. The sample was mixed with a stirring rod and allowed to set for 30 min. The stirred sample was then transferred quantitatively into a sedimentation cylinder and filled to the mark with distilled water while hydrometer was in suspension. The plunger was inserted and used to mix the content thoroughly, the hydrometer was carefully lowered and the first hydrometer reading was taken after 40 s of thorough mixing. The hydrometer was removed from suspension and the temperature of the suspension was taken.

### Calculation

$$\% \text{ silt + clay} = \frac{\{(R40 \text{ Sec} - R_a) + R_c\} \times 100}{\text{Weight of soil}} \quad (1)$$

$$\% \text{ clay} = \frac{\{(R2 \text{ hours} - R_b) + R_d\} \times 100}{\text{Weight of soil}} \quad (2)$$

$$\% \text{ silt} = (\text{silt} + \text{clay}) - \text{clay} \quad (3)$$

$$\% \text{ sand} = 100 - (\text{silt} + \text{clay}) \quad (4)$$

where  $R_a = 40$  s hydrometer reading for the control;  $R_b = 2$  h hydrometer reading for the control;  $R_c =$  corrected 40 s hydrometer reading;  $R_d =$  corrected 2 h hydrometer reading;  $R40$  seconds = 40 s hydrometer reading for the sample;  $R 2 \text{ h} = 2$  h hydrometer reading for the sample.

From information on percent sand, silt and clay, the soil textures were determined using the USDA textural triangle. Dispersion ratio was done by determining the amounts of silt and clay in calgon-dispersed as well as water-dispersed samples using Bouyoucos hydrometer method of particle size analysis described by Gee and Or (2002). Dispersion ratio was determined as a measure of aggregate stability using the formula

$$\text{Dispersion ratio} = \frac{\% \text{ silt + clay (H}_2\text{O)}}{\% \text{ silt + clay (calgon)}} \times 100 \quad (5)$$

Soil organic carbon (OC) was determined by the procedure of Walkley and Black using the dichromate wet oxidation method (Nelson and Sommers, 1996). One (1) g of air-dried soil samples were weighed in duplicate on a filter paper and transferred into a 250 ml conical flask, 10 ml 0.167 M of  $K_2Cr_2O_7$  was added. Then 20 ml of concentrated  $H_2SO_4$  was added and the soil and reagent were immediately swirled gently for one minute until they were thoroughly mixed. Afterward, the reagents were swirled more rapidly for one minute and then allowed to stand for 30 min. 100 ml of distilled water was added after 30 min, 4 drops of ferroin indicator were added. Titration was done with 0.5 iron (II) sulphate. The colour of the soil reagents changed from sharply green to brownish red colouration. Then the titre value was taken for each sample beginning with the blank titre value. The blank value was to standardize dichromate. The calculation was done using the following formula:

$$\% \text{ organic carbon} = \frac{(B - S) \times N \times 0.003}{\text{Weight of soil}} \times 100 \quad (6)$$

where  $B =$  blank titre value,  $S =$  sample titre value and  $N =$  normality of ferrous sulphate.

Total N was determined by the micro-Kjeldahl digestion method (Bremner, 1996). One (1) gram of 2 mm sieved air dry soil sample was weighed in duplicates, and then transferred into test tubes. One macro Kjeldahl tablet was added to each individual sample in a test tube. The test tubes were then placed in a standing machine for one hour as the digester was being prepared. The test tubes were then placed on the digester and the content was digested for one hour to a temperature of 420 °C. Then the tubes were lifted from the digester and placed back on a stand to cool off for 30 min. Then distillation and titration were done, respectively. Available P was determined by Bray-1 extraction followed by molybdenum blue colorimetry (Frank et al., 1998). Exchangeable K, Ca, Na and Mg were extracted by leaching 5 g of soil sample with 50 mL ammonium acetate at pH 7 (Hendershot et al., 2007). K and Na in the extract were read on a flame photometer while Ca and Mg were read on Atomic Absorption Spectrophotometer. The CEC was determined by the  $BaCl_2$  compulsive exchange method as described by Gillman and Sumpter (1986). Soil pH was determined using a soil-water medium at a ratio of 1:2 with a digital electronic pH meter.

After the establishment of treatments (planting of fallow crops), five long (about 15 cm) nails adapted from Anikwe et al. (2007) were randomly driven into the topsoil of each experimental plot perpendicular to the soil surface, and its exposure over three years was used to monitor soil loss or soil removal by erosion from each plot. The length of each nail exposed in each plot was measured using a string and meter rule.

At the end of the third year of fallow, soil samples were collected on a treatment (fallow- *Tithonia*, *Pennisetum* and *cajanus*) basis. Soil chemical properties, bulk density, porosity, moisture content and dispersion ratio at 0–15 cm soil depth were done as described above (soil chemical properties were analysed for both 0–15 cm and 15–30 cm soil depth).

#### 2.4. Pot experiment and analysis of maize leaves

Soil samples were collected from plots that were under three year's fallow of *Pennisetum*, *Tithonia*, and *Canjanus*. The soil samples were randomly collected from different points with soil auger from each treatment/fallow plots and later bulked into three per treatment. Pots that had been perforated at its base were filled with 20 kg soil taken from each treatment and arranged in CRD in screen house where the pots were planted to maize (*Zea mays*). At tasseling, leaf samples were collected from each pot for leaf analysis. These samples were analyzed for leaf N, P, K, Ca, and Mg as described by Tel and Hagarty (1984). Leaf N was determined by the micro-Kjeldahl digestion method. Ground samples were digested with nitric-perchloric sulphuric acid mixture for the determination of P, K, Ca, and Mg. Phosphorus was determined colorimetrically using the vanadomolybdate method, K was determined using a flame photometer, and Ca and Mg were determined by the EDTA titration method.

#### 2.5. Statistical analysis

Data collected from each fallow plots were subjected to analysis of variance (ANOVA) test using SPSS 17.0, and treatment means were separated using Tukey's HSD test (honestly significantly different test) with  $p = 0.05$ .

### 3. Results

#### 3.1. Physical and chemical properties of the site (0–15 cm) before experimentation

Data on the physical and chemical properties of the experimental site are presented in Table 1. The soils at the 0–15 cm and 15–30 cm depth were classified as a sandy soil, acidic, and fairly high in bulk density and low levels of OC, total N, P, exchangeable K, Ca, and Mg. Soil at the 15–30 cm depth was moderate in available P according to the critical level of 3.0% OM, 0.20% N, 10.0 mg  $kg^{-1}$  available P, 0.16–0.20 cmol  $kg^{-1}$  exchangeable K, 2.0 cmol  $kg^{-1}$  exchangeable Ca, and 0.40 cmol  $kg^{-1}$  exchangeable Mg recommended for crop production in ecological zones of Nigeria (Akinrinde and Obigbesan, 2000). The sand, silt and nutrient contents tend to reduce with depth while the clay content increased with depth.

#### 3.2. Physical properties of soil under *Tithonia*, *Pennisetum* and *Cajanus* fallows after three years

Data on the effects of *Tithonia*, *Pennisetum*, and *Cajanus* fallows for three years on soil physical properties are presented in Table 2. *Cajanus* fallow significantly has the highest bulk density, soil loss, and dispersion ratio and lowest porosity and moisture content compared with *Tithonia* and *Pennisetum* fallows. There were no significant differences in the values of sand, silt, and clay contents of the soil after three years of *Tithonia*, *Pennisetum*, and *Cajanus* fallow, however, *Cajanus* fallow slightly increased the sand content of the soil by about 3% and reduced the clay

**Table 1.** Mean  $\pm$  standard deviation of the physical and chemical properties of the site (0–15 cm) before experimentation.

| Property                                 | 0–15 cm         | 15–30 cm        |
|--|-----------------|-----------------|
| Organic matter (%)                       | 2.45 $\pm$ 0.04 | 2.40 $\pm$ 0.04 |
| pH (water)                               | 5.71 $\pm$ 0.5  | 5.60 $\pm$ 0.5  |
| Total N (%)                              | 0.17 $\pm$ 0.01 | 0.15 $\pm$ 0.02 |
| Available P (mg kg <sup>-1</sup> )       | 10.1 $\pm$ 0.3  | 8.8 $\pm$ 0.2   |
| Exchangeable K (cmol kg <sup>-1</sup> )  | 0.13 $\pm$ 0.01 | 0.12 $\pm$ 0.01 |
| Exchangeable Ca (cmol kg <sup>-1</sup> ) | 1.61 $\pm$ 0.03 | 1.58 $\pm$ 0.03 |
| Exchangeable Mg (cmol kg <sup>-1</sup> ) | 0.35 $\pm$ 0.03 | 0.33 $\pm$ 0.03 |
| CEC (cmol kg <sup>-1</sup> )             | 2.21 $\pm$ 0.04 | 2.19 $\pm$ 0.04 |
| Sand (%)                                 | 68.1 $\pm$ 5.3  | 65.6 $\pm$ 5.5  |
| Silt (%)                                 | 16.1 $\pm$ 3.1  | 15.8 $\pm$ 3.1  |
| Clay (%)                                 | 15.8 $\pm$ 3.4  | 18.6 $\pm$ 4.3  |
| Textural class                           | Sandy loam      | Sandy loam      |
| Bulk density (g cm <sup>-3</sup> )       | 1.45 $\pm$ 0.03 | 1.51 $\pm$ 0.03 |
| Porosity (%)                             | 45.3 $\pm$ 3.8  | 43.0 $\pm$ 3.8  |
| Moisture content (%)                     | 11.4 $\pm$ 2.2  | 10.1 $\pm$ 2.2  |
| Dispersion ratio (%)                     | 81 $\pm$ 6.7    | 84 $\pm$ 6.6    |

**Table 2.** Physical properties of soil under *Tithonia*, *Pennisetum* and *Cajanus* fallows after three years.

|                   | Bulk density (g cm <sup>-3</sup> ) | Porosity (%) | Moisture content (%) | Sand (%) | Silt (%) | Clay (%) | Soil loss (cm) | Soil loss (kg ha <sup>-1</sup> ) | Dispersion ratio (%) |
|-------------------|------------------------------------|--------------|----------------------|----------|----------|----------|----------------|----------------------------------|----------------------|
| <i>Tithonia</i>   | 1.11c                              | 58.1a        | 22.5a                | 67.4a    | 16.5a    | 16.1a    | 1.01c          | 112.2c                           | 52c                  |
| <i>Pennisetum</i> | 1.27b                              | 52.1b        | 17.1b                | 67.9a    | 16.3a    | 15.8a    | 1.51b          | 191.8b                           | 60b                  |
| <i>Cajanus</i>    | 1.46a                              | 44.9c        | 13.6c                | 70.2a    | 15.3a    | 14.3a    | 2.28a          | 332.9a                           | 75a                  |

Values followed by similar letters under the same column are not significantly different at  $p = 0.05$  according to Tukey's HSD test (honestly significantly different test).

content by 9.5% compared with the soil before the start of fallow. Similarly, the *Tithonia* fallow reduced the sand content of the soil by about 1% and increased the clay content by 1.9% compared with the initial soil before the start of the fallow. *Tithonia* fallow has the most improved soil physical properties. The order was *Tithonia* > *Pennisetum* > *Cajanus*.

### 3.3. Chemical properties of soil under *Tithonia*, *Pennisetum* and *Cajanus* fallows after three years

Results of the effects of *Tithonia*, *Pennisetum*, and *Cajanus* fallow for three years on soil chemical properties at 0–15 cm and 15 cm–30 cm are presented in Table 3. *Tithonia* fallow has the highest values of OM, N, P, K, Ca, Mg CEC, and pH compared with *Pennisetum* and *Cajanus* fallows N values between *Tithonia* and *Pennisetum* at 0–15 cm and 15–30 cm soil depth are similar. Also, pH between *Tithonia* and *Pennisetum* for 0–15 cm soil depth are similar but the value of pH for *Tithonia*, *Pennisetum*, and *Cajanus* fallows was not significantly different for 15–30 cm soil depth. *Tithonia* increased SOM by about 23%, 7.5%, and 20%, respectively, compared with the initial soil, *Pennisetum*, and *Cajanus* fallow for 0–15 cm soil depth. At the 0–15 cm soil depth, *Tithonia* and *Pennisetum* fallow increased the pH after three years compared with initial soil by 8.6% and *Cajanus* fallow by 5.3%. *Tithonia* fallow increased soil (chemical properties) fertility compared with *Pennisetum* and *Cajanus* fallows.

### 3.4. Leaf nutrient concentrations of maize planted with soil under *Tithonia*, *Pennisetum* and *Cajanus* fallows after three years

Results of the effects of leaf nutrient concentrations of maize planted with soil under *Tithonia*, *Pennisetum* and *Cajanus* fallow after three years are shown in Figure 1. *Tithonia* fallow significantly has the highest values of maize leaf N, P, K, Ca and Mg with *Cajanus* fallow having the least values. The order was *Tithonia* > *Pennisetum* > *Cajanus*.

## 4. Discussion

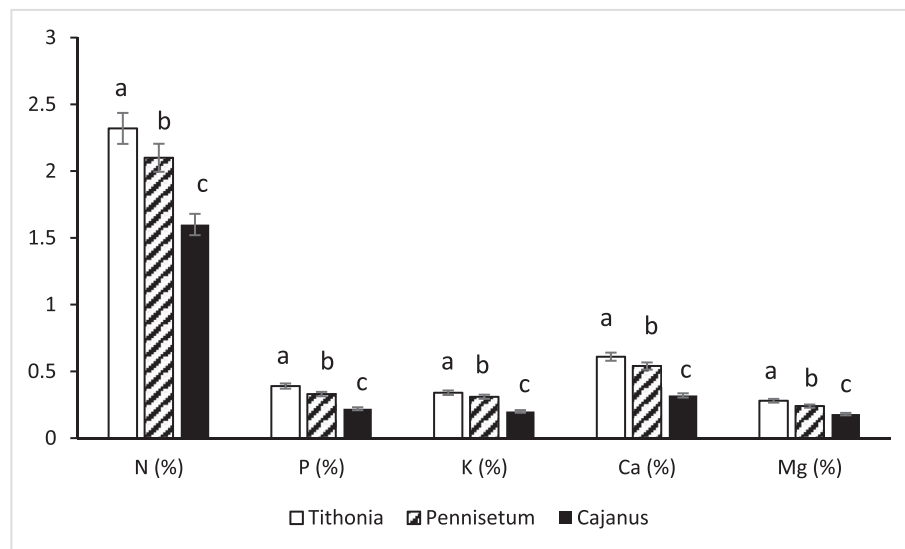
The soil of the sites prior to experimentation was low in nutrients. This state of the soil is characteristic of Nigerian savanna soils. Adegbite et al. (2020) reported that Nigeria's savanna soils are low in organic matter and chemical fertility. The fairly high bulk density and low soil fertility status could also be adduced to the previous continuous cultivation using implements such as disc plough, disc harrow, and disc ridger, and wheel traffic of tractor passes over years, which compacts the soil and degrades the soil properties. The lower clay content at the 0–15 cm soil layer relative to the 15–30 cm layer could be adduced to sorting of soil materials by biological and/or agricultural activities, clay migration or surface erosion by run-off or combination of these (Idoga and Azaguku, 2005).

**Table 3.** Chemical properties of soil under *Tithonia*, *Pennisetum* and *Cajanus* fallows after three years at 0–15 cm and 15–30 cm depth.

|                   | SOM (%) |         | N (%)  |         | P (mg kg <sup>-1</sup> ) |         | K (cmol kg <sup>-1</sup> ) |         | Ca (cmol kg <sup>-1</sup> ) |         | Mg (cmol kg <sup>-1</sup> ) |         | CEC (cmol kg <sup>-1</sup> ) |         | pH (H <sub>2</sub> O) |         |
|-------------------|---------|---------|--------|---------|--------------------------|---------|----------------------------|---------|-----------------------------|---------|-----------------------------|---------|------------------------------|---------|-----------------------|---------|
|                   | 0–15cm  | 15–30cm | 0–15cm | 15–30cm | 0–15cm                   | 15–30cm | 0–15cm                     | 15–30cm | 0–15cm                      | 15–30cm | 0–15cm                      | 15–30cm | 0–15cm                       | 15–30cm | 0–15cm                | 15–30cm |
| <i>Tithonia</i>   | 3.01a   | 2.48a   | 0.21a  | 0.16a   | 27.1a                    | 10.8a   | 0.24a                      | 0.13a   | 2.44a                       | 1.20a   | 0.58a                       | 0.31a   | 3.46a                        | 1.71a   | 6.20a                 | 5.71a   |
| <i>Pennisetum</i> | 2.81b   | 2.28b   | 0.20a  | 0.16a   | 20.3b                    | 9.4b    | 0.20b                      | 0.11b   | 2.20b                       | 1.14b   | 0.51b                       | 0.24b   | 3.32b                        | 1.54b   | 6.20a                 | 5.70a   |
| <i>Cajanus</i>    | 2.51c   | 2.01c   | 0.18c  | 0.14b   | 12.1c                    | 8.1c    | 0.14c                      | 0.10c   | 1.81c                       | 0.90c   | 0.38c                       | 0.18c   | 2.41c                        | 1.21c   | 5.74b                 | 5.64a   |

Values followed by similar letters under the same column are not significantly different at  $p = 0.05$  according to Tukey's HSD test (honestly significantly different test).





**Figure 1.** Leaf nutrient concentrations of maize planted with soil under *Tithonia*, *Pennisetum* and *Cajanus* fallows after three years. Vertical bars show standard errors of paired comparisons; bars marked with different letters show means significantly different at 5% level according to Tukey's HSD test (honestly significantly different test).

The reduced bulk density and increased porosity of the soil in *Tithonia* fallow plots compared with *Cajanus* was due to an increase in soil organic matter (OM) from the litters of the fallow plant. The presence of the high litter materials as a result of the regular return of plant residue to the soil in *Tithonia* fallow plots would have increased activities of beneficial soil fauna in OM decomposition which led to increased total pore space, which in turn decreased bulk density (Adekiya, 2019). Brady and Weil (1999) reported that the decomposition of OM from the litter materials produced polysaccharide which binds primary particles to become secondary particles and create larger pore spaces. The OM can also influence soil structural properties by enmeshing soil primary particles and macroaggregates into macro aggregation through the direct physical action of roots, and production of cementing agents from enhanced microbial activities. These aggregation processes and properties may reduce soil bulk density and increase porosity (Goldammer et al., 1994; Hargrove et al., 1989; Islam and Weil, 2000). *Cajanus* has less foliage returned to the soil to act as a mulch to cover the soil and at the same time decompose and become SOM. The low surface litter resulted in low OM and therefore compaction of the surface soil and consequently high apparent density and low porosity. This observation implies that continuous exposure of soil to rainfall without residue cover compacts the soil.

The increased moisture content of *Tithonia* fallow compared with others could be due to increased SOM in *Tithonia* plots which would have improved soil aggregation thereby resulting in creating more pore spaces as a result of greater earthworm burrowing (Adekiya et al., 2020). Another reason for the differences in water content between *Tithonia* fallow plots and the rest could probably also be due to the differences in bulk density between these treatments. The bulk density of the *Cajanus* plots was higher (reducing the spaces where water could be retained) compared with the bulk density of the *Tithonia* fallow plots. The increase in water retention of soil due to the addition of organic matter may be related to the increased absorptive capacity of the soil (increase in total surface area) (Fageria and Gheyi, 1999). de Jong (1983) and Haynes and Naidu (1998) found an increase in water content with increasing SOM content and Wolf and Snyder (2003) stated that an increase of 1% SOM can add 1.5% additional moisture by volume at field capacity.

*Tithonia* fallow plots reduced dispersion ratio compared with *Cajanus* plots. This was added to the higher OM from *Tithonia* fallow plots. The SOM stabilized the soil structure and reduced dispersion ratio since organic matter addition is essential for stabilizing soil against physical degradation and soil erosion. Soils with a high dispersion ratio are weak

structurally and can easily be eroded (Adekiya et al., 2016). Lado et al. (2004) reported that in sandy loam soil an increase of OM content from 2.3% to 3.5% reduced the aggregate breakdown, soil dispersivity, and the seal formation at the soil surface under raindrop impact conditions.

The reduction in soil loss in *Tithonia* fallow plots relative to others was added to increased aggregation which might have increased infiltration rate and therefore reduce runoff.

The slight increase in sand content in *Cajanus* plots compared with the initial soil may be attributed to soil erosion because its soils are not totally covered with plant residue. Also, the slight increase in clay content in *Tithonia* fallow plots could be related to a high earthworm activity in this fallow plot.

Therefore, the main reason for improved soil physical properties under *Tithonia* fallow for this study could be related to the high biomass yield of the fallow plant which when returned to the soil resulted in high OM which stabilized soil structure by increasing porosity, moisture content and reducing bulk density, dispersion ratio, and soil loss. Hence, for this study, the correlation coefficient between SOM and soil bulk density, porosity, moisture content, soil loss, and dispersion ratio were all significant with R values of -0.99, 0.99, 0.92, -0.98, and -0.99, respectively at  $P < 0.05$ .

Soil chemical properties were in the order *Tithonia* > *Pennisetum* > *Cajanus*. This is consistent with the SOM values of these treatments. The treatments *Tithonia* and *Pennisetum* produced high biomass yield and made a lot of return to the soil compared with *Cajanus* treatment with less biomass and insufficient return of plant residue to the soil. These residues are acted upon by microorganisms and consequently decomposed to SOM and release nutrients such as N, P, K, Ca, and Mg.

The low N and P level in the *Cajanus* fallow was apparently due to insufficient return of plant residue to the soil and the higher N in *Tithonia* fallow was due to massive return of biomass to the soil. Organic matter is a major indigenous source of available N that it contains as much as 65% of the total soil P and provides significant amounts of sulfur (S) and other nutrients essential for plant growth (Bauer and Black, 1994). Exchangeable K, Ca and Mg also declined in plots with *Cajanus*. These results also indicated that exchangeable Ca, Mg, and K contents in the soil are closely related to soil organic matter and crop residue return. There is generally a good correlation between SOM and CEC and McGrath et al. (1988) noted that the CEC of a sandy soil increased from 75 to 158 cmol  $\text{c} \cdot \text{g}^{-1}$  as SOM increased from 0.46 to 1.39%. The drop in soil pH in *Cajanus* plots may also result in a decrease in CEC value.

Therefore, the nutrients in *Tithonia* fallow plots are higher because of higher biomass yield and high return of plant biomass to the soil. Atayese and Liasu (2001) found that soils under *Tithonia* contained arbuscular mycorrhizal fungi spore which enhanced absorption of nutrients from the soil to biomass. Because of the ability of the weeds to protect the soil, proliferate surface soil with their roots, attract fungi, increase biomass and organic matter; the fallows were able to improve soil structure and porosity, reduce bulk density, and increase soil nutrient. Shokalu et al. (2010) found that *Tithonia* significantly improved pH, N, P, K, Mg, and Zn contents of the soil. Yusuf and Fawole (2006) reported that *Pennisetum* decomposed and add nutrients to the soil. In an experiment in southern Nigeria (Juo and Lal, 1977) to compare management effects on soil organic matter accumulation, a three-year fallow with guinea grass (*Panicum maximum*) maintained a SOM level comparable to that under forest fallow and fallowing with leguminous species such as pigeon pea (*Cajanus cajan*) caused a significant decline in SOM. Furthermore, *Tithonia* has higher SOM and nutrient not because of the higher returns of its biomass to the soil only, but also from the contributions from the decay of the root and stem. The roots of the other fallow plants (*Pennisetum* and *Cajanus*) still continue to grow each year of fallow but *Tithonia* roots and stems decayed every year and add fresh OM and nutrients to the soil. Quideau (2002) reported that in grassland ecosystems, up to two-thirds of organic matter is added through the decay of roots.

The result that soils under *Tithonia*, *Pennisetum*, and *Cajanus* fallows had higher values of organic matter, N, P, K, Ca and at the surface (0–15 cm depth) relative with subsoil layer (15–30 cm depth) could be attributed to the fact that more organic matter decomposition occurred in the upper layer of soil profile because the more organic matter was added through litter fall due to the fallowing of soils (Agbede and Afolabi, 2014). Also, the pH, K, Ca, and Mg decreased with depth due to clay mineralogy effects on CEC (Adekiya et al., 2011).

It should be noted that at the end of the fallow period and for regular crop cultivation, the fallow crops (*Tithonia*, *Pennisetum*, and *Cajanus*) were ploughed back into the soil.

The response of leaf nutrient concentrations of maize to different fallow soils was consistent with the values of soil chemical properties recorded for these treatments. There was increased nutrient availability in the soil as a result of *Tithonia*, *Pennisetum*, and *Cajanus* fallows leading to increased uptake by maize plants.

## 5. Conclusion

Results from this study showed that fallow remains an important component in the restoration of soil productivity of a derived savanna zone of Nigeria. Results also showed that *Tithonia* fallow improved soil physical and chemical properties and leaf nutrient concentration of maize compared with *Pennisetum* and *Cajanus* fallows. This was adduced to the regular return of plant residues to the soil in *Tithonia* fallow which resulted in high OM and increases soil N, P, K, Ca, Mg, CEC and pH and also stabilized soil structure by increasing porosity, moisture content, and reducing bulk density, dispersion ratio, and soil loss. Due to the short period of fallow, level of soil fertility restoration under *Tithonia* fallow might not be satisfactory after three years, however, due to the raised level of soil fertility, the quantity of fertilizer needed to sustain the productivity of that soil would have significantly reduced. Therefore, plant species of high nutrient contents and high return of biomass to the soil is necessary for quick restoration of soil productivity in a derived savanna ecology.

## Declarations

### Author contribution statement

Aruna Olasekan Adekiya: Conceived and designed the experiments; Wrote the paper.

Charity Aremu: Analyzed and interpreted the data.

Taiwo Michael Agbede: Wrote the paper.

Wutem Sunny Ejue; Ayodele Tunmise Oni: Performed the experiments.

Kehinde Abodunde Adegbite; Ibukun Elizabeth Olayiwola; Babatunde Ajiboye; Adeniyi Olayanju: Contributed reagents, materials, analysis tools or data.

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Data included in article/supplementary material/referenced in article.

### Declaration of interests statement

The authors declare no conflict of interest.

### Additional information

No additional information is available for this paper.

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