



Performance of farm residues management techniques on selected soil properties and maize (*Zea mays*) yield on the Eastern Flanks of Mount Cameroon

Godswill A. ASONGWE^{1*}, Irene B BAME², Maxwel A. FORBIN¹, David T. TIKU¹, Aaron S. TENING³ And Terence Nkwanwir SUINYUY^{4,5}

¹Department of Environmental Science, Faculty of Science, University of Buea, P. O. Box-63 Buea, Cameroon.

²Institute of Agricultural Research for Development (IRAD), Bambui, P.O Box 51, Bamenda Cameroon.

³Department of Agronomic and Applied Molecular Sciences, Faculty of Agriculture and Veterinary Medicine, University of Buea, P. O. Box - 63, Buea, Cameroon.

⁴School of Biology and Environmental Sciences, Faculty of Agriculture and Natural Sciences, University of Mpumalanga, P/Bag X11283, Mbombela, 1200, South Africa.

⁵School of life Sciences, College of Agriculture, Engineering and Sciences, University of KwaZu-Natal (Westville Campus), Durban 4000, South Africa.

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*Corresponding Author

Asongwe Godswill Azinwie

E-mail: asongwe2003@gmail.com.

Tel: +237 674663304

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ABSTRACT

Huge quantities of crop residues are generated annually in agricultural farms and are variedly handled by farmers. These residues are important nutrients for crops and also play a primordial role in soil physical, chemical and biological properties. Their retention/recycling is thought to naturally improve soil nutrient content, maintain soil productivity, reduces dependence on artificial fertilizers and also mitigating greenhouse gases emissions. However, such residues are bulky and farmers are in dire need of convincing knowledge on their sustainable management.

The present study evaluated the effects of four crop residue management techniques (removal, burning, mulching and incorporation) on selected soil physicochemical properties and maize yield in the vulnerable hilly topography of the eastern flanks of Mount Cameroon. A 4x4 complete randomized block design (RCBD) experiment was laid down and maize (CMS 8704 variety) was planted. Surface soil samples were equally collected from the plots before treatment application and at harvest. They were analysed for their physicochemical properties using standard methods. Maize growth and yield parameters were measured at harvest. The data collected were subjected to descriptive and inferential statistics.

The results indicated that soil bulk density, moisture content, organic matter contents, total nitrogen, available phosphorus, potassium, calcium and magnesium levels increased with mulching and incorporation but decreased with total removal of residues. Plant heights were 10%, 6.1% and 2.3% higher for mulching, incorporation and burning relative to total removal, respectively. Grain yield were similarly 10%, 6.1% and 5.1% higher for mulching, incorporation and burning relative to total removal, respectively. A highly significant positive relationship ($R^2 = 0.9976$) was obtained between grain yield and soil organic matter. The study concluded that, the retention of residues through the methods of mulching and incorporation were the best approaches to improve soil quality and crop yield. By recycling crop residues back into the soil, farmers can enhance soil fertility and structure, herby reducing the need for chemical fertilizers. There is therefore the need to educate farmers on the essentiality of residues incorporation and mulching within the farm and their long-term impacts. This is indispensable for promoting soil sustainability and safeguarding food security.

1.0 INTRODUCTION

The human race is plagued with a network of interconnected challenges: water scarcity, land degradation, food insecurity, and climate change due to increased greenhouse gases emissions (Mohammed *et al.*, 2020), which affects the sustainable use of natural resources. Agricultural land which, holds huge potential, are notoriously mismanaged and vulnerable. With ever increasing population, providing food for the population and reducing damage on the environment requires appropriate farm management techniques. Within the agricultural milieu, farm residues are considered valuable natural resources with potential of enhancing soil physical (such as soil moisture, temperature, aggregate formation, bulk density and hydraulic conductivity), chemical and biological properties (Singh *et al.*, 2019). Crop residues retention/recycling naturally improves soil nutrient content, maintains soil productivity, reduces dependence on artificial fertilizers (Kabirinejad *et al.*, 2014) thereby improving soil health but also

significantly contributes in mitigating greenhouse gases emissions (Cherubin *et al.*, 2021). It is thought that when crop residues are retained in soils their decomposition have both positive and negative effects on the environment and crop productivity.

Huge quantities of crop residues are generated annually in agricultural farms and are variedly handled by farmers. In most parts of the developing world, during farm preparation, the residues constitute nuisance to farmers because of their bulkiness. Techniques often used for residues management includes: burning, incorporation into beds, surface placement, ex-situ transportation (total clearance) etc.

In situ burning of residues is often the dominant technique used by farmers but a potential fire hazard and a source of atmospheric pollution endangering global climate. It also amounts to loss of plant nutrients and organic matter (Singh *et al.*, 2019). Furthermore, this technique increase the vulnerability of soils to degradation processes. In addition, Kumar *et al.* (2023) reported that burning of residues produces hydrophobic

components of organic matter, vaporizes big part of organic matter in the topsoil, and adversely affects the soil conditions. As a result, burning is not often considered as an environmentally sound method of soil and crop residue management. According to Kumar *et al.* (2023), in the long term, the phenomenon of residues burning along with climate change exigencies sets a serious challenge in maintaining the quality of natural resources and sustainable crop production.

Residues incorporation into the soils is believed to enhance recovery of microbial carbon and increases moisture, microbial activity. Such microbes consume oxygen consumption, which leads to anaerobic conditions (Tahgizadeh-Toosi *et al.*, 2021).

Residue removal can adversely impact soil and environment quality, with attendant decline in net primary productivity. According to Blanco-Canqui and Lal (2009), the removal of residues accelerates evaporation as the soil is exposed to direct sun rays, increases diurnal fluctuations in soil temperature, and reduces input of organic matter needed to improve the soil's ability to retain and recycle water. Furthermore, it reduces macro- (e.g., K, P, N, Ca, S and Mg) and micronutrient (e.g., Fe, Mn, B and Zn) pools in the soil.

On the other hand, the retention of crop residues in soil plays an important role in maintaining soil productivity given that residues are a large reservoir of plant nutrients. They improve the physical and biological properties of soils, protect them from wind and water erosion (Sidhu and Beri, 1989).

Within the past decades, food security has remained a major global issue especially in less developed countries (Akoko *et al.*, 2019). More than 1 billion people are estimated to lack sufficient dietary energy availability while at least twice that number suffer micronutrient deficiencies (Akoko *et al.*, 2019). According to stocking (2003), in most agro-ecosystems, declining crop yield is exponentially related to loss of soil quality. Lal (2009) stated that soil degradation has negative impact on human nutrition and health through its adverse effects on the quantity and quality of food production.

Food security remains a challenge in Buea district in particular and Cameroon in general with the proportion of undernourished people increasing every day since the food riots of 2008 (Beckline and Kato, 2014). The link between farm residue management and food security can be seen in the fact that poor farm residue management could lead to low agricultural productivity, since agricultural productivity is fundamentally affected by the productivity status of the soil.

Farmers around the mount Cameroon region use different techniques to manage their farm residues which are; are burning, complete removal, surface mulching and incorporation in soil. Some of these traditional practices are characterised by limited soil conservation strategies. Some of these techniques are known to adversely affect soil conditions and the environment. With the approach of the new planting season, many farmers in Buea use bush fires which is

perceived as an easy way of preparing their farmland. Considering the educational level of these small scale farmers, they have limited knowledge on the adverse effects of bushfires.

Literature points that the soil in Buea is prone to degradation or decline in its quality through a plethora processes not excluding residues management techniques. In order to promote sustainable agricultural practices in the area, prevents soil degradation, contributes towards the achievement of SDG2 (fight against hunger), this work was set to a) Examine the effect of four crop residues management techniques on the physicochemical properties of soils b) determine maize yield under different farm residue management techniques and c) assess the relationship between the soil physicochemical properties and maize yield under different residue management regimes.

2.0 MATERIALS AND METHODS

2.1 Description of the study site

2.1.1 Location

The study was carried out in the Environmental Science Experimental Farm of the University of Buea. Buea, in the South West Region of Cameroon. The area lies within the tropical rainforest belt, and located within latitude 4 and 5° N and longitude 8 and 10°E (MINEPAT, 2008), (Figure 1). It occupies a surface area of 870 Sq.km, with an estimated population of 300,000 inhabitants. Buea has a subtropical highland climate. Due to its location at the foot of Mount Cameroon, the climate tends to be humid, with two distinct seasons (a more than four months of dry season from November to mid-March and seven months of rainy season that runs from mid-March to October).

Mean annual rainfall stands at about 3.100 mm \pm 1.100 (Suh *et al.*, 2008). The mean annual temperature is approximately 26 °C and shows only limited variations of approximately 4°C throughout the year (Suh *et al.*, 2008). The relative humidity varies between 70 and 80% while the annual sunshine lies between 900 to 1200 hours. Such conditions are favorable for maize cultivation. The rocks are dominantly basaltic and the soils are basically volcanic (Yerima and Van Ranst, 2005) also making them suitable for agriculture. The later reported that due to the generally hilly nature of the area, these soils are well drained and have also been weathered and partly covered by more recent deposits. Major crops cultivated in the area include tomatoes, cabbage, okro, pepper, corn, cocoyam, yams, cassava, plantains, beans, maize, vegetables and even some cash crops such as palm trees, cocoa and bananas.

In Buea Sub-Division like in most parts of Cameroon, maize is the principal staple food crop accounting for a significant proportion of calorie intake by the population. Apart from providing sustained and secured food supply in terms of high yields, it also

remains a significant boost to the income of the peasant farmers given that much of the maize yields are often sold in local and sub-regional markets (Nguh *et al.*,

2017). First season for maize cultivation runs from February to July while the second season runs from August to December.

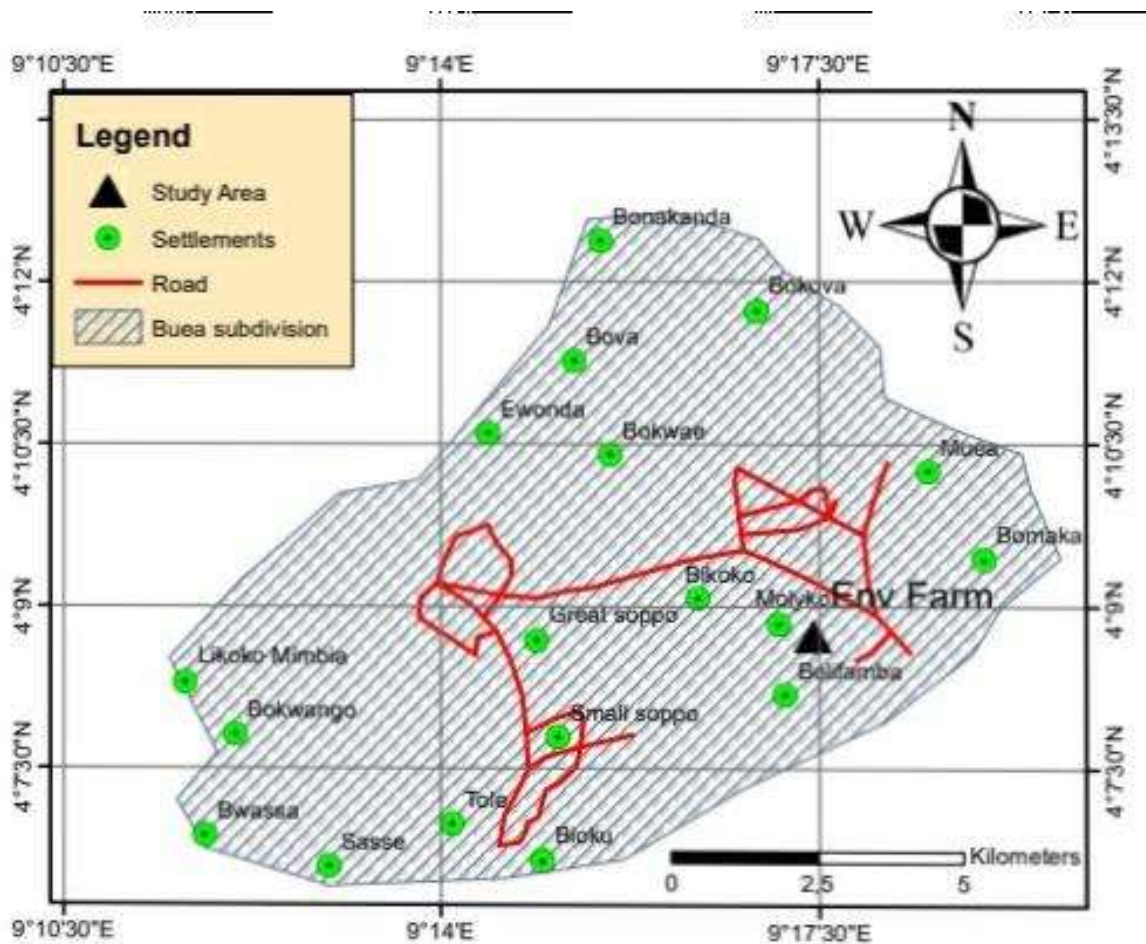


Figure 1: Map of the study area

2.1.2 Land Preparation and experimental design

A total land area of 484 m² was used for the experiment during the first cropping season of 2022 (as of March). The chosen plot had not been cultivated for two years. After clearing, residues (dominantly *Centrosoma pubescens* and *Pennisetum purpureum*) were left to dry. The area was then demarcated into 16 sub-plots, each

measuring 3 m x 3 m with a 2 m distance between each other to avoid side interactions. An experiment was laid out as a Randomized Complete Block Design (RCBD) with 4 treatments replicated 4 times. The treatments were 4 different residues management techniques dominantly practiced in the area: total residue removal (T1), complete burning (T2), surface mulching (T3) and incorporation (T4), (figure 2).

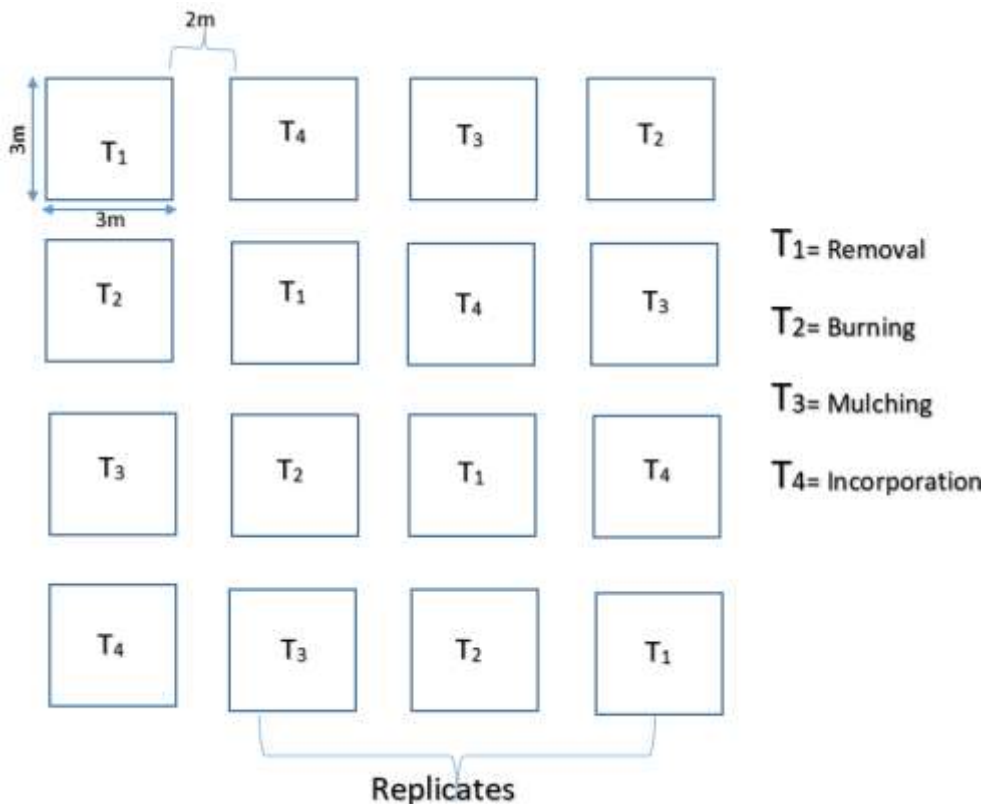


Figure 2: Experimental design showing plots layout

2.1.3 Treatment application

The residues left were herbaceous materials that easily decompose. For surface mulching and incorporation, the residues were pre-treated by chopping into fine materials to ease decomposition. Mulching application was by spreading the chopped residues evenly on the soil surface (no tillage was done to this treatment). For incorporation, soil was tilled and the chopped residues were incorporated. For burning, the residues were spread evenly on plots and then burnt. For total removal the residues were completely removed off the

experimental plots leaving the soil surface bare. The same estimated amount of residues were used for mulching, incorporation and burning (figure 3)

The CMS 8704 maize variety (recommended for the area) was purchased from the South West Regional Delegation of the Ministry of Agriculture and Rural Development. With a planting distance of 0.8m x 0.8m, 4 seeds were sown per hole. Three weeks after germination, the maize plants were thinned down to 3 plant per stand by removing the least performing ones. The entire area was kept weed free throughout the experiment through manual weeding.



Figure 3: Treatment application

Measurement of growth parameters

For plants sampling, 10 maize plants were selected in the middle rows of each plot and tagged for the measurement of growth parameters: Plant height (cm) was taken from the ground level to the last leaf. The mean height was taken as the score for each plot. The number of leaves per plant was determined by counting the total number in the 10 plants randomly selected and the average score was noted. The stem diameter (mm) was taken as the diameter of the stem measured to the nearest millimetre at the base of the maize plant from the 10 randomly selected plants. The mean stem diameter score for each plot was computed.

Measurement of yield parameters

The number of ears per plant was recorded from the count of ten randomly selected plants in the middle rows on each plot at crop harvest. The ear diameter was measured from the 10 representative ears using a veneer calliper and the average value was recorded for each plot. The number of grain lines were counted on the 10 representative ears and the average value was recorded.

The number of grain rows per ear was determined by counting the number of grains per lines from ten representative ears and the average. The number of grains per ear was calculated by multiplying the number of lines per ear by the number of grains per

line and the average was recorded for the plot. The weight of 1000 grains were counted from the 10 representative ears and weighed using an electronic balance. The weight is adjusted to 12.5% moisture content. The grain yield was calculated using the formula proposed by Tandzi and Mutengwa (2020). It is stated as follows; Yield (kg/ha) = [(number of kernel rows per ear × number of ears per m²/100) × (weight of 1000 – kernel (g)/1000) × 10,000]

2.1.4 Soil sampling

For each treatment, an improvised metal ring was carefully driven into an undisturbed soil using a hammer to collect soils in order to determine the bulk density. The samples were dried in an oven regulated at 105°C to constant weight. The bulk density was then calculated using the formula

$$\text{Bulk density } \left(\frac{g}{cm^3} \right) = \frac{\text{Oven dried weight (g)}}{\text{Soil volume (cm}^3\text{)}}$$

The samples used for bulk density were equally used to determine the moisture content, which was calculated as;

$$\text{Moisture content} = \frac{\text{wet weight} - \text{dry weight}}{\text{dry weight}} \times 100\%$$

Surface soil samples were also collected from the different plots before treatment application and just before harvest. They were collected from the rooting zone of maize (0 to 20 cm). From each plot, the samples were randomly collected from four different spots using a hand trowel. These four samples were collected at the edge of a zig-zag pattern laid on the plot. They were then pooled to form a composite sample. The samples were air-dried sieved through a 2 mm sieve and analyzed in duplicates for their physical and chemical properties in the Soil, Water and Plants Laboratory of the University of Dschang Cameroon using standard methods. Particle size distribution was determined using Bouyoucos hydrometer method (Pawels *et al.*, 1992). Soil pH (1:2.5 w/v soil solution ratio) in water was determined by the use of glass electrode pH-meter (Pawels *et al.*, 1992). The Walkley and Black method was used for organic carbon determination. Modified Kjeldahl distillation method (Pawels *et al.*, 1992) was used to determine soil total nitrogen. The determination of available phosphorus was achieved with Bray 2 method (Pawels *et al.*, 1992). The cation exchange capacity (CEC) was determined using the procedure of Anderson and Ingram as grossly described by (Pawels *et al.*, 1992) and then expressed in Cmol (+)/kg of soil. Potassium (K) and sodium (Na) in the extract were determined using flame photometer and magnesium (Mg) and calcium (Ca) were determined by complexometric titration. Exchangeable acidity was determined by the method of Juo as described by (Pawels *et al.*, 1992).

2.2 Data analysis

The data collected in the study was subjected to descriptive and inferential statistics using Microsoft Excel version 2013 and SPSS statistical package version 20.5. Descriptive statistics includes the use of tables, bar charts, pie charts, frequencies, percentages, means, etc. Inferential statistics includes the use of correlations, regressions, etc.

3.0 RESULTS

3.1 Effect of farm residue management on soil physico-chemical properties

The percentage change of the different physicochemical properties varied considerably under the different residues management techniques (Table 1). Average bulk density increased by 3.4% (0.88g/cm³ to 0.91g/cm³) and 1.05% (0.95g/cm³ to 0.96g/cm³) after total removal and burning respectively whereas it decreased by 8% (0.88g/cm³ to 0.81g/cm³) and by 8.9% (from 0.9g/cm³ to 0.82g/cm³) after mulching and incorporation, respectively.

From the study, average soil moisture content increased in an ascending order from total removal by 38.9% (i.e. from 34.02 to 47.25%) < burning by 46.4% (ranging from 33.98 to 49.73%) < incorporation by 63.1

% (ranging from 31.15 to 50.8%) < mulching by 69.5% (from 34.64 to 58.72%). Moisture retention was thus significantly better in mulching and incorporation compared to total removal and burning with mulching having 6.5% better moisture content than incorporation.

Comparatively, there was a slight variation in pH (in water) after total removal, mulching and incorporation contrary to the 9.1% increase (ie from 6.28 to 6.85) was recorded after burning. Average pH only decreased by 0.8% after total removal (6.18 to 6.13) and incorporation (6.40-6.35) while it only increased by 0.8% (6.25 to 6.30) after mulching.

Average soil OC content was observed to decreased significantly by 40.4% (from 1.36 to 0.81%) after total removal and slightly by 2% (from 1.51 to 1.48%) after burning while it increased significantly by 30.6% (1.68 to 2.19%) after surface mulching and by 24.3% (1.36 to 1.69%) after incorporation. In comparison, mulching increased average soil OC contents by 6.1 better than incorporation respectively whereas total removal reduced average soil OC by 38.4 than burning, respectively.

The average total nitrogen (N) increased by 26.3% (0.19 to 0.24%) after burning, 80 % (0.20 to 0.36%) after mulching and 69.2% (0.13 to 0.22%) after incorporation while it decreased by 9.1% (0.22 to 0.20%) after total removal at the end of the experiment. The increase in total N with mulching was 10.8% and 53.7% higher than with incorporation and burning, respectively. In general percent change in total nitrogen stood in the order of total removal < Burning < incorporation < surface mulching.

The average soil calcium (Ca) content increased significantly after all four treatments. The percentage increase were 104 % (1.74 to 3.55 Cmol (+)/kg) after total removal, 196.4% (1.37 to 4.06 Cmol (+)/kg) after burning, 107.2% (2.07 to 4.29 Cmol (+)/kg) after mulching and 116.8 % (1.84% to 3.99 Cmol (+)/kg) after incorporation. The lowest increase in Ca was therefore recorded after total removal while the highest increase was recorded after burning relative to the other treatments.

The different crop residues management techniques also significantly affected the soil magnesium (Mg) content at different extents. The average magnesium concentrations increased by 24.3% (from 0.7 to 0.87 Cmol (+)/kg) after total removal, by 51.5 % (0.33 to 2.15 Cmol (+)/kg) after burning, 78.7 % (0.89 to 1.59 Cmol (+)/kg) after mulching while it decreased by 44.3% (0.88 to 0.4 Cmol (++)/kg) after incorporation. Again, increase in Mg levels was highest with burning and lowest with total removal relative to the other treatments.

The average potassium content increased significantly across all four treatments at the end of the experiment. The percentage increase were; 821 % (0.19 to 1.75 Cmol (+)/kg) for total removal, 1189 (0.19 to 2.45 meq/100g) for burning, 945 % (0.20 to 2.09 Cmol (+)/kg) for mulching and 613 (0.22 to 1.57) for incorporation.

All four treatments recorded reductions in average soil sodium content at the end of the experiment.

The percentage decrease were; 71.2% (0.52 to 0.15 Cmol (+)/kg) for total removal, 46.2 (0.26 to 0.14 Cmol (+)/kg) for burning, 26.3% (0.19 to 0.14 Cmol (+)/kg) for mulching and 29.4 % (0.17 to 0.12 Cmol (+)/kg) for incorporation.

The average available phosphorus for burning increased by 80.5 % (33.41 to 60.29 mg/kg) for burning, 0.83 % (40.73 to 41.07mg/kg) for mulching and 10.7% (37.04 to 41.01 mg/kg) for incorporation while it

decreased by 12 % (35.72 to 31.43mg/kg) for total removal at the end of the experiment.

The average cation exchange capacity (CEC) significantly decreased in all treatments at the end of the experiment. The percentage decreases were; 28.9 % (21.25 to 15.11 Cmol (+)/kg) for total removal, 30.5 % (22.25 to 15.46) for burning, 33.4 % (22.25 to 14.82) for mulching and 31.2 % (22.25 to 15.30).

Table 1: Physicochemical properties of soils before and after (at harvest) treatment application

Physico-chemical properties	Period	TREATMENTS							
		Removal	% change	Burning	% change	Mulching	% change	incorporation	% change
Bulk density (g/cm ³)	Before	0.88	3.4	0.95	1.05	0.88	- 8.0	0.90	- 8.9
	After	0.91		0.96		0.81		0.82	
Moisture content (%)	Before	34.02	38.9	33.98	46.4	34.64	69.5	31.15	63.1
	After	47.25		49.73		58.72		50.80	
Texture (%)									
clay	Before	32.19	- 34.4	31.75	-33.4	31.56	- 34.7	31.50	- 37.3
	After	21.13		21.13		20.62		19.75	
silt	Before	30.81	-19.2	31.50	- 25.8	32.56	- 16.1	32.38	- 28.6
	After	24.88		23.37		27.31		23.12	
Sand	Before	37.25	45.0	37.00	50	35.88	45.1	36.13	58.1
	After	54.00		55.50		52.06		57.13	
Soil Reaction									
pH-water	Before	6.18	- 0.8	6.28	9.1	6.25	0.8	6.40	- 0.78
	After	6.13		6.85		6.30		6.35	
pH-KCl	Before	5.45	- 5	5.68	1.2	5.45	- 7.8	5.58	- 10.4
	After	5.18		5.75		5.08		5.00	
Organic matter									
OC (%)	Before	1.36	- 40.4	1.51	- 2.0	1.68	30.6	1.36	24.3
	After	0.81		1.48		2.19		1.69	
OM (%)	Before	2.35	- 40.4	2.61	- 2.3	2.91	29.9	2.35	24.3
	After	1.40		2.55		3.78		2.92	
Nitrogen tot. (%)	Before	0.22	- 9.1	0.19	26.3	0.20	80	0.13	69.2
	After	0.20		0.24		0.36		0.22	
C/N	Before	4.46	- 5.4	8.25	-25.2	9.67	- 30.8	11.62	- 33.0
	After	4.22		6.17		6.69		7.78	
Ca ²⁺ (Cmol (+)/kg)	Before	1.74	104.0	1.37	196.4	2.07	107.2	1.84	116.8
	After	3.55		4.06		4.29		3.99	
Mg ²⁺ Cmol (+)/kg	Before	0.70	24.3	0.33	551.5	0.89	78.7	0.88	44.3
	After	0.87		2.15		1.59		0.49	
K Cmol (+)/kg	Before	0.19	821.1	0.19	1189.5	0.20	945	0.22	616.3
	After	1.75		2.45		2.09		1.57	
Na ⁺ Cmol (+)/kg	Before	0.52	-71.1	0.26	- 46.2	0.19	- 21.1	0.17	- 29.4
	After	0.15		0.14		0.15		0.12	
CEC pH7 Cmol (+)/kg	Before	21.25	- 28.9	22.25	- 30.5	22.25	- 33.4	22.25	- 31.2
	After	15.11		15.46		14.82		15.30	
Bases Saturation (%)	Before	14.91	181.2	9.80	482.2	15.22	259.9	13.98	189.1
	After	41.93		57.06		54.77		40.42	
available phosphorus (mg/kg)	Before	35.72	- 11.9	33.41	80.5	40.73	0.83	37.04	10.7
	After	31.48		60.29		41.07		41.01	

3.2 Maize growth and yield under different farm residue management techniques

3.2.1 Maize growth attributes

At the end of the experiment, mulching recorded the highest (13.8) average number of leaves per plant while total removal recorded the lowest (12.8) (Figure 4a). The average number of leaves per plant were in the order of mulching > incorporation > burning > total removal but not significantly different.

Stem diameter slightly varied across the different techniques of residues management (figure 4b). Mulching recorded the highest (26.5 mm) average stem diameter while total removal recorded the lowest (22.2 mm). Average stem diameters were in the descending order of surface mulching >

Incorporation > burning > total removal but with no significant difference ($P=0.07$) at 5% probability level.

As shown on figure 4c, the highest (277.8 cm) average plant height was recorded in the mulching treatment while total removal recorded the least (252.5cm). In general, plant heights were in the order mulching > incorporation > burning>total removal but not significantly different ($P=0.16$).

3.2.2 Maize grain yield and yield components

From the study, figure 4d, highest (52.31 mm) average ear diameter were recorded in mulching while burning recorded the lowest (49.52 mm). In general average ear diameters stood in the order of mulching > incorporation > total removal > burning but at the 5% significant level, with no significant difference between the treatment ($P=0.32$).

Just as for ear diameter mulching recorded the highest (17.32cm) average ear length while total removal recorded the lowest (16.04cm) figure 4e. The average ear length were in the order mulching>incorporation>burning>total removal with no significant difference ($P=0.75$) at the 5% probability level. Furthermore, from figure 4f mulching equally recorded the highest (15.0) average number of grain lines per ear while total removal recorded the lowest (13.7). The average grain lines per ear were in the order mulching>incorporation>burning>total removal with no significant difference ($P=0.06$). The average number of

grains per ear were in the order of mulching> total removal>burning>incorporation with no significant difference ($P=0.3$). Mulching recorded the highest average number of grains per ear (520) while incorporation recorded the lowest (454.3) figure 4g.

As shown in figure 4h, incorporation recorded the highest (233.9g) average thousand grain weight while total removal recorded the lowest (228.6 g). The average thousand grain weight was in the order incorporation>mulching>burning>total removal with no significance ($P=0.94$). From figure 4i mulching recorded the highest (2081.5kg/ha) average maize grain yield while total removal recorded the lowest (1886.8kg/ha). Average maize yields were in the order mulching>incorporation>burning>total removal with no significant difference ($P=0.37$) between them.

3.2.3 Relationship between selected soil physicochemical properties and yield

In order to understand how selected soil properties influenced maize grain yield and which property influenced it the most, the selected properties and grain yields under different residue management methods were plotted as a scatter diagram and regression equation established and the R^2 values were reported.

The results showed a negative relationship ($R^2 = 0.4572$, $r = -0.68$) between average bulk densities and grain yields figure (5 a). A very strong positive relationship ($R^2 = 0.9109$, $r = 0.95$), which is significant was obtained between moisture content and yield (figure 5b). Similarly, a highly significant positive relationship ($R^2 = 0.9976$, $r=0.997$), was obtained between grain yield and OM (figure 5 C), Total nitrogen also showed a positive relationship ($R^2 = 0.6608$, $r = 0.81$) with yield figure 5 d, which is non-significant.

The average pH-water and grain yields under the different residues management showed a very weak positive relationship ($R^2 = 0.0358$, $r = 0.19$) figure 5 e. The average available P and grain yields under the different residue also showed a weak positive relationship ($R^2=0.0774$, $r=0.29$), which is non-significant figure 5 f. On the contrary, Ca and grain yield showed a very strong positive relationship ($R^2 = 0.9178$, $r=0.96$) figure 5 g.

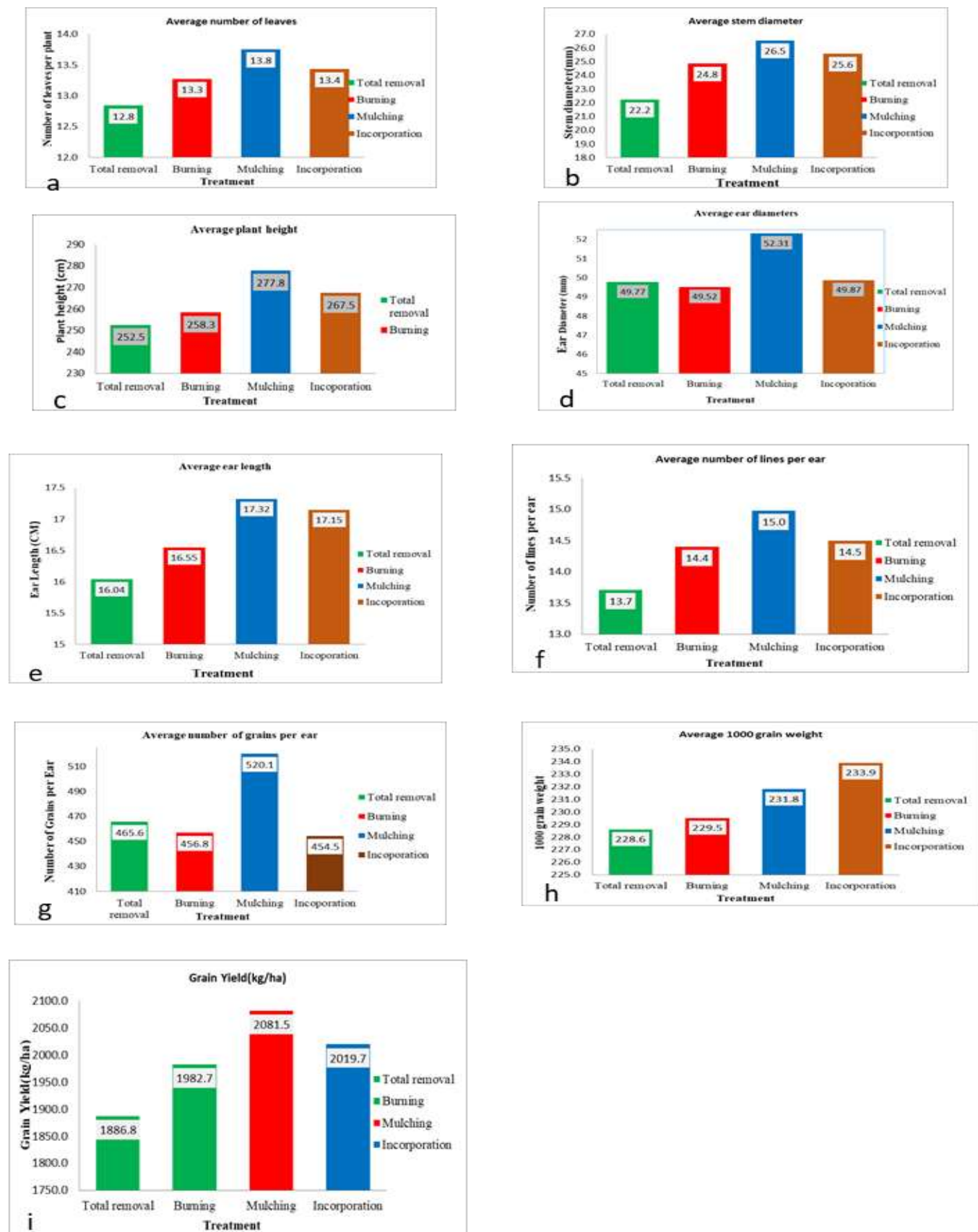


Figure 4: Average a) number of maize leaves b) maize stem diameter c) maize plant height d) maize ear diameter e) maize ear length f) grain lines per ear g) maize grains per ear i) maize yields under different farm residues management techniques.

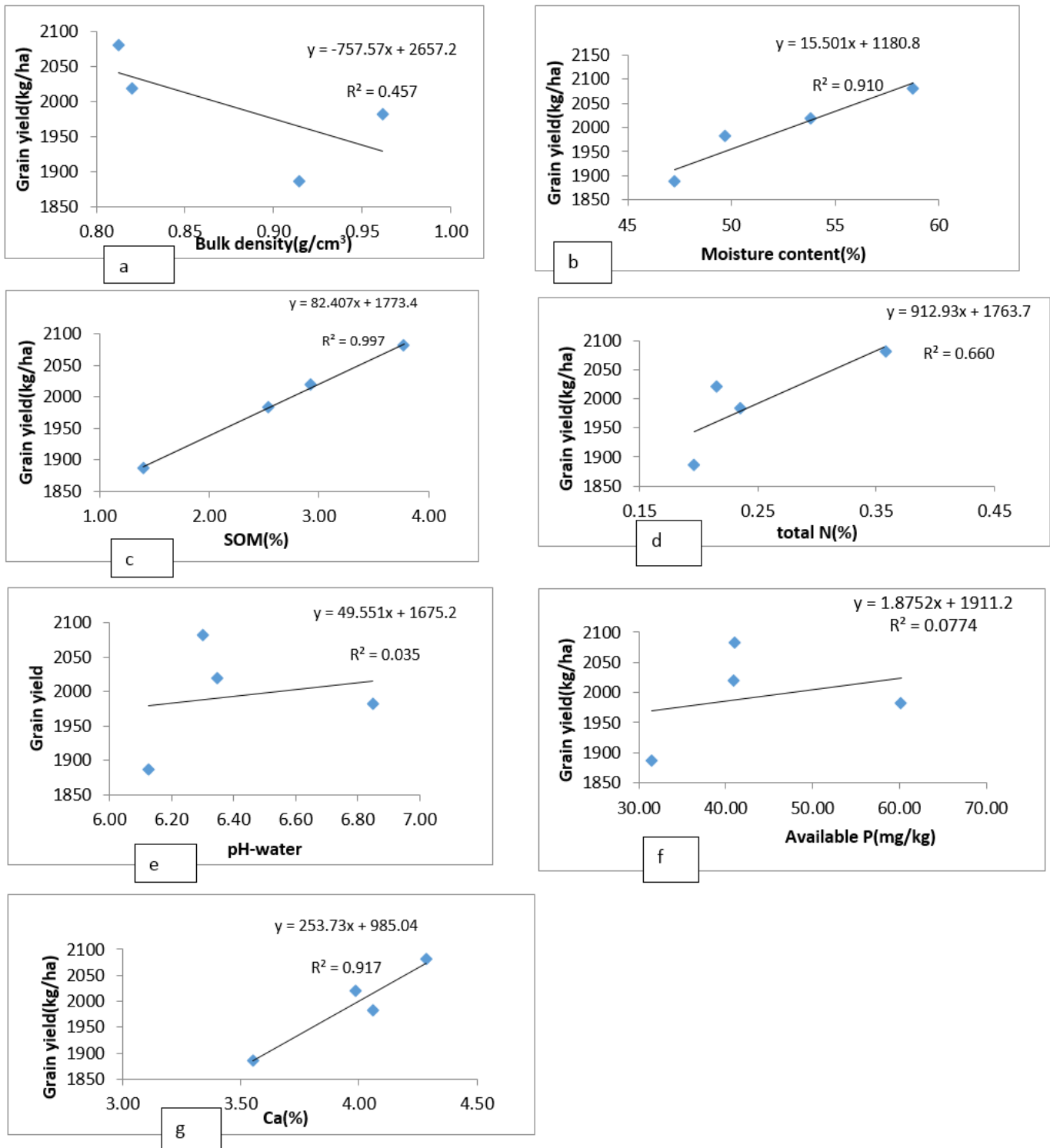


Figure 5: Relationship between a) bulk density b) moisture content c) SOM d) Total N e) pH f) available P and g) Ca and yield.

4.0 DISCUSSIONS

4.1 Effect of farm residue management techniques on soil physicochemical properties

Although not significant, the increase in average soil bulk density by 0.03g/cm³ after total residue removal could be

associated to the fact that residues removal exposes soils to the severe impact of raindrop leading to densification of surface layers (Blanco-Canqui and Lal, 2009). This result is in line with that of Blanco-Canqui *et al.* (2006) who reported that stover removal at rates of 50% increased bulk density by 0.15 mg/ m³ in no till silt loams in Ohio after one year. Similarly, the increase in

average soil bulk density by 0.01g/cm^3 after burning within one cropping season may be attributed to the loss of organic matter after burning which results to the destruction of soil structure and hence increased bulk density of the soil. The findings of this study contradicts those of Kumar *et al.* (2023) who observed that residue burning reduced bulk density by 15.4%. On the other hand, the decrease in average soil bulk density by 0.07g/cm^3 after mulching with residues may be ascribed to the fact that mulch protects the soil from direct rain impact (Mulumba and Lal, 2008). In a similar manner, decomposed residues from mulch reduce bulk density because soil organic matter has lower density than mineral fraction (Blanco-Canqui and Lal, 2009) and this result is in line with that of Cherubin *et al.* (2021) who reported that mulching with grass reduced bulk density by 1.10g/cm^3 . Also, average bulk density decreased by 8.9% after residue incorporation which could be attributed to probable microbial activity and residue decomposition with products that favours more aggregation and thus reduces bulk density. This result is in strong agreement with Singh *et al.* (2019) who reported that soil bulk density decreased by 6.92 % due to the incorporation of residue though after four years. Generally, residue incorporation enhances infiltration and hydraulic conductivity and increased water content and plant available water.

The significant increase in average soil moisture content across all treatments can be partly accounted for by rainfall (measurement before treatment application was done when it was dry season and after application when it was rainy season). Although soil moisture content increased after for all treatments, mulching and incorporation recorded higher moisture content values in comparison to total removal and burning. Higher moisture retention in residue amended plots (mulching and incorporation) in comparison to total removal and burning could be associated to reduced evaporation rates (Mandal *et al.*, 2004) as coverage reduces direct impact of radiation. Furthermore, residue-derived soil organic matter also has the potential to interact with soil matrix thereby increasing the specific surface area essential for the adsorption and retention of water molecules (Ramteke *et al.*, 2018). On the contrary, bare soils easily lose moisture upon the removal of a protective coverage (Blanco-Canqui and Lal, 2009). These findings corroborate with those of Mirzaei *et al.* (2021) who reported that residue treated plots either with no tillage (surface retention) or conventional tillage (incorporation) significantly improved soil moisture content in comparison to plots with no residue. In addition, between the 2 residue amendments mulching had a slightly better moisture content retention compared to incorporation which means that mulching is more efficient in conserving soil moisture content because mulch enhances the formation of a thin air-dry laminar layer on the top of bare soil, which hinders turbulent vapour exchange between the soil and atmosphere (Singh *et al.*, 2019). and also covers more soil surface compared to incorporation. Raffa *et al.* (2015), also

supported that more soil water conservation is achieved when the same quantity of residue material is used as mulch compared with that incorporated into the soil.

The average pH-water changes for total removal, mulching and incorporation were non-significant as changes were 0.05-0.06. However, the average pH-water after burning increased considerably by 0.5 (9.6%) which could be attributed to the liming effect of ash that reduces soil acidity (Blanco-Canqui and Lal, 2009) and to consumption of hydrogen ions during the combustion of organic acids in soil. Similar result has been reported by Kaur *et al.* (2019) who observed that the mean value for pH of soil samples increased significantly from 7.94 to 8.46 after burning.

Treatments significantly affected soil organic carbon contents variably. According to Raffa *et al.* (2015), plant residues have multiple functions to soil when SOC is concerned; it is a major source of organic C, it is an operative pathway reducing SOC losses by the processes of wind or water erosion. Furthermore, it stabilises soil temperature thereby reducing organic matter decomposition (especially when applied as mulch) (Kaur *et al.*, 2019). These processes could have principally accounted for the significant increases in the average soil organic carbon by 30.4 and 24.3% for mulching and incorporation, respectively.

The average total N was significantly improved for mulching, incorporation and burning. Increase in Total average N by 80 % % after mulching and 69.2 % after incorporation may be due to the decomposition of residues which release N to the soil. These results are in line with Alharbi, (2017) and Zhao *et al.* (2019) who in separate experiments reported higher Total N in mulched surface layers than un-mulched layers. Higher total N was recorded by mulching compared to incorporation and this agrees with the findings of Sinha *et al.*, 2018 who observed that total N concentrations were greater with surface placement than incorporation of residue. Also, the increase in average total N after burning could be because burning enhanced the release of nitrogen from the residues, increasing total-N content. Several studies have also reported an increase in nitrogen after fire (Mirzaei *et al.*, 2021).

The average soil sodium content decreased across all treatments with total removal recording the highest reduction (72.1%) compared to burning, mulching and incorporation. The reduction in sodium levels after burning and total removal of residues could be attributed to leaching since Na is weakly held by the soil colloid. 17. Mirzaei *et al.* (2021) similarly observed a reduction in Na level in burnt area..

Plant residues are an important reservoir of essential macronutrients (e.g., K, P, N, Ca, and Mg) and micronutrient (e.g., Fe, Mn, B, Zn, and S) pools (Blanco-Canqui and Lal, 2009). Plant residues are decomposed by various soil organisms thereby releasing these nutrients to the soil which accounts for increase in K, available P, Ca and Mg levels after residue retention either through mulching or incorporation as shown in the results of this study. Also, soil nutrients may increase after burning with

intensity fires since fire chemically converts nutrients bound in dead plant tissues and the soil surface to more available forms or the fire indirectly increases mineralization rates through its impacts on soil microorganisms (Mehmood, 2017). This probably accounts for the significant increase in K, available P, Ca and Mg levels after burning as shown in the results of this study. The increase in average K after burning may be due to ash deposition by fire which contains large amount of potassium and this agrees with the findings of Chungu *et al.* (2020) who reported that one year after fire, K increased 2.5 times from 22.5 meq on unburned sites to 57.0 meq on burned sites but decreased in subsequent years. Also, the increase in average K after residue incorporation agrees with the findings of Zhao *et al.* (2019) who reported that straw incorporation significantly increased the soil available K, soil depths of 0–20 cm averagely by 64% on sandy, loamy soils. The significant increase in available K after mulching with residues conforms to the findings of Alharbi, (2017) who reported that mulch treatment significantly increased available K by 27.6 and 20 % in the beginning and end of season respectively.

The 12 % decrease in average available P after total removal of residues may be due to loss through erosion or reduction in nutrient pools since residues which are main reservoirs have been removed from soil. This result agrees with Mohammed *et al.*, (2020) who observed that in the U.S, stover removal at about 40% reduced P by 14%. Similar reports in the later area by Blanco-Canqui and Lal (2009) indicating that complete stover removal reduced available P concentration by 20 mg kg⁻¹ on the sloping silt loam in the 0- to 20 cm soil depth. The huge increase (by 80.5%) in average available P after burning may be due to the deposition of ash at the end of the process. Tabi *et al.* (2013) working in Nigeria also observed similar patterns in available P increase immediately after burning. The increase in average available P after mulching and incorporation may be due to decomposition of residue because during the decomposition of residues, a series of low molecular weight organic acids may be released, improving the availability of P in soil and reducing the nutrient-adsorption capacity of clay minerals. Raffa *et al.* (2015), reported that residues incorporation increased available P by organic matter decomposition and release of P during this process along with desorption of rock phosphate by increasing the organic acids in soil.

Average soil CEC decreased significantly by 28.9-33.4% after all treatment applications. Blanco-Canqui and Lal (2009) observed that CEC decreased with increase in rate of stover removal in the three soils in Ohio.

Generally, in conventional tillage system, due to soil disturbance by plough, higher oxidation and decomposition residues could not make a significant contribution to macronutrients (Mirzaei *et al.*, 2021). Therefore larger amounts of residue are needed to improve the nutrient status in this system. In minimum/no till systems, the retention of minimal quantities of

residues is significant to increase soil macronutrients, reflecting better decomposition circumstances under the no till system. Thus implying that the release of soil nutrients is less in incorporation than mulching as observed in incorporation in this study.

4.2 Maize growth and yield under different farm residue management techniques.

The results of this study showed that there was no significant difference ($P>0.05$) in maize growth parameters and yield components between the different farm residue management techniques. This could be ascribed to fact that the only one season duration of residue management practices since the effects of these management techniques on growth and yield are not always felt in short term but rather in long term application. Nevertheless, the small differences in maize growth and yield parameters must be addressed in order to find the most suitable farm residue management technique to improve agronomic production.

The higher values in average plant height, number of leaves and stem diameter with burning, mulching and incorporation compared to total removal could be attributed to the nitrogen levels in these management practices. Nitrogen is considered the limiting nutrient for agricultural productivity due to its requirements for plant growth in large quantities but also because soils, particularly in the tropics, are almost always N-deficient. Nitrogen captured by maize plants accumulates in stems and leaves, promoting photosynthesis and growth yield. Many studies have reported Nitrogen to be the most limiting nutrient for maize growth followed by Phosphorus and then Potassium (Ciampitti and Vyn, 2012; Mehmood, 2017). Another factor that could have contributed to better plant growth is soil moisture content because if moisture is very low and subsequent transpiration is too high, the plant closes its stomata openings to minimize water loss and wilting which means photosynthesis is slowed and subsequently plant growth. Therefore, it is safe to say that better moisture content observed in plots with mulching and incorporation could be one of the major reasons for the slightly better maize growth in mulching and incorporation when compared to burning and total removal. Also, higher maize growth in mulching and incorporation could be attributed to better control of weeds in early growth stages of crop which provided the crop plants with better environment for utilizing growth resources efficiently resulting in better growth. Higher growth with burning, mulching and incorporation has also been reported by Mbah and Nneji (2011) who observed that the plant (maize) height values in the residue management treated plots in the first cropping season were 14.2, 10 and 13% for surface mulch, burning and incorporation and slash and incorporation higher than the control (with no residue) respectively. In a four years study on rice carried out at Krishi Vigyan Kendra, by Singh *et al.* (2019), plant height was 10 cm and 3cm higher with incorporation and burning relative to removal,

respectively. Better moisture retention and microclimate under residue mulch might be the reason for improved growth parameters compared to incorporation. Chime *et al.* (2020) reported that mulching with elephant grass recorded higher number of leaves, plant height, and stem girth compared to the control (no mulch).

Growth parameters (plant height, number of leaves and stem diameter) play the most important role contributing to the grain yield, biological yield and ultimately the economics of maize (Khedwal *et al.*, 2018). This means that higher maize growth parameters will most likely translate to higher grain yield. The results showed that average grain yield in mulching was 10% higher than total removal. Singh *et al.* (2015) also reported that maize had significantly higher grain yield and stover yield in the plots under mulching. The 6.1% higher average grain yield in incorporation compared to total removal agrees with results of with Shafi *et al.* (2007) who reported that crop residues incorporation significantly increased grain yield of maize compared with the residues removed treatment.

4.3 Relationship between selected soil properties and yield under different residue management techniques

The strong negative relationship between bulk density and grain yield means higher bulk density contributed to lower grain yield. This could be ascribed to the fact that with high bulk density, the roots of plants will dominantly remain shallow, resulting to poor growth, reduced vegetative cover to protect the soil from erosion. It also affects soil aeration which influence the uptake of water and nutrients and thus yield.

Also, strong significant positive relationship between moisture content and grain yield is indicative that soil moisture content promotes grain yield. Therefore, the higher soil moisture contents in mulching and incorporation had a contribution to the slightly higher grain yields recorded by these practices.

Similarly, the significant very strong relationship between SOC, grain yield means SOC significantly affected grain yield. This implies that, the increase in SOC after mulching and incorporation contributed to higher grain yield recorded by these practices relative to total removal and burning. Kumar *et al.* (2024) had similarly established inverse relationship between crop yield and bulk density.

The strong positive relationship between total N and yield means total N contents had a positive effect on grain yield which was though not significant. The positive influence is related to the fact that high soil N content, which provides an adequate nitrogen source or translates into more available N to be extracted by plants, could significantly enhance plant N uptake and thus improve crop productivity. Similar findings have been reported by Kumar *et al.* (2024).

Generally, the results showed that maize grain yield was significantly affected by soil moisture content, SOC and Ca contents.

CONCLUSION

The study concludes that the retention of farm residues in soil either by surface mulching or incorporation exerts favourable effects on some soil physical and chemical properties which are: improvement (decrease) soil bulk density, increase of moisture content, organic matter contents, total nitrogen, available phosphorus, potassium, calcium and magnesium levels whereas complete removal of residues from soil has detrimental effects to soil such as increase bulk density, lower moisture content, reduction in organic carbon and organic matter contents, total nitrogen and available phosphorus. Maize growth and grain yield is better with farm residue retention (mulching and incorporation) than total removal and burning. Mulching is the best farm residue management technique in terms of improvements in soil physicochemical properties and thus maize growth and yield. The increase in maize growth and grain yield by farm residue retention is not significant with short term application as well as the improvement of some soil properties. The study recommends that mulching practices with plant residues should be adopted by farmers in the Buea municipality as the best method to manage farm residues in order to promote material recycling, improve soil quality with a positive effect on crop yield. This also reduces farmers' dependency on chemical fertilizers which are costly and misuse degrades soil in long run.

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Authors' contribution

This work was carried out in collaboration with all authors. Author GAA, IBB, MAF, AST designed the study. MAF collected the data. AGA performed the statistical analyses and co-wrote the draft with the assistance of other authors. All read and approved the final manuscript.

Competing Interests

Authors have declared that no competing interests exist.

Data Availability

Data for this study is available upon reasonable request from the corresponding author.

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