Colloquia SSSN 44 (2020) 190-197

Colloquia Series

Available online at www.publishingrealtime.com

Publishing Real Time

Colloquia SSSN 44 (2020)

Proceedings of the 44th Conference of Soil Science Society of Nigeria on Climate-smart soil management, soil health/quality and land management: synergies for sustainable ecosystem services

Effects of mulch types on soil physicochemical properties, carbon sequestration, growth and yield of Bambara groundnut [*Vigna subterranea* (L.) Verdc.] in Agbani Area Enugu State

Ikenganyia, E. E. , and Anikwe, M. A. N.

Department of Agronomy and Ecological Management Faculty of Agriculture and Natural Resources Management,

Enugu State University of Science and Technology, Agbani, Enugu State

Abstract

Field trials were conducted in 2017 and 2018 planting season at the Teaching and Research Farm of the Faculty of Agriculture and Natural Resources Management, Enugu State University of Science and Technology, Agbani. The experiment was laid out in randomized complete block design with three replications. The treatments were six different mulching materials (wood shavings, grass mulch, black polythene, clear polythene mulch, sawdust and no mulch material). The obtained results showed that Bambara groundnut grown on plots mulched with *Panicum maximum* produced significantly ($p < 0.05$) the highest pod weight per plant 87.50 g plant $^{-1}$ (2017) and 95.10 g plant^{-1} (2018) respectively when compared with the other treatments. The result showed a significant difference ($p < 0.05$) on the number of leaves, leaf area index, and the number of pods per plant at four and eight weeks after planting in 2017 and 2018 planting season respectively. Soil sample tests revealed that plots mulched with sawdust had the highest soil bulk density with a value of 1.43 g cm-^{3} (2017) and 1.39 g cm-^{3} (2018) whereas the lowest was recorded in the unmulched plots (control) [1.02 g cm-^{3} (2017) and 1.00 g cm-^{3} (2018). Plots mulched with sawdust had more carbon content [0.137 mg c ha^{-1} (2017) and 0.141 mg c ha^{-1} (2018)] than the other treatments. Whereas the lowest carbon sequestration value was recorded in control and clear polythene plot treatment with a value of 0.049 mg c ha^{-1} (2017) and 0.051 mg c ha^{-1} (2018) respectively. The study showed that that Bambara groundnut grown on plots mulched with sawdust had the highest carbon content than the other mulch type.

Keywords: Mulch types, carbon sequestration, Panicum maximum, Bambara groundnut, sawdust.

Corresponding Author's E-mail Address: eejike43@yahoo.com: Phone: +2348064960700
https://doi.org/10.36265/colsssn.2020.4428

Peer-review under responsibility of 44th SSSN Conference LoC2020.

1.0. Introduction

Bambara groundnut [*Vigna subterranea* (L.) Verdc.] represents the third most important grain legume in semi-arid Africa after cowpea *(Vigna unguiculata)* and groundnut (*Arachis hypogaea*) (Ocran, 1998; Mkandawire, 2007). It is variously known as "izindlubu" (Zulu, South Africa); "Jugo beans" (South Africa); "Ntoyo cibemba" (Zambia); "Gurjiya" or "Kwaruru" (Hausa, Nigeria); "Okpa" (Igbo, Nigeria); "Epa- Roro" (Yoruba, Nigeria); "Nyimo beans" (Zimbabwe). Bambara groundnut seed contains 63% carbohydrate, 19% protein and 6.5% oil (Linnemann, 1987). The gross energy value of Bambara groundnut seed is greater than that of other typical pulses such as cowpea, lentil (*Lens esculenta*) and pigeon pea (*Cajanus cajan*) (FAO, 1982). It is deficient in sulphur-containing amino acids (Azam-Ali *et al*., 2001); some genotypes contain higher amounts of methionine and lysine than is found in other legumes (NRC, 2006). It is resistant to high temperature and is suitable for marginal soils where other leguminous crops cannot be grown (Yamaguchi, 1983). Despite its nutritional value, it is still considered as one of the prioritized neglected and underutilized crop species in Nigeria (Dansi *et al*., 2012).

Agronomic practice such as the use of mulch for the cultivation of this crop has not yet been fully determined in Nigeria, especially in the south-east. Furthermore, there is a paucity of information on the impact of mulch on soil carbon sequestration. Mulching improves soil agro-physical properties (Strizaker et al., 1989). Mulching also minimizes the use of nitrogen fertilizer (Jones *et al.*, 1977), warms the soil (Singh *et al.,* 1988), improves the soil physical condition, and suppresses weed growth (Iruthayaraj *et al.,* 1989) and could account for increased yield (Ravinder *et al.,* 1997).

Carbon is found in all living organisms and is the primary building block for life on Earth. Carbon exists in many forms, predominately as plant biomass, soil organic matter, and as the gas carbon dioxide (CO_2) in the atmosphere and dissolved in seawater. Carbon sequestration is the long -term storage of carbon in oceans, soils, vegetation (especially forests), and geologic formations. Soils contain approximately 75% of the carbon pool on land—three times more than the amount stored in living plants and animals (Brady and Weil 2002). Therefore, soils play a significant role in maintaining a balanced global carbon cycle. The primary way that carbon is stored in the soil is as soil organic matter (SOM). SOM is a complex mixture of carbon compounds, consisting of decomposing plant and animal tissue, microbes (protozoa, nematodes, fungi, and bacteria), and carbon associated with soil minerals. Carbon can remain stored in soils for millennia, or be quickly released back into the atmosphere (Brady and Weil 2002) Removing CO_2 from the atmosphere is only one significant benefit of enhanced carbon storage in soils. Improved soil and water quality, decreased nutrient loss, reduced soil erosion, increased water conservation, and greater crop production may result from increasing the amount of carbon stored in agricultural soils. Management techniques, such as conservation tillage, cover crop, crop rotation and use of amendments and mulch are successful in providing a net carbon sink in soils.

Therefore, the objective of this study is to determine the effects of mulch types on soil physicochemical properties, carbon sequestration, growth and yield of Bambara groundnut [*Vigna subterranea* (L.) Verdc.] in Agbani area, Enugu South East, Nigeria.

2.0. Materials and Methods.

2.1. Description of the experimental site

Field trials were conducted at the Teaching and Research Farm of the Faculty of Agriculture and Natural Resources Management, Enugu State University of Science and Technology, Agbani on May, 2 in 2017 and 2018 planting season respectively. The site is located on latitude $06^0 52'$ North, longitude $07^0 15'$ East and altitude 450 meters above sea level (Anikwe *et al*., 2017). The area has an annual rainfall which ranges from 1700 – 2010 mm. The rainfall pattern is bimodal and is between April and October, and the dry season is between November and March. The soil's textural class is sandy loam with an isohyperthermic soil temperature regime (Anikwe *et al*., 2017) and is classified as Typic Paleudult of the order ultisol (Anikwe *et al*., 2016).

2.2. Soil sample collection and analyses

Soil samples were collected from the topsoil at a depth of 0 to 15 cm before sowing and at four and eight weeks after sowing in 2017 and 2018 cropping season respectively. Three representative soil samples were randomly collected per plot and bulked to form a composite soil sample for each plot. A total of eighteen and composite soil samples were collected for an experiment in 2017 and 2018 cropping season. Samples were air-dried, ground and passed through a sieve of 2 mm standard mesh size. The soil pH was determined with a pH meter using 1: 2.5 soil to 0.1 N KCl (potassium chloride) suspension according to Page *et al.,* (1982). Organic carbon was determined using the Walkley and Black wet digestion method (Bremner and Mulvaney, 1982). Soil organic matter content was obtained by multiplying the value of organic carbon by 1.724 (Van Bemmelen factor). Total nitrogen was determined by Micro-Kjeldahl procedure (Page *et al*., 1982). Available phosphorus was determined by extraction with Bray II extractant as described by Bray and Kurtz (1945) and determined colorimeterically using the ascorbic acid method (Murphy and Riley, 1962). Exchangeable potassium was determined by extraction using one ammonium acetate (NH_4OAC) solution and determined by the flame emission spectroscopy as outlined by Anderson and Ingram, (1993). Aluminium and hydrogen content (exchangeable acidity) was determined by the titrimetric method after extraction with 1.0 N KCl (Mclean, 1982). The cation exchange capacity was determined by NH_4OAC displacement method (Rhoades, 1982). Calcium and magnesium were respectively determined by the complexometric titration method, as described by Chapman (1982). Particle size distribution analysis was done by the hydrometer method (Gee and Bauder, 2002) and the corresponding textual class determined by the United State Department of Agriculture Soil Texture Triangle. Base saturation was determined by the method outlined by Page *et al.* (1982). Bulk density determination was carried out using the core method as described by Blake and Hartage (1986). Total porosity was determined by the method described by Obi (2000). Saturated hydraulic conductivity was done using the method described by Klute (1965)

2.3. Experimental design

Six different mulching materials (wood shavings, grass mulch, black polythene, clear polythene mulch, sawdust and no mulch material) were used as treatments (Table 1). The treatments were laid out in a randomized complete block design with three replications. A total of eighteen experimental units was laid out for this experiment.

Table 1: Rates of application per bed of the mulch types.

Mulch type	Rate of application per bed
No mulch	0 kg per bed
Sawdust	6 kg per bed
Clear polythene	$4m^2$ per bed
Black polythene	$4\ m^2$ per bed
Grass mulch	6 kg per bed
Wood shavings	6 kg per bed

2.4. Field operations

A total land area measuring 190 m^2 (19 m x 10 m) was used for the experiment. The land was divided into three blocks (columns: north-south direction), and each was sub-divided into six plots (rows: east-west direction), making a total of eighteen plots. Plots (beds) measuring 2 m x 2 m (4 m^2) were separated by 1 m x 1 m pathway between and in between plots. Beds were made measuring 30 cm high (Figure 1). The seeds of Bambara groundnut were planted at 2 seeds per hole at 5cm depth using a plant spacing of 20 cm x 45 cm Sowing was done at the rate of two seeds per hole and thinned to one plant at two weeks after planting. Prophylactic application of 15 ml of Karate (Pyrethroid insecticide) in five litres of water was applied at one, four, six and eight weeks after sowing to avert pest incidence. Three plants at the centre rows were sampled during data collection. Weeding was done using a traditional hoe.

Figure 1. Layout of the treatments in the field

2.5. Soil carbon sequestration

The soil organic 10^4 carbon pool was determined using the equation stated below

SOC pool (mg C ha^{-1}) =

$$\frac{(\%\ \text{SOC x bulk density of soil x depth x 1})\ \text{m2 ha} - 1}{100} \quad (1)$$

2.6. Data collections (Figure 2a-c)

2.6.1. number of leaves per plant

The total number of leaves per plant was counted. The plant per plot was randomly selected, and the mean was taken.

Figure 2a. Leaf area determination

Figure 2b. Uprooting Bambara groundnut [*Vigna subterranea* (L.) Verdc.] plant from the soil for nodule count

Figure 2c. Fresh pods at harvest

2.6.2. Leaf area index

The leaf area index was obtained by measuring the length and width of the leaf using a meter rule. The result was calculated using the formula

$$\text{Leaf Area Index} = \frac{\text{leaf length x leaf width x } 0.85}{\text{plant spacing}} \quad (2)$$

2.6.3. number of pods per plant

The number of pods per plant was determined by counting the number of pods of each plant when uprooted.

2.6.4. Pod weight per plant

The pod weight was determined by placing the pods on the electronic scale and taking readings from the scale.

2.7. Statistical analysis

Data collected were subjected to analysis of variance (ANOVA) test for a randomized complete block design as outlined by (Gomez and Gomez, 1984). Significant means were separated using Fisher's least significant difference (F-LSD) at 5% probability level. Statistical analysis was executed using GENSTAT (2007) Statistical Software

3.0 Results and Discussion

3.1. Initial soil characteristics of the study area before planting in 2017 and 2018 planting season

The pre-planting analyses of soil properties for 2017 and 2018 planting seasons are presented in Table 2. The result indicated that the textural class of the study site over the two years planting seasons were loamy sand, which contained 47% (2017) and 45% (2018) coarse sand, 40% (2017) and 43% (2018) fine sand, 5% (2017 and 2018), 8% (2017) and 7 % (2018) silt.). The lowest bulk density value was lower in 2018 (1.50 mg m^{-3}) than the 2017 planting season (1.52 mg m^{-3}). The total porosity of soil indicated that the soil had a total pore space of 43% in 2017 and 43% in 2018 planting season. The saturated hydraulic conductivity of the soil was 22. 00 cm hr^{-1} in 2017 and 23.00 cm hr^{-1} in 2018 planting season respectively.

Percentage organic carbon was found to be 7.2 g kg^{-1} (2017) and 7.0 g kg^{-1} (2018) and total nitrogen contents were 0.041 g kg^{-1} (2017) and 0.044 g kg^{-1} (2018). The low values observed were below the critical levels for the study area. However, 2018 values were higher than the 2017 planting season. As expected, this indicated that the soils had higher values for nutrient in 2018 compared to 2017 planting season because of the influence of the legumes planted in the previous season. The soil pH in water was observed to be 6.3 (2017) and 6.0 (2018) indicating slight acidity according to the rating by Landon (1991).

The pre-planting exchangeable cations contents and exchangeable acidity of the soil in 2017 were (Mg^{2+} 0.90 c mol kg^{-1}, K^{+} 0.10 c mol kg^{-1}, Na^{+} 0.17 c mol kg^{-1}, Ca^{2+} 1.6 c mol kg^{-1}, Al^{3+} 3.06 c mol kg^{-1}, H^{+} 2.40 c mol kg^{-1} and

Table 2. Initial soil characteristics of the study area before planting in 2017 and 2018 planting season

Parameters	2017	2018
Particle size distribution (%)		
Coarse sand	47	45
Fine sand	40	43
Clay	5	5
Silt	8	7
Textural class	Loamy sand	Loamy sand
Bulk density (mg m^{-3})	1.52	1.50
Total porosity (%)	43	45
Saturated hydraulic conductivity (cm hr^{-1})	22.00	23.00
pH (water)	6.3	6.0
Organic carbon (g kg^{-1})	7.2	7.0
Total nitrogen (g kg^{-1})	0.02	0.04
Available phosphorus (mg kg^{-1})	8.82	8.88
Exchangeable bases (c mol kg^{-1})		
Calcium	1.6	1.4
Magnesium	0.90	0.92
Potassium	0.10	0.16
Sodium	0.17	0.18
Exchangeable acidity (c mol kg^{-1})		
Hydrogen	2.40	2.64
Aluminium	3.06	3.22
Cation exchangeable capacity (c mol kg^{-1})	8.90	8.97

CEC 8.90 c mol kg^{-1}). whereas in 2018, the values were (Mg^{2+} 0.92 c mol kg^{-1}, K^{+} 0.16 c mol kg^{-1}, Na^{+} 0.18 c mol kg^{-1}, Ca^{2+} 1.4 c mol kg^{-1}, Al^{3+} 3.22 c mol kg^{-1} H^{+} 2.64 c mol kg^{-1} and CEC 8.97 c mol kg^{-1}). Available phosphorus (Bray 11) was found to be 7.91 mg kg^{-1} (2018) and 8.82 mg kg^{-1} (2017).

3.2. Effect of mulch types on the number of leaves per plant of Bambara groundnut [Vigna subterranea (L.) Verdc.] at four and eight weeks after planting in 2017 and 2018 planting season.

Table 3 shows that the effect of mulch types on the number of leaves per plant of Bambara groundnut [*Vigna subterranea* (L.) Verdc.] at four and eight weeks after planting in 2017 and 2018 planting season were significant ($p < 0.05$). The highest number of leaves per plant was observed in plot mulched with grass (*Panicum maximum*) at four weeks after planting (55 and 59 in 2017 and 2018 planting season respectively and 160.00 and 167.00 at eight weeks after planting in 2017 and 2018 planting season. The significant difference among treatment effect may be because organic mulches decompose under appropriate water and temperature levels, nutrients are released to the soil and becomes available for root uptake or microbial use (Chalker *et al*., 2007).

Table 3. Effect of mulch types on the number of leaves per plant of Bambara groundnut [*Vigna subterranea* (L.) Verdc.] at four and eight weeks after planting in 2017 and 2018 planting season

Mulch type	**Four weeks after planting**		**Eight weeks after planting**	
	2017	2018	2017	2018
Control	44.00	46.00	121.00	126.00
Clear polythene	47.00	50.00	138.00	139.00
Black polythene	51.00	53.00	151.00	151.00
Grass mulch	55.00	59.00	160.00	167.00
Saw dust	50.00	52.00	141.00	143.00
Wood shaving	44.00	45.00	158.00	159.00
$F\text{-}LSD_{(0.05)}$	1.20	1.10	3.00	2.10

$F\text{-}LSD_{(0.05)}$ – Fisher's least significant difference at 0.05 probability level

3.3. Effect of mulch types on leaf area index of Bambara groundnut [Vigna subterranea (L.) Verdc.] at four and eight weeks after planting in 2017 and 2018 planting season.

The data showed in Table 4 indicated that the effect of mulch types on leaf area index of Bambara groundnut [*Vigna subterranea* (L.) Verdc.] at four and eight weeks after planting in 2017 and 2018 planting season were significant ($p < 0.05$). Bambara groundnut cultivated on plots mulched with *Panicum maximum* gave the highest leaf area index per plant at four weeks after planting 0.87 (2017) and 5.30 (2018) and at eight weeks after planting the leaf area index varied from 0.97 to 5.90 in 2017 and 2018 planting season respectively than the other mulch types

Table 4. Effect of mulch types on leaf area index per plant of Bambara groundnut [Vigna subterranea (L.) Verdc.] at four and eight weeks after planting in 2017 and 2018 planting season

Mulch type	**Four weeks after planting**		**Eight weeks after planting**	
	2017	2018	2017	2018
Control	0.70	0.74	5.10	5.24
Clear polythene	0.64	0.69	3.80	3.85
Black polythene	0.81	0.90	4.60	4.89
Grass mulch	0.87	0.97	5.30	5.90
Saw dust	0.74	0.76	3.30	3.38
Wood shavings	0.78	0.80	3.90	4.10
$F\text{-}LSD_{(0.05)}$	0.01	0.01	0.20	0.11

$F\text{-}LSD_{(0.05)}$ – Fisher's least significant difference at 0.05 probability level

3.4. Effect of mulch types on the number of pods per plant and fresh pod weight per plant of Bambara groundnut [Vigna subterranea (L.) Verdc.] at harvest in 2017 and 2018 planting season.

Table 5. Effect of mulch types on the number of nodules per plant of Bambara groundnut [Vigna subterranea (L.) Verdc.] at four weeks after planting in 2017 and 2018 planting season

Mulch type	Four weeks after planting	
	2017	2018
Control	23	25
Clear polythene	24	27
Black polythene	27	30
Grass mulch	33	36
Saw dust	30	33
Wood shavings	31	34
$F\text{-}LSD_{(0.05)}$	2	3

$F\text{-}LSD_{(0.05)}$ – Fisher's least significant difference at 0.05 probability level

Bambara groundnut grown on soil amended with *Panicum maximum* had significantly ($p < 0.05$) more number of fresh pods per plant (25 in 2017 and 28 in 2018) at harvest than the other treatments. The fresh weight of Bambara groundnut pods per plant at harvest planted on plots mulched with *Panicum maximum* were significantly ($p < 0.05$) the highest (87.50 g plant^{-1} in 2017 and 95.10 g plant^{-1} 2018) in comparison with the other mulch types (Table 5)

3.5 Effects of mulch types on bulk density and total porosity of the soil in 2017 and 2018 planting season

Bulk density of soil showed in Table 6 were significantly ($p < 0.05$) higher in plots amended with sawdust (1.43 g cm-^{3} and 1.39 g cm-^{3} in 2017 and 2018 planting season respectively) than the other treatments. the lowest bulk density was observed on soil with no mulch application (1.02 g cm-^{3} in 2017 and 1.00 g cm-^{3} in 2018 planting season.) More so, the Effects of total porosity of the soil in 2017 and 2018 planting season was also observed to be significant ($p < 0.05$). Soils without any mulch application had more pore spaces than the other mulch types (61.51% and 63.00% in 2017 and 2018 planting season respectively) from the results, 2018 values are higher than 2017 planting season values this could be attributed to the impact of the previous planting season of soil.

Table 6. Effect of mulch types on the number of pods per plant and weight of fresh pod per plant of Bambara groundnut [Vigna subterranea (L.) Verdc.] at harvest in 2017 and 2018 planting season

Mulch type	Number of pods per plant		Weight of fresh pod per plant (g plant^{-1})	
	2017	2018	2017	2018
Control	10.00	10.00	32.30	34.00
Clear polythene	12.00	13.00	49.40	51.00
Black polythene	17.00	20.00	66.50	72.32
Grass mulch	25.00	28.00	87.50	95.10
Sawdust	20.00	22.00	73.70	76.53
Wood shaving	18.00	21.00	48.3	52.00
$F\text{-}LSD_{(0.05)}$	3.60	2.20	5.10	4.21

$F\text{-}LSD_{(0.05)}$ – Fisher's least significant difference at 0.05 probability level

3.6. Effect of mulch types on soil carbon sequestration in

Table 7. Effect of mulch types on soil total nitrogen (g kg-1) at harvest in 2017 and 2018 planting season

Mulch type	2017	2018
Control	0.02	0.03
Clear polythene	0.03	0.05
Black polythene	0.03	0.05
Grass mulch	0.04	0.05
Saw dust	0.03	0.04
Wood shaving	0.02	0.04
$F\text{-}LSD_{(0.05)}$	0.01	0.01

$F\text{-}LSD_{(0.05)}$ – Fisher's least significant difference at 0.05 probability level

Table 8. Effects of mulch types on bulk density and total porosity of the soil in 2017 and 2018 planting season

Mulch type	Bulk density (g cm^{-3})		Total porosity (%)	
	2017	2018	2017	2018
Control	1.02	1.00	61.51	63.00
Clear polythene	1.25	1.02	55.57	59.11
Black polythene	1.04	1.02	52.00	55.20
Grass mulch	1.30	1.28	50.97	53.71
Saw dust	1.43	1.39	47.55	49.22
Wood shaving	1.39	1.39	48.04	50.22
F-LSD$_{(0.05)}$	0.03	0.02	2.00	3.00

F-LSD$_{(0.05)}$ – Fisher's least significant difference at 0.05 probability level

Table 9. Effect of mulch types on soil carbon sequestration (mg c hac-1) in 2017 and 2018 planting season

Mulch type	2017	2018
Control	0.049	0.051
Clear polythene	0.049	0.052
Black polythene	0.054	0.061
Grass mulch	0.058	0.061
Saw dust	0.137	0.141
Wood shavings	0.077	0.079
F-LSD$_{(0.05)}$	0.004	0.003

F-LSD$_{(0.05)}$ – Fisher's least significant difference at 0.05 probability level

2017 and 2018 planting season

The results presented in Table 7 revealed that the effect of mulch types on soil carbon sequestration in 2017 and 2018 planting season was significant ($p < 0.05$). Soils covered with sawdust captured more carbon than the other treatments (0.137 mg c hac^{-1} and 0.141 mg c hac^{-1} in 2017 and 2018 planting season respectively). Soil without any mulch application had the fewer carbon contents (0.049 mg c hac^{-1} and 0. 051 mg c hac^{-1} in 2017 and 2018 planting season respectively).

4.0 Conclusion

The Bambara Groundnut mulched with *Panicum maximum* was found to be different in growth characteristics as well as pod yield. The study showed that the grass mulch recorded a greater number of pods than the other treatments. This places *Panicum maximum* as the best mulch material for the cultivation of Bambara groundnut in Agbani area. Soil sample test revealed that plots mulched with sawdust had the highest soil bulk density with a value of 1.43 g cm-^{3} (2017) and 1.39 g cm-^{3} (2018) whereas the lowest was recorded in the unmulched plots (control) [1.02 g cm-^{3} (2017) and 1.00 g cm-^{3} (2018). Plots mulched with sawdust had more carbon content [0.137 mg c ha^{-1} (2017) and 0.141 mg c ha^{-1} (2018)] than the other treatments. Whereas the lowest carbon sequestration value was recorded in control and clear polythene plot treatment with a value of 0.049 mg c ha^{-1} (2017) and 0.051 mg c ha^{-1} (2018) respectively. The study showed that that Bambara groundnut grown on plots mulched with sawdust had the highest carbon content than the other mulch type

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