



Improving soil physico-chemical properties and maize (*Zea mays*) performance under coastal savanna condition with different organic mulches

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Abstract

Application of organic mulching is a current management practice that seeks to improve soil moisture conservation, increase soil fertility and crop production. The study was carried out to quantify the effect of different organic mulches on some soil properties at three crop stages and maize production under coastal savanna condition. Four treatments of mulch; maize stover (MS), dry grass straw (GS), palm frond (PF) mulches at 3 Mg ha⁻¹ each and no-mulch (NM) (control) with three replications were laid out in a complete randomized block design. After two consecutive cropping seasons, different organic mulches had no significant effect on the examined soil properties at the seed emergence stage. However, at both tasseling and harvest stages, the differences of bulk density, total porosity, organic carbon content and macro-nutrients (NPK) among the treatments were significant and were in the order of GS > MS > PF > NM. The germination rate was in the order of NM (91.0%) > MS (89.9%) > GS (86.8%) > PF (87.9%). The effect of mulches on both the plant height and the LAI was in the order of GS > MS > PF > NM. The increase in grain yield over the control were GS 18 %, MS 19 % and PF 14 % while that of the WUE relative to the control were 155 %, 122 % and 57 % for GS, MS and PF respectively. Dry grass mulch could be used to improve soil properties and achieve higher maize production in the study area.

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Introduction

Organic mulches can conserve soil moisture, mitigate soil erosion, improve soil conditions, suppress weed growth, and provide organic matter and plant nutrients in the soil (Bilalis *et al.* 2002; Jodaugienė *et al.*, 2006). Depending on the type of mulch material used, mulching preserves soil water, reduce soil temperature and consequently promotes seedling establishment and increases the seedling survival under extreme conditions mainly by reducing the soil surface exposure to direct solar radiation (Murungu *et al.*, 2011; Benigno *et al.* 2012; Woods *et al.*, 2012). Organic mulches can also improve physical, chemical and biological properties of soil, as they decompose and release nutrients to the soil (Carter, 2002). Youkhana and Idol (2009) noted that organic mulching increases organic matter through decomposition which in turn improves soil moisture conservation. Huang *et al.* (2008) and Chaparro *et al.* (2012) also observed that organic material for mulching increases soil organic matter content that can improve soil physical and chemical properties as well as the activities of the soil microbial community.

Organic mulching enhances soil environment and this increases crop growth and yield (Lal *et al.*, 1979). Yang *et al.* (2006) noted that organic mulching enhances crop growth and yield through improving water content of soil, heat energy and addition of nitrogen and other minerals that improve the nutrient status of the soil. Mahmood *et al.* (2011) also observed that organic mulching conserves soil moisture content by reducing evaporation which in turn mitigates the negative effects of water stress on plant growth and yield especially in semi-arid conditions.

In most developing countries, including Ghana, a large number of farmers rely on rainfall for their crop production and it is estimated that about 58 % of the world's food production comes from rain-fed agriculture (Rosegrant *et al.*, 2002; Rockström *et al.*, 2003). However, these countries in the tropics experience high evapotranspirative losses of soil moisture due to high temperatures. Many of the crops including maize which is a major staple food in these

tropical countries therefore suffer from water stress as a result of high evapotranspiration rate (Norman *et al.*, 2002; FAO, 2008). Besides soil water stress, low soil fertility and high cost of fertilizer account for low yield in maize production in these countries. According to Adu (1979) the soils for maize production in Ghana, are mostly low in organic carbon (< 0.2 %), available phosphorus (<10 mg kg⁻¹), total nitrogen (< 0.2 %) and also are prone to evaporative soil moisture loss as a result of high temperatures. In view of this, there is the need to control the loss of soil moisture through evaporation and also improve soil fertility. This can be achieved through organic mulching. In spite of the organic mulching benefits enumerated above, the potential of organic mulches to realize the full benefits for crop production depends on the type of the organic material used. Gruber *et al.* (2008) observed that there is no effect of wood chips as mulching on crop yield. The objective of the study, therefore, is to determine the effect of different organic mulches on soil physico-chemical properties as well as on the growth and yield of maize.

Materials and methods

Study site

The study was conducted at the School of Agriculture Teaching and Research Farm, University of Cape Coast in 2015 and repeated in 2016. The site is within the coastal savanna zone of Ghana and lies on latitude of 5.1° N and longitude 1.4° W, and is about 300 m A.S.L. The site experiences bimodal rainfall regime with the major rainy season between March and July, and the minor season between September and November with a dry season from December to February. The bimodal rainfall pattern gives rise to major and minor growing seasons.

The annual rainfall is between 900 -1000 mm (Asamoah, 1973; Asare, 2004). The temperatures are high throughout the year with the mean of 23.5 °C. The relative humidity is generally high and is about 90 -100 % during the night and about 70 % during the day (Asamoah, 1973; Asare, 2004). The soil belongs to Benya series which could be classified as Acrisol (FAO) or Ultisol (USDA) (Asamoah, 1973).

Experimental design and treatments

A complete randomized block design (CRBD) was used for the experiment. The treatments used were maize stover mulch (MS), grass straw mulch (DG), palm frond mulch (PF) and no-mulch (NM) which served as control, and each treatment was replicated thrice.

The land for the study was first cleared, ploughed and harrowed to obtain moderate soil tilth. Four blocks were then created and each block was subdivided into three plots, giving a total of 12 plots with each having a dimension of 3.0 m × 2.3 m. Small passages of 0.5 m width were created between the plots to allow easy movement for irrigation and other cultural practices. The mulches were cut into pieces and applied on the surface at 3 Mg ha⁻¹.

The test crop used was a local variety of maize called 'Obatanpa' which had early maturity period (80 - 85 days). Planting (direct sowing) was done on 05/03/2015, on the same day that the mulching was applied. Two seeds were hand-sown at a row-to-row distance of 90 cm and plant-to-plant distance of 40 cm. Each plot had 4 rows and each row had 6 hills into which the seeds were planted. After thinning, each plot had a total of 24 plants. Cultural practices such as weeding and irrigation were carried out as and when required.

The weeding was done mostly by hand picking and the irrigation was by the use of watering can. The irrigation was supplemental and was applied when there was less or no rainfall and the crops started showing signs of wilting (folding of leaves).

The amount of irrigation water used was based on the crop water requirement, ET_c, of the maize. Using Class A pan method, the ET_c was calculated by the equations (Allen *et al.*, 1998):

$$ET_o = K_p E_{pan} \quad (1)$$

$$ET_c = K_c ET_o \quad (2)$$

ET_o is reference evapotranspiration (mm d⁻¹), K_p is pan coefficient (-), E_{pan} is mean pan evaporation (mm d⁻¹), ET_c is the crop water requirement (mm d⁻¹), and K_c is crop factor (-).

The maize (Obatanpa) had a total growing period of 85 days, and the duration of the growth stages and their corresponding K_c values were as follows: the initial stage = 20 days, K_c = 0.4; crop development stage = 25 days, K_c = 0.8; mid-season stage = 25 days, K_c = 1.15; and late season stage = 0.7, K_c = 0.7 (Allen *et al.*, 1998).

Using a twenty year (1995 – 2014) pan evaporation obtained from an agro-meteorological station (No.: 0501/044/23) which was about 100 m away from the study site, the calculated monthly ET_c and the other evapotranspirative parameters for the growing period are shown in Table 1.

Soil sampling and analysis

Both disturbed and undisturbed soils were sampled within 15 cm depth (Gao *et al.*, 2010) at three stages of the maize growth: seed emergence, tassel and harvest. The soils were sent to Soil Science Department laboratory to analyze for bulk density, total porosity, moisture content, organic carbon, total nitrogen, available phosphorus and exchangeable potassium.

The bulk density was determined using the core method (Blake and Hartge, 1986). The soil moisture content was first determined using gravimetric method and then converted to volumetric moisture by multiplying the gravimetric moisture and the bulk density (Kutilek and Nielsen, 1994). The total porosity was calculated using the bulk density and the particle density of 2.65 g cm⁻³. The soil organic carbon was determined using the Walkley-Black method (Nelson and Sommers, 1982). The total nitrogen was determined by Kjeldahl digestion method (Bremner and Mulvaney, 1982) and the available phosphorus was determined using the Bray-1 method (Olsen and Sommers, 1982). The potassium (K) was determined using the flame photometer (Rhoades, 1982).

Measurement of maize growth, yield and water use efficiency (WUE)

The maize growth parameters measured were seed germination rate, plant height, leaf area index (LAI) and days to tassel.

The seed germination rate was determined after maize seed emergence (6 days after sowing) had ceased, by counting the number of germinated seeds on each treatment plot and expressed as a percentage of total number of seeds sown.

Six maize plants were randomly selected on each plot and tagged for the measurement of the other growth parameters starting from 2 WAP to 10 WAP. The maize height above ground was measured weekly and the mean height was calculated. Similarly, the lengths and widths of the leaves of the maize crops were measured and the leaf area index (LAI) was then calculated using the formula mentioned by Babiker (1999) as:

$$LAI = LL \times LW \times \frac{\text{no. of leaves}}{\text{plant}} \times 0.75 \times \frac{\text{no. of plants}}{m^2} \quad (3)$$

LL is leaf length (cm), LW is leaf width (cm), and 0.75 is correction factor.

The number of days for tasseling was counted as the days after planting that at least 50 % of the maize tasseled. The crop grain yield was also determined by harvesting the maize (when matured) on each plot, dehusked and the cobs were weighed. A sub sample of 6 cobs then were randomly selected and weighed. The 6 sub sample cobs were shelled, the grains were oven dried at 80 °C for 48 hours and then weighed. The grain yield (GY) was then calculated as:

$$GY (kg ha^{-1}) = \frac{(DG\text{Yof6cobs})}{(FW\text{of6cobs})} \times (TFW\text{ofcobs}) \times 1449.3 \quad (4)$$

DGYof6cobs is weight of dry grain yield of 6 sub sample cobs, FWof6cobs is weight of fresh 6 sub sample cobs, TFWofcobs is total weight of fresh cobs and 1449.3 is a factor to convert the plot area (6.9 m²) to a hectare.

The water use efficiency (WUE) was determined as the ratio of grain yield (kg ha⁻¹) to the amount of water supplied (total rainfall and irrigated water) as outlined by Sinclair *et al.* (1984). The rainfall amounts for the study period were also obtained from the agro-meteorological station (No.: 0501/044/23).

Data analysis

The data were statistically analyzed using Analysis of variance (ANOVA) component of Genstat discovery 4.10.5(win32) edition and the means were compared using least significant difference (LSD) at 5 % probability level.

Results and discussion

Soil physico-chemical properties response to mulching materials

The soil of the experimental field was sandy loam (sand = 78.4 %; silt = 9.0 %; clay = 12.6 %) and was slightly acidic with pH of 6.5. Table 2 shows some soil physico-chemical properties of the experimental field under different mulches at three maize (emergence, tasseling and harvesting) stages.

Table 1. Monthly maize crop water requirement and other evapotranspirative parameters during the growing period.

Month	E _{pan} (mm d ⁻¹)	K _p	ET _o (mm d ⁻¹)	K _c	ET _c (mm d ⁻¹)
March	11.6	0.70	8.12	0.40	3.30
April	9.50	0.70	6.65	0.90	6.00
May	6.70	0.70	4.69	0.90	4.20

E_{pan} is pan evaporation; K_p is pan factor; ET_o is reference evapotranspiration; K_c is crop factor; ET_c is crop water requirement.

Seed emergence stage

At seed emergence, there soil properties except

organic carbon and potassium showed no significant (p = 0.05) difference among the treatments.

This suggested that the spatial variability of the soil properties was minimal and also the period of the organic mulches application was too short for sufficient mulches decomposition to make any meaningful impact on the soil properties. Even though the soil organic carbon contents in all the plots were low because they were less than

2 % (John *et al.*, 2010, the soils could support the maize growth because the organic carbon contents were higher than 0.75 % (Sheoran *et al.*, 2010). Generally, the soils were low in N (< 2.0 %), adequate in P (< 100 ppm) and slightly moderate in K (> 0.30 cmol_c kg⁻¹) (Adu, 1995) (Table 2).

Table 2. Effect of different mulches on soil properties within 15 cm depth at three maize growth stages.

Maize stages of soil sampling	*Mulches	Bulk density (g cm ⁻³)	Total porosity (%)	Soil moisture (%)	Organic carbon (%)	Total nitrogen (%)	Available phosphorus (ppm)	Exch. Potassium (cmol _c kg ⁻¹)
Emergence	NM	1.50a	43.40a	7.30a	1.28a	0.06a	7.33a	0.40a
	MS	1.46a	44.91a	7.16a	1.45b	0.07a	7.33a	0.33b
	GS	1.47a	44.53a	7.18a	1.35c	0.05a	7.47a	0.43a
	PF	1.47a	44.53a	7.19a	1.32ac	0.06a	7.33a	0.43a
Tasseling	NM	1.49a	43.77a	4.00b	1.29a	0.05a	3.61b	0.47c
	MS	1.40b	47.17b	11.47c	1.51d	0.14b	10.23c	0.24d
	GS	1.34c	49.43c	7.87d	1.60e	0.22c	13.54d	0.74e
	PF	1.30c	50.94c	9.17e	1.89f	0.13b	9.29e	0.39af
Harvesting	NM	1.47a	44.53a	5.77f	1.37c	0.08a	5.26f	0.47c
	MS	1.33c	49.81c	11.87g	1.60e	0.15b	10.26c	0.24d
	GS	1.23d	53.58d	8.73h	1.76g	0.23c	13.94d	0.74e
	PF	1.38bc	47.92bc	9.27e	1.70h	0.14b	9.64e	0.39af
LSD(0.05)		0.040	1.65	0.203	0.045	0.036	0.667	0.036

*NM = No mulch; MS = Maize stover; GS = Dry grass straw; PF = Palm frond

In a column, figures bearing same letter(s) do not differ significantly at 5% probability level.

Tasseling stage

At tasseling stage of the maize, the average bulk densities for NM, MS, GS and PF plots were 1.49, 1.40, 1.34 and 1.30 g cm⁻³ respectively, and the corresponding average total porosity were 43.77, 47.17, 49.43 and 50.94 % (Table 1). On all the plots, there was a reduction of the bulk density with corresponding increase in total porosity from the crop emergence to tasseling, and the level of reduction was significantly (p = 0.05) greater on the mulched plot than the no-mulched plots. This could be as a result of decomposition of the organic mulches and the leaf falls of the maize crop which probably improved the structure of the soils. This corroborated with observation by Shepherd *et al.* (2002) that mulching on the soil lead to decrease soil bulk density and increase total porosity. The lower soil bulk density of the PF plots compared to MS and GS plots suggested that the palm frond quickly decomposed, thereby improving the soil structure earlier than the maize straw and the grass straw.

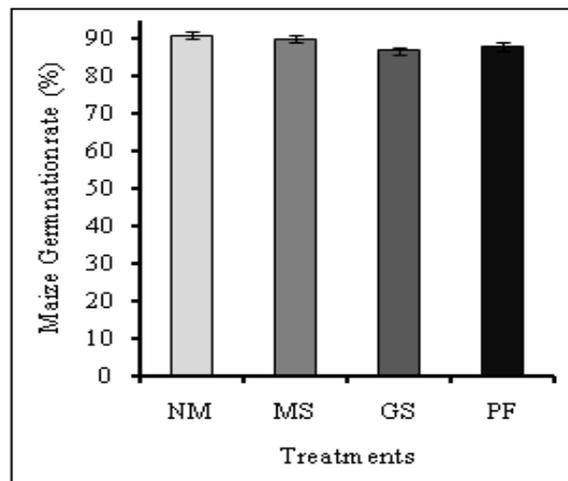


Fig. 1. Maize germination rate as affected by different organic mulches.

The average soil moisture recorded were in the order of MS (11.47 %) > PF (9.17 %) > GS (7.87 %) > NM (4.00 %). The average moisture contents were significantly (p = 0.05) different among the treatments. It was noted that all the mulches had higher moisture content than the plots with no-mulch.

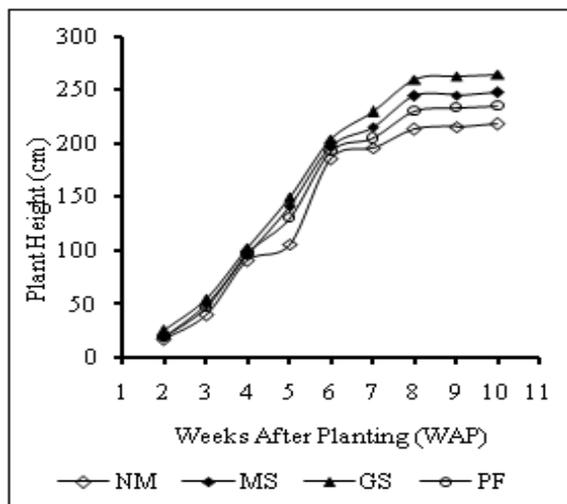


Fig. 2. Effect of organic mulches on maize height.

This corroborated with Carter (2002) who noted that organic mulching reduced soil water evaporation and therefore enhanced more retention of soil moisture. Studies conducted by Agele *et al.* (2000), Ghosh *et al.* (2006) and Fraedrich and Ham (1982) also showed that mulching with organic materials conserved soil moisture and consequently increased crop production.

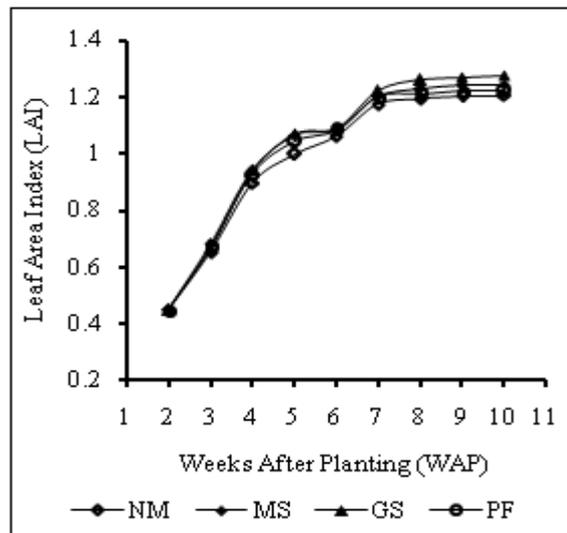


Fig. 3. Effect of organic mulches on maize LAI.

The average organic carbon content at the different treatments plots followed similar trend as the soil bulk density. The average organic carbon contents were in the order of PF (1.89 %) > GS (1.69 %) > MS (1.51 %) > NM (1.29 %). Yadav *et al.* (1995) and Astier *et al.* (2008) also observed an increase of soil organic carbon in plots covered with grass mulch.

The organic carbon content was significantly ($p = 0.05$) different among the plots. This higher carbon content in PF plots could be that the palm frond decomposed faster than the other organic mulch. The total nitrogen for NM, MS, GS and PF plots were 0.05, 0.14, 0.22 and 0.13 % respectively.

The effect of the mulching materials on the total nitrogen was not significant between MS and PF plots. However, significant ($p = 0.05$) differences existed between MS and PF on one hand and the other treatments. The total nitrogen for all the mulched treated plots increased from the crop emergence stage to tasseling stage. However, the total nitrogen for no-mulch plot decreased from the crop emergence stage (0.06 %) to tasseling stage (0.05 %) even though the difference was not significant. This suggested that the nitrogen from the decomposition of the crop leaf fall on the no-mulch plot alone was inadequate to compensate for the nitrogen loss through crop uptake.

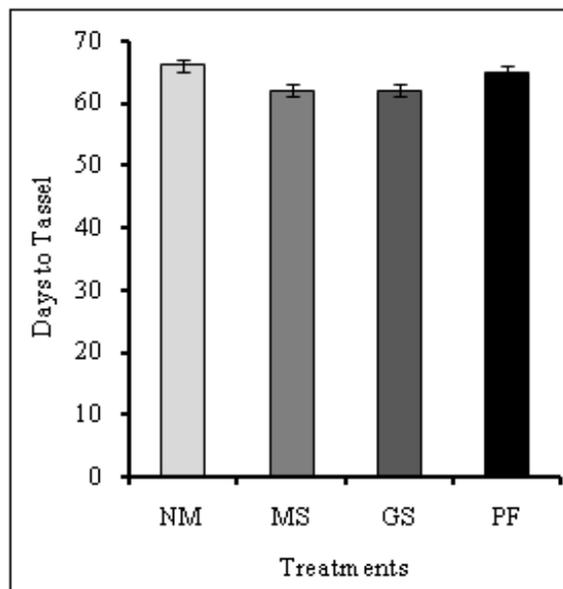


Fig. 4. Days to maize tassel as affected by organic mulches.

The average phosphorus content during the tasseling stage for treated plots were in the order of GS (135.40 ppm) > MS (102.29 ppm) > PF (92.94 ppm) > NM (36.12 ppm). Significant ($p = 0.05$) differences occurred among all the treatments. From Table 1, the phosphorus content in all but NM plots increased from emergence stage to tasseling stage of the crop.

The increase in available phosphorus in GS, MS and PF plots at the crop tasseling stage indicated that the decomposition of maize stover, dried grass and palm fronds mulches added sufficient amounts of phosphorus to the soil. The average soil exchangeable potassium for the NM, MS, GS and PF plots during the crop tasseling stage were 0.47, 0.24, 0.74 and 0.39 $\text{cmol}_e \text{kg}^{-1}$. Significant differences existed among the treatments. The potassium content reduced from crop emergence stage to tasseling stage in MS and PF plots whilst there was an increase in GS and NM plots. This suggested that the maize stover and the palm fronds could not release sufficient potassium during decomposition to the soil for both plant use and microbial activity but the dry grasses straw could release enough potassium to the soil.

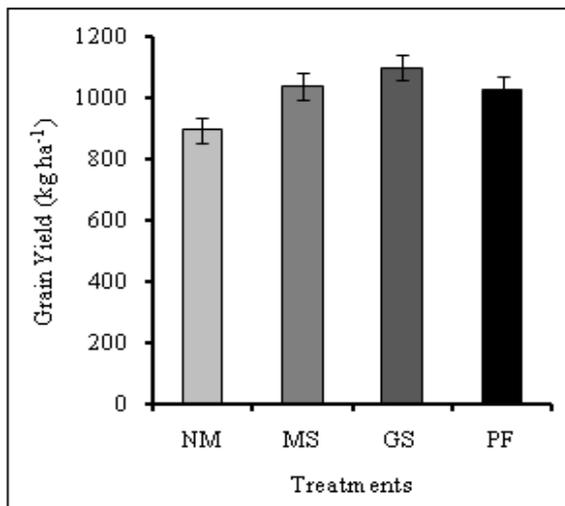


Fig. 5. Effect of organic mulches on grain yield.

Harvesting stage

At harvesting stage of the maize, the average bulk densities recorded were the order of NM (1.47 g cm^{-3}) > PF (1.38 g cm^{-3}) > MS (1.33 g cm^{-3}) > GS (1.23 g cm^{-3}) (Table 1). Significant differences existed among the treatments. The soil bulk densities reduced significantly ($p = 0.05$) at harvesting stage compared to the tasseling stage for all the treatments except the PF plots which increased. Similar trend was recorded for the total porosity. This suggested that organic matter from the decomposition of palm fronds to improve soil porosity was inadequate due to the presence of the excessive midribs. There was also significant ($p = 0.05$) differences in soil moisture content among the treatment plots with the NM, MS,

GS and PF plots having 5.77, 11.87, 8.73 and 9.27 % respectively. Comparing the soil moisture content for the various treated plots at crop harvest to corresponding soil moisture values at crop tasseling stage, all the treatments experienced significant ($p = 0.05$) increase except the PF plots which increase was marginal. This indicated that the palm frond decomposed faster than the other mulching materials leaving only the midribs thereby making most parts of the plots bare to have enhanced evaporation. Even though the NM plots recorded the lowest moisture content (5.77 %), there was an increase in soil moisture compared to the tasseling stage and this could be due to the maize leaf falls that partially covered the soil surface. It was noted that from the tasseling stage to the harvesting stage, the organic carbon increased with a corresponding decrease of bulk density at the various plots. The average organic carbon content for NM, MS, GS and PF were 1.37, 1.60, 1.76, and 1.70 % respectively. Significant differences existed among the treatments and the dry grass straw mulch sustained and improved the organic carbon content more than the other organic treatments. This was similar to observation by Kakaire *et al.* (2015) that organic mulches helped maintain and improve soil organic matter. From crop tassel to crop harvest the soil organic carbon content for MS, GS and NM plots increased while the PF reduced and this was reflection of the pattern in the soil bulk density and total porosity. The organic carbon reduction of the PF plots could be due partly to the presence of excessive midribs of the palm fronds that reduced the amount of organic materials that decomposed and partly to early decomposition of the fronds resulting to unsustainable organic carbon in the soil. The average total nitrogen contents in the soils were in the order GS (0.23 %) > MS (0.15 %) > PF (0.14 %) > NM (0.083 %). No significant difference existed between MS and PF but they were significantly different from GS and NM. The soil total nitrogen on all the treatment plots were generally low and Roose and Barthès (2001) explained that mulches on the soil surface mineralized much less immobilized nitrogen than when the same materials were incorporated into the soil.

The average soil available phosphorus content for NM, MS, GS and PF plots were 52.64, 102.61, 139.41 and 96.38 ppm respectively. Significant differences existed among the treatments. The highest soil available phosphorus for GS indicated among the organic materials used as mulched dry grass straw provided and maintained the phosphorus better than the other organic materials. However, comparing the phosphorus in the plots at harvest stage and the corresponding plots at tassel stage showed no significant difference between them except the NM. The soil exchangeable potassium content was in the order of GS ($0.74 \text{ cmol}_c \text{ kg}^{-1}$) > NM ($0.47 \text{ cmol}_c \text{ kg}^{-1}$) > PF ($0.39 \text{ cmol}_c \text{ kg}^{-1}$) > MS ($0.24 \text{ cmol}_c \text{ kg}^{-1}$) and was significantly different from each other.

Effect of different mulches on maize growth, yield and water use efficiency

Fig. 1 shows the maize seed germination rate under maize stover (MS), dry grass straw (GS), palm frond (PF) mulched and no-mulched (NM) plots. The germination rates were in order of NM (91.0%) > MS (89.9%) > GS (86.8%) > PF (87.9%). However, the germination rate was not significant ($p = 0.05$) among the treatments. A germination rate of less than 100 % obtained from all the plots could be attributed to some colonies of ants observed on the plots which probably fed on the seeds thereby reducing the seeds' viability to realize their full germination potential. The degree of ant colonization was higher on PF, followed by GS, then MS and the least was NM. These different degrees of ant colonization reflected the differences in germination rates observed. Since the NM plots were bare, there was very minimal number of ant colonies observed and this could be the cause of relatively higher germination rate for the NM. This agreed with the observation by Knowler and Bradshaw (2007) that organic mulches offered cover for small slugs and pest that could devastate seeds and seedlings to reduce plant population.

Fig. 2 shows the maize heights on both mulched and no-mulched plots. The maize heights on the different plots followed similar pattern and clear-cut differences showed after 6 WAP. At 10 WAP, a

maximum plant height of about 265 cm was obtained on the GS, followed by MS (247 cm) then PF (237 cm) and the least was NP (218 cm) plots. Statistical analysis showed that there was a significant ($P = 0.05$) difference between GS and the other treatments, between MS and PF on one hand and NM but not between MS and PF. The general maximum maize heights measured on the mulched plots could be attributed to the ability of organic mulches to conserve sufficient soil moisture and maintained adequate soil nutrients in terms of nitrogen, phosphorus and potassium (Table 2) for plant growth and development as noted by Norman *et al.*, (2002). The variation in plant height observed under the different mulched plots could be attributed to the differences in the soil moisture conserved and the provision of soil nutrients (NPK) by the different mulches. However, the least maize height measured on NM plots could be attributed to relatively less soil moisture probably due to higher evaporation coupled with inadequate soil nutrients (NPK) from uncovered (bare) plots.

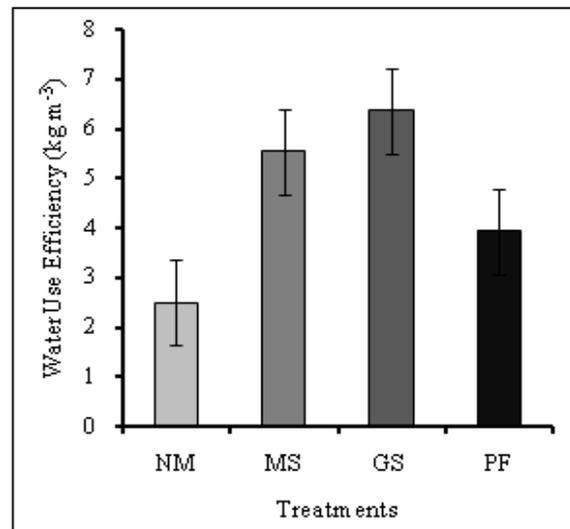


Fig. 6. Effect of organic mulches on water use efficiency (WUE).

Fig. 3 shows the maize leaf area index (LAI) for 10 weeks on both mulched and no-mulched plots. The maize LAI on the mulched plots increased sharply from about 0.45 at 2 WAP to about 0.9 at 4 WAP after which the differences started to show. At 10 WAP, the maize LAI was in the order of GS (1.28) > MS (1.24) > PF (1.22) > NM (1.21).

This generally corroborated with explanation by El-Kader *et al.* (2010) that organic mulches conserved moisture for plant growth which increased plant leaf area in relation to ground cover. Statistical analysis indicated that there was no significant ($p = 0.05$) difference between GS and MS. Similarly, the effects of MS, PF and NM on maize LAI were not significantly ($p = 0.05$) different. However, there was a significant ($p = 0.05$) difference between GS and NM.

Fig. 4 shows the number of days to tassel on different mulched treated and no-mulched treated plots. Both the MS and GS had relatively lower number of days of 62 to tassel followed by PF which had 65 days and NM had 66 days. This corroborated with Iftikhar *et al.* (2011) who observed varied number of days for chilli plants to flower in wheat straw and rice straw mulches.

There was no significant ($p = 0.05$) difference in the tassel days of maize between MS and GS, and between PF and NM. However, significant ($p = 0.05$) difference existed between MS and GS on one hand and PF and NM on the other. The variation in maize tassel days among the different mulches reflected the different contribution of the amount of moisture retained and nutrients released in the soil by the mulches (Table 2). This suggested that the higher the amount of moisture retained and nutrient released the faster the crop development and the shorter the tassel period. This probably might have contributed to maize on GS and MS plots reaching tassel stage earlier than maize on PF and NM plots.

Fig. 5 shows the maize yield under different mulched and no-mulched plots. The order of maize yield as affected by different mulching materials were of GS (1098 kg ha^{-1}) > MS (1038 kg ha^{-1}) > PF (1024 kg ha^{-1}) > NM (893 kg ha^{-1}). Statistical analysis showed no significant ($P = 0.05$) difference in yield among the mulched plots but significant differences existed between the mulched plots and NM. This agreed with Nasir *et al.* (2011) and Norman *et al.* (2002) that mulching conserved moisture content which in turn

increased plant yield. Even though there was significant differences among the mulched plots, the relatively higher yield obtained on GS plots could be attributed to the grass mulch ability to release high nutrient (NPK) into the soil (Table 2) compared to the other mulches. The lower yield on NM plots could be attributed to low soil moisture and low soil nutrient release due to the bare soil surface of the plots.

From Fig. 6, the water use efficiency (WUE) of the maize obtained under different mulches were in the order of GS ($6.35 \text{ kg ha}^{-1} \text{ m}^{-3}$) > MS ($5.53 \text{ kg ha}^{-1} \text{ m}^{-3}$) > PF ($3.93 \text{ kg ha}^{-1} \text{ m}^{-3}$) > NM ($2.49 \text{ kg ha}^{-1} \text{ m}^{-3}$). Statistically, there was significant ($p = 0.05$) difference between GS, and PF and NM on one hand but not between GS and MS. The higher WUE under GS could be attributed to the ability of the dry grass mulch to maintain more soil moisture for plant growth compared to the other mulches (Table 2). The least WUE on NM could be low retention of soil moisture due to higher evaporative loss of soil moisture from its bare soil surface (Norman *et al.*, 2002; Nkansah *et al.*, 2003).

Conclusion

The study revealed that organic mulches (maize stover, dry grass straw and palm frond) conserved and increased soil moisture, improved bulk density, organic carbon content and macro-nutrients (NPK) relative to control (no-mulch). However, comparing the effects of the different organic mulches on the soil bulk density and moisture content, MS provided higher moisture content than GS and PF while the GS improved the soil bulk density better than MS and PF. Also comparing the effects of the mulching materials on the soil organic carbon content, the PF supplied higher amount at the crop early stages but reduced during crop harvesting while the GS sustained the provision of the organic carbon in the soil. The GS effects on the provision and maintenance of macro-nutrients (NPK) were better compared to MS and PF. Similarly, the organic mulches maximized maize growth and increased the yield with respect to the control (no-mulch) and among the different organic mulches the order was of GS > MS > PF.

The water use efficiency (WUE) of the maize obtained under GS plots was also higher compared to MS and PF plots even though the difference between GS and MS was not significant ($p = 0.05$). Therefore it can be concluded that the dry grass straw had higher improvement of the examined soil physico-chemical properties and subsequently maximum maize growth, increased maize yield and higher WUE, followed by maize stover and then palm frond when used as mulching materials and this reflected the interactions of soil properties and maize performance.

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