

EFFECTS OF SHORT-TERM FALLOW SPECIES ON SELECTED SOIL PROPERTIES, CARBON SEQUESTRATION AND MAIZE YIELD

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ABSTRACT

The study was conducted to determine the effect of short-term fallow on soil properties, carbon sequestration, and maize yield at the Obafemi Awolowo University Teaching and Research Farm, Ile-Ife, Nigeria. The field was laid out in a randomized complete block design. The fallow treatments were *Megathyrsus maximus*, *Pueraria phaseoloides*, *Chromolaena odorata*, and Native fallow. The fallow treatments were planted and established for 3 months before being incorporated into the soil. Using standard methods, the parameters assessed include bulk density, pH, organic carbon, exchangeable cations, total nitrogen, carbon sequestered, and total porosity. *Megathyrsus maximus* fallow improved bulk density, exchangeable cations, and total porosity and sequestered more carbon compared to *Pueraria*, *Chromolaena*, and natural fallow. *Megathyrsus* also increased organic carbon and total nitrogen by 41.3% and 32.8%, respectively, compared with the other treatments. Maize dry matter yield was significantly ($P < 0.05$) increased by *Chromolaena* (10.98 tons/ha), *Megathyrsus* (9.69 tons/ha), and natural fallow (9.16 tons/ha) three months after incorporation compared to *Pueraria* (7.54 tons/ha). Therefore, fallow plant species of high quality are necessary for the improvement of soil properties. Overall, *Megathyrsus* showed the best promise in terms of improvement of soil chemical properties and carbon sequestration while *Chromolaena* improved dry matter yield.

Keywords: Carbon Sequestration; Short Fallow; Soil Physical and Chemical Properties; Maize dry matter yield

INTRODUCTION

Soils in Nigeria 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 (Ojo *et al.*, 2023). 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 have been used to improve 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 and nutrient imbalance (Agbede *et al.*, 2018).

Fallow replenishes nutrients removed by crops, reduces erosion and leaching, and maintains better soil physical and biological conditions. It reduces soil disturbance which ultimately protects soil organic carbon (SOC) and promotes SOC sequestration (Nwite and Alu, 2017). Until the first quarter of the twentieth century, the problem was not serious since farmers could easily open up new land for cultivation. However, due to population growth and alternative demand for land other than agriculture, the period of fallow has drastically reduced (Nzeako *et al.*, 2019). Short fallow periods using selected fast-growing leguminous plant species in small areas can be a very promising method to increase the

productivity of smallholder farming systems (Munthali *et al.*, 2014). Improved fallows with legumes have the potential to enhance soil fertility via biological nitrogen fixation and nutrient cycling and increase overall crop yields (Mafongoya *et al.*, 2006). The fallow period is now too short to adequately restore soil fertility. Therefore, there is a dire need to research fast-growing crop/weed species that produce a large amount of high-quality biomass during a short period which can add reasonable nutrients and organic matter to the soil (Agbede and Afolabi, 2014).

Some of the crops and weed species that grow on or near smallholder farms have relatively high nutrient concentrations. Among these crop/weed species are; guinea grass (*Megathyrsus maximus* formally *Panicum maximum*), siam weed (*Chromolaena odorata*), and *Pueraria phaseoloides*. Guinea grass (*Megathyrsus maximus*) is commonly used in soil conservation systems due to its high above-ground biomass yield, higher C:N ratio (Hontoria *et al.*, 2016), and dense root system, which is related to intense microbial activity. *Chromolaena odorata* is deep-rooted, fast-growing, and produces substantial biomass. *Pueraria phaseoloides* has been reported to have the ability to spread rapidly once established. For instance, Tijani (2006), reported that short fallow with *Pueraria phaseoloides* is an attractive option for sustaining the water use efficiency of continuously cropped farmlands.

The type of plant material used as fallow may influence the physical, chemical, and biological properties of the soil, carbon sequestration, and crop yield at the end of the fallow period. This is due to the variations in morphological and biochemical qualities of each fallow crop. Furthermore, the carbon footprint of soil management

technologies requires attention in the face of challenges in global climate change. This remains a knowledge gap in the deployment of these fallow species. There is, therefore, a need to research the effect of different fallow in a short fallow system on soil properties, and crop yield. The objective of the study was to assess the effect of shortfallow systems on soil physicochemical properties, carbon sequestration, and maize yield.

MATERIALS AND METHODS

The field experiment was carried out at the Obafemi Awolowo University Teaching and Research Farm, Ile-Ife, Nigeria. It lies on latitudes 07° 32' N and 07° 33' N and longitudes 04 ° 32' E and 04° 34' E with an altitude of about 244 m above mean sea level. It is located in the rainforest ecology of Southwest Nigeria with an average annual rainfall of 1500 mm and a bimodal distribution with peaks in June and September. The experimental field was ploughed and harrowed using a disc plough and harrow to a depth of 15 cm to homogenise the soil. Three (3) seeds of maize (SAMMAZ-38) were planted per hole in the soil to exhaust its nutrients before planting the fallow crops. The exhaustion occurred due to the extraction of nutrients by maize without adding any fertilizer throughout the period of its growth.

The experimental design was a randomized complete block design with four replications. Each plot was 10 m by 10 m with 2 m space between plots (separating blocks) and 1 m space within plots (separating treatments). The experiment involved four short fallow treatments which were: *Megathyrsus maximus*, *Pueraria phaseoloides*, *Chromolaena odorata*, and Native fallow (different weeds species on the plot include Couchgrass (*Digitaria abyssinica*), Bahama grass (*Cynodon*

dactylon), Elephant grass (*Pennisetum purpureum*)).

Land preparation was done by ploughing and harrowing the entire land area. The fallow treatments were planted in each test plot and manually weeded three times to ensure the test plots were only populated with the fallow species. The control (native fallow) plot was not weeded. The natural fallow was allowed to grow and the fallow species were established for 3 months, after which the fallow species and the native fallow (control) on each plot were ploughed into the soil. The minimum and the maximum temperature during the three-month growth period are 24.9 °C and 25.6 °C respectively while the total rainfall is 1081.7 mm. Three seeds of maize were planted per hole at a spacing of 75 cm by 50 cm on the ploughed soil as a test crop. Thinning was done two weeks later to one stand per hole.

Samples were taken two times. The first sample was taken before the fallows were established. The fallow crops were planted and allowed to grow for 3 months after which they were ploughed and incorporated into the soil. The second sample was taken 3 months after incorporation. Five (5) soil samples were collected randomly from each of the plots using a soil auger at two soil depths: 0-15 cm and 15-30 cm. The samples from each plot at different depths were bulked, properly mixed, and sub-sampled for laboratory analyses. Undisturbed soil samples were also collected at 0-15 cm and 15-30 cm depth from each plot using a cylindrical core sampler to evaluate bulk density (Blake and Hartge, 1986), total porosity using the saturation method proposed by Flint and Flint (2002). Collected composite soil samples were air-dried and sieved using a 2 mm sieve ready for analysis. The particle size analysis of the soils was determined using a modified

Bouyoucos (1951) hydrometer method as described by (Gee and Or, 2002).

Soil pH was determined potentiometrically in a soil-water suspension ratio of 1:2 in 0.01 M CaCl₂ using a glass electrode pH meter (Thomas, 1996). Soil organic carbon was determined by the procedure of Walkley and Black using the dichromate wet oxidation method (Nelson and Sommers, 1996). Total Nitrogen was determined using the modified macro-Kjeldahl digestion method (Bremner, 1996). Available phosphorus was determined using the Bray-1 method (Kuo, 1996). Exchangeable K, Ca, Na, and Mg were determined by extracting the soils with 1 N ammonium acetate solution buffered at pH 7 (Thomas, 1982). K and Na in the extract were read on a flame photometer while Ca and Mg were read on Atomic Absorption Spectrophotometer.

Maize yield was determined based on kernel weight. The yield determination based on grain weight was modified to a required percentage of moisture content (MC, 12%) using the formula reported by Ngoune and Mutengwa (2019):

$$\text{Grain Yield} = \left[\frac{\text{Grain weight} \times 10 \times \frac{100(100 - MC)}{100 - \text{Adjusted MC}}}{\text{Plot Area}} \right]$$

Dry matter yield was determined according to the method of Draper (2004). Maize plants were sampled from at least five points on each plot. At each plot, a row of ten plants was selected, and the plant that appeared most representative of the row was cut from above the ground. This was done in each plot on days 29 and 75. This maize biomass was packed and oven-dried to a constant weight at 75 °C for dry weight determination.

$$\text{Dry Matter Yield} = \text{Plant population} \times \text{Dry weight of plant}$$

Carbon sequestered was calculated by measuring the net change in carbon stored

over time as described by Pearson *et al.* (2007) using three variables (soil sampling depth, bulk density, and organic carbon concentration) to obtain the amount of carbon sequestered per unit area

$$\begin{aligned} \text{Carbon sequestration: } C \text{ (t/ha)} \\ = \left[\left(\text{soil bulk density} \left(\frac{g}{cm^3} \right) \right. \right. \\ \left. \left. \times \text{soil depth (cm)} \times \% C \right) \right] \times 100 \end{aligned}$$

In this equation, % C was expressed as a decimal fraction. C(t/ha) was later converted to kg/ha in this study

Data obtained were analyzed using analysis of variance, and mean separation was done by Duncan's multiple range test at 5% levels of probability.

RESULTS

Initial physical and chemical properties of the experimental site at (0–15 cm)

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 was classified as sandy loam and they were strongly acidic. The soil bulk density (Db) and total porosity ranged between 1.35-1.42 g cm⁻³ and 41.18 -

47.78%, respectively. Soil organic carbon (SOC), total nitrogen, and available phosphorus were low when compared to the critical levels recommended for crop production in ecological zones of Nigeria (Adekiya *et al.*, 2021).

Physical properties of soil under fallow treatments 3 months after incorporation into the soil

Data on the effects of the treatments on soil physical properties are presented in Table 2. There was no significant difference in the soil bulk density and porosity, but unlike other treatments, the soil bulk density was further reduced in the *Megathyrus* fallow plot after incorporation compared to the bulk density before fallow crop planting. The subsoil bulk density was higher than that of the surface soil, which is in agreement with the previous work of Akinde *et al.*, 2020. Also, after the incorporation of the fallow treatments, there was no significant difference ($P < 0.05$) in total porosity among the treatments in both the surface and sub-surface depth. However, *Megathyrus* fallow had the highest total porosity of 48.68% and 44.15% in surface and subsurface soil respectively.

Table 1. Initial physical and chemical properties of the site before planting of fallow crops

Treatment	NF	PP	MM	CO	NF	PP	MM	CO
Property	0 – 15 cm depth				15 – 30 cm depth			
pH (CaCl ₂)	4.89	4.78	4.93	4.90	5.09	4.98	5.13	5.13
Organic carbon (OC) (%)	1.69	1.65	1.70	1.69	1.58	1.54	1.59	1.58
Total nitrogen (TN) (g kg ⁻¹)	1.33	1.32	1.31	1.32	1.35	1.35	1.33	1.35
Available Phosphorus (mg kg ⁻¹)	2.86	2.85	2.84	2.73	2.67	2.67	2.66	2.55
Exchangeable Ca (cmol kg ⁻¹)	10.91	10.67	10.99	10.93	10.37	10.13	10.44	10.38
Exchangeable Mg (cmol kg ⁻¹)	1.16	1.13	1.17	1.16	1.10	1.07	1.11	1.10
Exchangeable K (cmol kg ⁻¹)	0.20	0.19	0.20	0.20	0.19	0.18	0.19	0.19
Textural class	SL	SL	SL	SL	SL	SL	SL	SL
Bulk density (g cm ⁻³)	1.38	1.35	1.39	1.38	1.41	1.38	1.42	1.41
Porosity (%)	45.58	47.47	47.78	46.21	41.18	44.01	44.32	42.12

NF = natural fallow, PP = *Pueraria phaseoloides*, MM = *Megathyrus maximus*, CO = *Chromolaena odorata*, Ca = calcium, Mg = magnesium, K = potassium

Table 2. Physical properties of soil under fallow after 3 months

	Bulk density (g cm ⁻³)		Porosity (%)		FMC (cm ³ cm ⁻³)		K (-2 cms ⁻¹) (10 ⁻³)
	0-15cm	15-30cm	0-15cm	15-30cm	0-15cm	15-30cm	0-15cm
Megathyrsus	1.36a	1.48a	48.68a	44.15a	0.50a	0.39a	4.33a
Pueraria	1.47a	1.60a	44.53a	39.62a	0.48a	0.40a	7.57a
Chromolaena	1.43a	1.50a	46.04a	43.50a	0.51a	0.47a	7.15a
Natural Fallow	1.54a	1.63a	41.89a	38.40a	0.51a	0.44a	4.76a

Means with the same alphabet in each column for each soil depth are similar according to Duncan’s Multiple Range Test at 5% probability level.

Chemical properties of soil under fallow treatments 3 months after incorporation into the soil

Data on the effects of fallow on soil chemical properties at 0-15cm and 15-30 cm are presented in Tables 3a and 3b. The soil pH and available phosphorus under the fallowed plots were not significantly different ($p < 0.05$) from one another both in the surface and subsoil. The OC (23.98 g/kg) and TN (1.74 g/kg) contents of the surface soil for the plot fallowed by *Megathyrsus* were significantly ($p < 0.05$) higher than other treatments. The plot fallowed with *Pueraria* had the significantly lowest OC value (12.87 g/kg) but the joint significantly highest TN along with *Megathyrsus*. In the subsoil, OC values was significantly highest (25.14 g/kg) in the plot fallowed by *Megathyrsus*, while the plot

followed by *Pueraria* had the lowest OC value (14.75 g/kg). *Megathyrsus* increased total nitrogen and OC at 0-15cm soil depth by 32.8% and 41.3% respectively compared with the initial soil. In the surface soil depth, the plot fallowed by *Pueraria* had the lowest Ca concentration (4.93 cmol/kg) and was significantly ($p < 0.05$) lower than other treatments, while other plots were not significantly different from one another. The soil Mg in plots fallowed by *Megathyrsus* was only significantly higher ($p < 0.05$) than that of *Chromolaena* in the surface soil. K in plots fallowed with *Pueraria* and *Chromolaena* were significantly higher ($P < 0.05$) than K in plots fallowed with *Megathyrsus* and native weed species (control). The carbon-nitrogen ratio was lowest in *Pueraria* (7:1) and highest in *Megathyrsus* (13:1).

Table 3a. Chemical properties of soil under fallow after 3 months

	pH (CaCl ₂)		OC (%)		TN (g kg ⁻¹)		C:N
	0-15cm	15-30cm	0-15cm	15-30cm	0-15cm	15-30cm	
MM	4.72a	4.66a	2.40a	2.51a	1.74a	1.63a	13:1
PP	4.50a	4.66a	1.29d	1.48d	1.74a	1.63a	7:1
CO	4.69a	4.63a	2.07b	2.26b	1.72b	1.63a	12:1
NF	4.33a	4.52a	1.66c	1.85c	1.69c	1.64a	9:1

Table 3b. Chemical properties of soil under fallow after 3 months contd.

	P (mg kg ⁻¹)		Ca (cmol kg ⁻¹)		Mg (cmol kg ⁻¹)		K (cmol kg ⁻¹)		Na (cmol kg ⁻¹)	
	0-15cm	15-30cm	0-15cm	15-30cm	0-15cm	15-30cm	0-15cm	15-30cm	0-15cm	15-30cm
MM	3.21a	2.88a	6.73a	8.16a	1.17a	0.81a	0.012b	0.023b	0.007b	0.046a
PP	4.09a	2.55a	4.93b	6.60a	1.04a	0.71a	0.047a	0.026ab	0.013a	0.026b
CO	3.55a	3.42a	6.70a	4.49a	0.66b	1.01a	0.047a	0.029a	0.013a	0.013c
NF	3.62a	3.02a	8.03a	4.39a	0.90ab	0.98a	0.023b	0.023b	0.013a	0.013c

MM = *Megathyrsus maximus*, PP = *Pueraria phaseoloides*, CO = *Chromolaena odorata*, NF = natural fallow, OC = organic carbon, TN = total nitrogen, P = available P, Ca = calcium, Mg = magnesium, K = potassium, Na = sodium, C:N = Carbon-nitrogen ratio. The means with the same alphabet in each column for each soil depth are similar according to Duncan's Multiple Range Test at a 5% probability level.

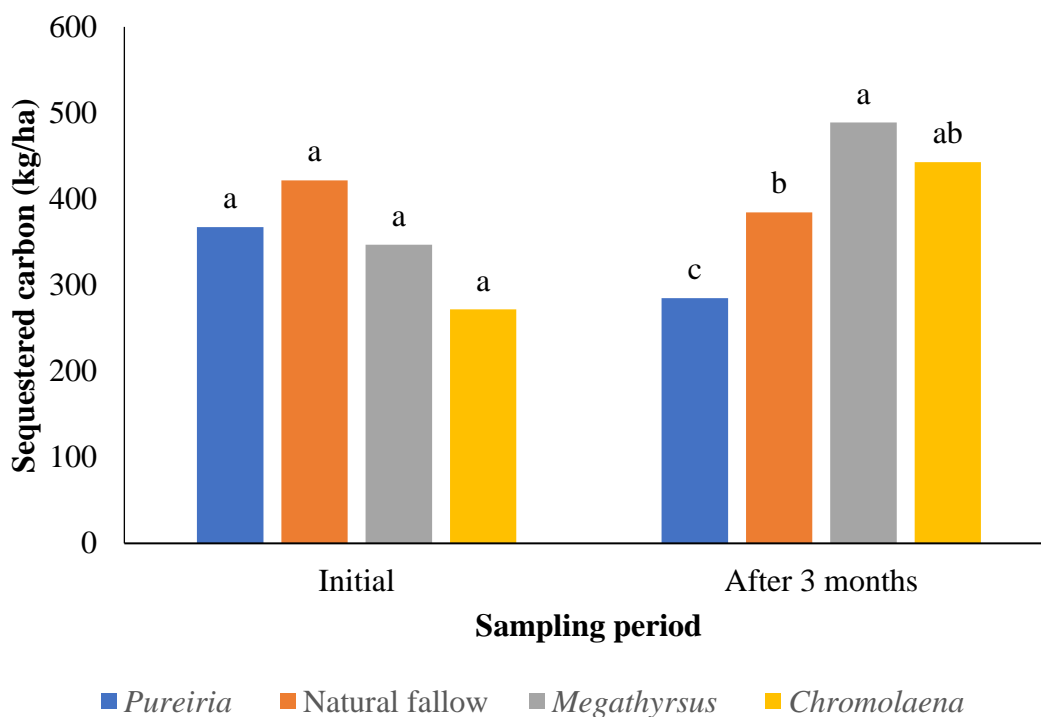


Figure 1. Effect of fallow on soil organic carbon sequestration of fallow before experimentation and 3 months after incorporating fallow into the soil. Means with the same alphabet are similar according to Duncan's Multiple Range Test at 5% probability level.

Carbon sequestration 3 months after fallow incorporation into the soil

Results of the effects of fallow on carbon sequestration at the initial and after three months are shown in Figure 1. At the initial stage of the experiment, there was no

significant difference ($p < 0.05$) between the treatments at the surface and subsurface depths. At harvest, there were significant differences ($p < 0.05$) among treatments. *Megathyrsus* sequestered the highest carbon (489 kg/ha) followed by *Chromolaena*,

although the two were not significantly different. *Megathyrsus* was significantly higher than natural fallow and *Pueraria* with both having 443 and 384.6 kg/ha sequestered carbon, respectively (Figure 1).

Maize dry matter of biomass and grain yield

Results in Figure 2 and 3 show the effect of fallow on grain yield and dry matter yield (DMY) of biomass. There was a general increase in the DMY with time across the treatments and peaking at day 75 after planting. On day 29 (early vegetative stage) after planting, the DMY of the cultivated maize crop was not significantly different ($p < 0.05$) across all the fallow treatments. However, on day 75 (reproductive stage) after planting, the DMY of the maize crop differed significantly ($p < 0.05$). *Chromolaena* had the highest biomass DMY (10.98 t/ha) and was highly significantly different from the plot fallowed with *Pueraria* (7.54 t/ha) with the lowest value. There was no significant difference ($p < 0.05$) between the different treatments for maize grain yield.

DISCUSSION

The initial nutrient status of the soil for the sites before the experiment was low. This could also be adduced to the previous maize that was planted to mine the soil of its nutrients. Adegbite *et al.*, (2020) reported that Nigeria's soils are low in organic matter and chemical fertility. The reduced bulk density and increased total porosity of the soil in *Megathyrsus* fallow plots, compared with other fallows, could be due to the

massive adventitious rooting system of *Megathyrsus* (Lucas *et al.*, 2019). The subsoil bulk density was higher than that of the surface soil, which signifies that bulk density increased with an increase in depth, corroborating the study of Akinde *et al.*, (2020) that reported that bulk density increased with soil depth. Lower soil bulk density on the surface may be due to litterfall or higher biomass and greater soil fauna activities (Adekiya, 2019). There is no significant difference in the soil's physical properties after the incorporation of fallow crops. This could be due to the duration of fallow crops. If fallow crops are not given adequate time to establish or their growth is terminated too early, their impact on soil physical properties is limited (Adekiya *et al.*, 2021). This statement was corroborated by Odunze (2003) who reported that the level of nutrients (OC, TN, and Avail P) in soils depends mainly on the quantity of plant material and residue returned to the soil. The plot fallowed by *Megathyrsus* had the highest OC contents (23.98 g/kg) in the surface and subsurface soil while *Pueraria* had the least (12.87 g/kg) and this result corroborates Banful and Hauser (2011), who found lower OC under a plot fallowed by *Pueraria* compared to the plot fallowed by *Megathyrsus*. The nitrogen level in *Pueraria* could be due to the insufficient return of plant residue and insufficient time for fallow development. This was corroborated by Oguntade (2000), who reported a slow release of nitrogen by *Pueraria*. Plant biomass is the primary source of SOC and, when it decomposes, adds to the SOC stocks.

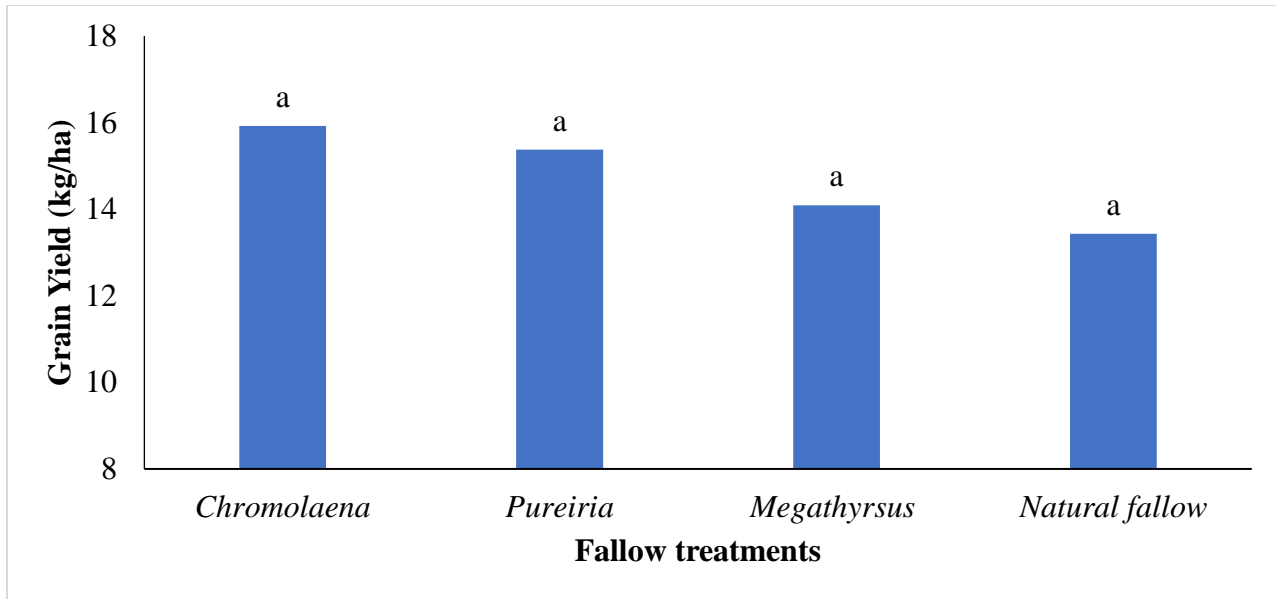


Figure 2. Grain yield of maize under different fallow treatments. Means with the same alphabet are similar according to Duncan’s Multiple Range Test at 5% probability level.

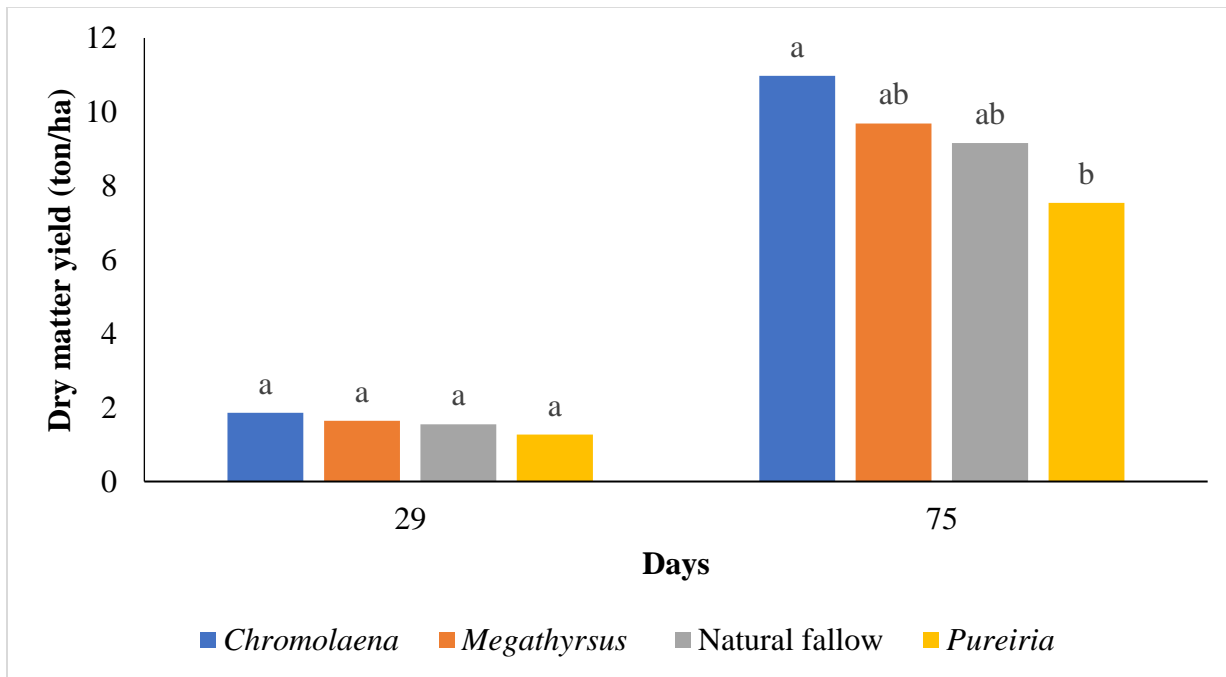


Figure 3. Effect of fallow on dry matter yield of maize at different sampling days. Means with the same alphabet are similar according to Duncan’s Multiple Range Test at a 5% probability level.

The stable OC fraction contributes to carbon sequestration (Tiefenbacher *et al.*, 2021). *Chromolaena* and *Megathyrus* had higher carbon sequestered. This could be due to the

higher rate of organic carbon addition to the soil because the accumulation of organic matter enhances the sequestration of OC in soils (Liu *et al.*, 2005). Ontl *et al.*, (2015)

reported that crops with high root biomass may enhance physically protected SOC stocks due to soil organic matter stabilization and decomposition process in the soil. *Chromolaena* and *Megathyrus* are shrubs and grass respectively, which decompose slowly compared to herbaceous *Pueraria*. *Megathyrus* had the highest C:N ratio (Table 3), and it sequestered more carbon. This aligns with Chen *et al.*, (2018) and Hansen *et al.*, (2019), who reported that crop residue with a higher C:N ratio is associated with soil organic carbon build-up.

The increase in maize biomass DMY with time across the treatments peaking at day 75 after planting could be due to an increase in total nitrogen, soil organic carbon, available phosphorus, and exchangeable bases across the treatment plots compared to the control. The plot fallowed by *Chromolaena*, though low, had the highest grain yield which could be attributed to the fact that *Chromolaena* residues decomposed quickly and improved soil properties, as also reported by Tian *et al.* (2015). This is contrary to the higher yield obtained under legume (*Pueraria*) by Cheruiyot *et al.*, (2003), whose reason was tied to the ability of *Pueraria* to fix nitrogen as a legume. This was also the case in Tijani (2006) and Tijani *et al.* (2008), who reported that *Pueraria* gave the highest maize grain yield among other fallow treatments including *Megathyrus*. According to Tondoh *et al.*, (2013), biomass created by *Chromolaena* is a key factor influencing soil quality improvement, since decomposed *Chromolaena* litter increases the soil's SOC, N, P, Ca, and Mg content. It also increases the density of soil macroinvertebrates, mainly earthworms which aid in decomposition for rapid nutrient release (Mboukou-Kimbatsa *et al.*, 2007).

CONCLUSION

The study investigated the effects of some fallow species on soil properties and carbon

sequestration. The findings from this study showed that fallow is an important component in restoring soil productivity. *Megathyrus maximus* was more effective in improving soil properties, particularly chemical properties within three months when compared to other treatments, and it was also the best of the short-term cropped fallow species for soil amendment and carbon sequestration in the sandy loam. The yield of maize was improved by *Chromolaena* and *Pueraria*. To improve grain yield, it is recommended that ample time for the establishment and planting of fallow species of high nutrient contents with high return of biomass to the soil are necessary for the restoration of soil productivity.

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