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Soil fertility status of soils of Sudano-Sahelian and Humid Forest Zones of West Africa and some soil management strategies for smallholder farms

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Abstract
Knowledge of soil properties and fertility status of farmers' fields are basic information needed by Agricultural Extension Agents to guide farmers on wise and sustainable management of soil. The properties of some cultivated fields in the Sudano-Sahelian of Ghana and Humid Forest zones of Nigeria were studied. The aim was to quantify the soil properties and fertility status with a view to prescribing low input ecological technologies that would improve and sustain soil productivity. Core samples were taken from the depth of 0-40 cm in eleven and eight farmers' fields in the Upper East Ghana and South East Nigeria, respectively. Soil properties determined using standard methods were; pH, TN, SOC, SOM, P, Exchangeable bases, EA, base saturation, PSD, WP, FC, bulk density, P and SHC. Both soils were sand in texture (> 700 g kg^{-1}). The WP and FC were either below or within the lower border of critical levels. This shows crops in all the fields are prone to incipient wilting under any short dry spell. The chemical properties of the Sahelian-Sahelian zone showed that pH averaged 6.54 (moderate acidic), SOC 16 g kg^{-1} (low), TN 13 g kg^{-1} (very high), P, 18 mg kg^{-1} (moderate), K 0.23 C mol kg^{-1}) (moderate), ECEC 8.18 C mol kg^{-1} (medium fertility class). In the Humid Forest zones, pH was 4.38 (extremely acidic), SOC 7.41 g kg^{-1} (very low), N 1.78 g kg^{-1} (low), P 15.94 mg kg^{-1} (moderate), K 1.94 C mol kg^{-1} (very high) and ECEC 8.8 C mol kg^{-1} (medium fertility class). The fertility class indicates that the soils will response to external inputs and wise land management practices. A mix of Arbuscular mycorrhizal fungus (AMF), multipurpose tree species, contour cultivation, organic mulch, multiple crop mixture, under vetiver grass buffer strip is recommended.

Keywords
mycorrhizae, soil husbandry, soil rehabilitation, soil properties. vetiver, degraded soils

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Introduction

Agriculture is the primary source of livelihood of the people of Africa. It is estimated that 70 percent of the population in the continent are into various forms of farming. Yet, Africa, including Ghana and Nigeria are food insecure. With the projected increase in population by 2030 (close of SDGs) and 2050, food production needs to be geometrically increased. This is to achieve Sustainable Development Goal (SDG) 2 (zero hunger) and SDG 1 (eradicate poverty). The native fertility of the soils and productivity of most soil in Africa is low (Essoka *et al.*, 2008). This is further exacerbated by high rainfall erosivity and poor soil erodibility status of the that reduces soil pH particularly for the high rainfall zone (Oku and Armon, 2006). The traditional practice of exporting nutrients from the field through crop harvest and sometimes burning of biomass while preparing field for next planting is also worrisome contributing factor to poor soil fertility in Africa. The Upper East Region of Ghana lies within the Sudano-Sahelian agro-ecological belt of West Africa (SSBWA). Subsistence farming, poverty, food insecurity and extreme poverty dominate the landscape (Bationo *et al.*, 2003). This is because drylands are low productivity soil and traditionally unproductivity because of frequent drought. The soil of SSBWA is characterized by low and irregular rainfall, high temperature and low soil nutrient retention capacity. The native soil fertility is poor and unable to support high yield even improved seeds. (Bationo *et al.*, 2003; Oku, *et al.*, 2015). Erratic rainfall occasioned by climate change shortens the crop growing period. Rainfall ranged from 300 – 900 mm with an average temperature of 40 ºC. The entire northern zone of Ghana receives low amount of rainfall, but with high intensity resulting in severe flooding (Oku, *et al.*, 2015).

South East Nigeria lies in the Forest Zone of West Africa (FZWA) having annual rainfall ranging from 1500 mm to 2500 mm. Sometimes can be more than 4500 mm in the per-humid Forest Zone lying close to the Gulf of Guinea (Oku and Armon, 2006). The soil of the region is acidic in nature with excellent structural properties, but low in plant nutrients. The nutrient retentive capacity of the soil is low with observable increase in moisture stress (Sanchez and Salinnas (1981). Large extent of land sustaining smallholder farms in South East Nigeria are moderate to steep slope. The slopes were once protected by thriving forest and biodiversity in the region under natural forest ecosystem (Oku *et al.,* 2014). The sustainability of the ecosystem recycling process is enhanced and made possible by the falling and decomposing leaf litters, tree branches, macro and micro-organisms contributing to the soil organic matter pool. The burrowing activities of soil ecological engineers as earthworms and crickets, decayed roots increase the soil porosity and enhance water infiltration into the soil and water storage (Oku *et al.,* 2014). Mixture of population pressure, urban expansion and development, foreign land deals and unfair land distribution have contributed to the disappearance of the forest. From (Oku and Aiyelari, 2014) report, the conversion of the once thriving native forest leads to further reduction in the native fertility of the soil. The objectives of the study were to assessed the soil native fertility status of cultivated smallholder farms in two contrasting agroecological belts (Sudano-Sahelian and Humid Forest) of West Africa. Additionally, prescribe some low input nature base soil management strategies that would improve the soil productivity and sustain crop production.

Materials and methods

Experimental site location

The study in the humid forest belt was conducted on eight smallholder cultivated farmlands located on slopping lands ranging from 35 to 45 % in Obubra, Cross River State, South East Nigeria. The zone lies within the humid tropics (4º 45´ - 6º 5´ N; 7º 45´ 9º 00´ E). The rainy season starts from April while the dry season commences from October each year. The rainfall pattern is bimodal with peaks in June and September. The annual rainfall ranges from 2000 to 2250 mm (Oku,

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2011). The soils of the fields are classified as Oxic Dystropept (Inceptisol) Cross River State Ministry of Agriculture, 1989). The primary vegetation is the tropical forest transformed into a secondary forest and grass lands by farming, firewood harvesting and charcoal business activities. The study in the Sudano-Sahelian ecology was carried in eleven farmers' fields in villages of the Tungo District in the Upper East Region of Ghana. The soil had earlier been classified as Eutric Plinthosols, Endo Eutric – Stagnic Plinthosols, Gleyic Arenosols and Eutric Gleysols (Senayah, *et al.*, 2006). Rainfall in the Upper East Region is irregular with unimodal pattern coming from May /June to September / October with annual average of 800 mm to 1100 mm (Oku *et al.*, 2015). November to February is characterized by cool dry and dusty harmmattan winds with midnight temperature reaching 14 ^{o}C and midday temperature reaching 40^{o} C (MOFA, 2000).

Soil samples were taken in the fields in a randomized manner at a depth of 0-40 cm; they were then mixed to obtain a compound sample. A total of 11 and 8 fields were sampled in the Upper East Ghana and South East Nigeria, respectively. The samples were processed for routine soil properties analysis using standard methods. Particle size distribution (PSD) was determined by the hydrometer method (Gee and Bauder, 1986), bulk density as described by (Blake and Harte, 1986), while porosity was calculated as a function of the total volume not occupied by soil solids, assuming a particle density of 2.65 Mg m^{-3} (Danielson and Sutherland, 1986) Soil pH was determined using 1:2.5 soil water suspension (adequate to wet the electrode) using a pH meter (IITA, 1982). Organic carbon was determined by the wet oxidation method (Nelson and Sommers, 1982). Total nitrogen was determined using the Micro-Kjeldahl method (Bremmer and Mulvaney, 1982) While available phosphorous was assayed by the Bray P-I method (Olsen and Sommers, 1982) since the soils were not calcareous and Bray P – 2 method was used for samples from the lowland humid forest zone. Exchangeable bases (Ca, Mg, Na, and K) were extracted with 1 N NH4OAc buffered at pH 7.0 (Thomas, 1982). Exchangeable acidity (EA) was determined by titration with 0.05 N NaOH, while effective ECEC was taken as the summation of exchangeable bases and total exchangeable acidity (IITA, 1982). Soil variability was estimated using the Equation one given by (Wildings).

$$CV = \frac{S}{Z} * 100 \qquad [1]$$

where: S = standard deviation, which is the square root of the sample variance; Z = is the mean of measured values.

Results and discussion

Soil chemical properties and fertility status of soil of Sudano-Sahelian zone of Ghana

Table 1 shows soil chemical properties of farmers' fields in the Upper East Ghana, the Sudano-Sahelian belt of West Africa. There is no possible Mg and P inhibition in the soil with an exchangeable cation ratio of 3: 1 for Ca:Mg. This is because the Ca:Mg ratio greater than 2:1 indicates P will not precipitated in the soil, rather will be available to plants. However, Ca:Mg ratio of less than 2:1 implies the soil will require conditioner as lime to boost the pH value and cause the availability of P and free of Mg. (Manimel, *et al.*, 2013). Soil reaction of all the cultivated fields was between moderately acidic (5.5 – 6.5) and slightly acidic (6.6 – 6.9) (SSSA, 1996). With a mean pH value of 6.5, it can be said that the soil in the fields is moderately acidic. Nutrient availability, particularly P is optimal when the pH is close to neutral. Acidic soils precipitate P and have the tendency to limit availability of nutrient (Brady and Weil, 1986). The pH of the farmers' fieTlds in the Sudano-Sahelian belt is good for plant growth. (Bationo et al., 2003). Organic carbon is rated as very low (< 2 %) and SOM as moderate ((2 -3 %) (Udo *et al.*, 2009). Nitrogen in all the fields is rated as high (0.5 – 1.0 %). The observed high level of N in the soil can be linked to the constant cultivation

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of legumes which is part of the cropping system in this zone. The low SOC and moderate SOM in the soil is understood from the angle that plant biomass is hard to come by in the field. During the prolonged dry season, domestic animals and cattle are not tethered, but left to freely roam the village and eat whatever is available in the field. (Oku *et al.*, 2017)

Distribution of Available P were not the same in all the fields as presented in Table 1. It was medium in eight fields (8 – 25 mg kg^{-1}) and high in three fields (> 25 mg kg^{-1}) (Udo *et al.*, 2009). The variation in P (CV > 35 %) among the farmer fields is in line with report that P is not limited in tropical soil. It is also not evenly distributed, in the field, but occurs in patches in soils within the same field (Essoka *et al.*, 2008). Exchangeable bases vary in their status in the soil. Calcium (Ca) was moderate (2.1 – 5 c mol kg^{-1}). Magnesium (Mg) was high (> 1.0 C mol kg^{-1}). Sodium (Na) was low (< 0.3 c mol kg^{-1}) in all the fields. Potassium (K) was moderate (0.15 – 0.3 c mol kg^{-1}) indicating the soil will respond to K fertilization. The ECEC gives an overall assessment of the fertility status of the soil and assess if the soil will response to fertilizer application. The fields were between low and moderate fertility class. ECEC of < 8 c mol kg^{-1}) puts the soil in the low fertility class. Moderate fertility class possesses ECEC that ranges from 8 – 15 c mol kg^{-1}) (Udo *et al.*, 2009).

Table 1. *Chemical properties of some farmers field in the Upper East Ghana the Sudano-Sahelian Belt of West Africa.*

Cultivated Field	pH (H_20)	SOC	SOM	TN	Av P	Ca	Mg	Na	K	EA	ECEC	BS
	Water		g kg^{-1}		mg kg^{-1}				c mol kg^{-1}			g kg^{-1}
A	6.6	18.10	31.11	8.40	29.33	4.00	1.20	0.11	0.5	0.8	6.61	879
B	6.5	13.30	22.92	6.00	12.66	5.60	1.99	0.05	0.15	1.24	9.03	843
C	6.5	16.00	27.52	7.00	20.00	4.00	1.20	0.05	0.13	0.96	6.34	848
D	6.6	17.30	29.75	7.40	13.30	4.00	1.30	0.07	0.17	1.60	7.14	725
E	6.8	13.30	22.92	6.00	13.20	6.80	2.60	0.06	0.21	1.12	10.79	896
F	6.6	18.10	31.11	8.00	9.36	6.00	2.40	0.07	0.19	1.28	9.94	871
G	6.6	16.90	29.06	8.00	12.00	4.00	1.40	0.07	0.20	1.12	6.79	835
H	6.6	22.60	38.87	11.0	20.00	6.00	1.40	0.06	0.23	1.28	8.97	866
I	6.4	16.50	28.38	7.00	14.66	4.40	1.30	0.07	0.23	0.80	6.80	882
J	6.4	12.70	21.84	6.00	31.33	6.60	2.00	0.06	0.27	1.12	10.05	888
K	6.3	11.40	19.60	5.00	26.00	6.50	1.30	0.10	0.23	1.44	7.47	604
Mean	6.54	16.02	27.55	38.87	18.35	5.26	1.64	0.07	0.23	1.16	8.18	831
SD	0.14	3.19	5.48	5.48	7.56	1.18	0.51	0.02	0.10	0.25	1.61	8.84
CV %	2	19	19	19	41	22	31	27	43	21	19	10

SOC = soil organic carbon; SOM = soil organic matter; TN = total nitrogen; Av P = available phosphorus; Ca = calcium;
Mg = magnesium; Na = sodium; K = potassium; EA = exchangeable acidity; ECEC = exchangeable cation exchange capacity; BS = base saturation

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Soil chemical properties and fertility status of soil of humid forest zone of Nigeria

The chemical properties of cultivated fields in South East, the Humid Forest zone of Nigeria are presented in Table 2. The pH of the cultivated fields was extremely acidic (< 4.6) and strongly acidic (4.7 – 5.5). This pH is typical of the soils of the Humid Forest zone. Soil organic carbon (SOC) in all the fields was rated as very low (SOC < 2 %). SOM ranged from very low (< 1 %) to low (1 – 2 %) except in one field where SOM was moderate (2.1 – 4.2 %) (Udo *et al.*, 2009). The TN was low (0.1 – 0.2 %) except in one cultivated field where it was moderate (0.21 – 0.5 %) (Udo *et al.*, 2009). Water erosion prone soils are low in nitrogen due to the continuous washing away of topsoil by runoff. Available P ranged from low (< 15 mg kg^{-1}) to moderate (15 – 25 mg kg^{-1}) (FDAR, 2004). With low pH values, P is expected to be precipitated thereby making it unavailable to crops especially leguminous crops growing on such soil. K was high (K > 0.3 C mol kg^{-1}) in all the fields. Ca was low (Ca < 2 C mol kg^{-1}), Mg was low (Mg < 0.3 C mol kg^{-1}) except in one field where it was moderate (0.3 – 1.0 C mol kg^{-1}). Sodium (Na) was high (Na > 0.3 C mol kg^{-1}) in all the fields. The fields were both in the low fertility class (ECEC < 8 C mol kg^{-1}) and medium fertility class. (ECEC 8 – 15 C mol kg^{-1}) (Udo *et al.*, 2009).

Table 2. *Chemical properties of some farmers field in villages in South East Nigeria, the humid forest belt of West Africa*

Cultivated Field	pH (H_20)	SOC	SOM	TN	Av P	Ca	Mg	Na	K	EA	ECEC	BS
			g kg^{-1}		mg kg^{-1}			c mol kg^{-1}				g kg^{-1}
1	4.74	6.03	10.49	1.60	22.15	0.01	0.13	1.02	1.32	2.48	4.73	509
2	4.33	7.58	13.19	1.80	16.27	0.11	0.12	2.15	1.93	2.85	7.16	556
3	4.64	8.18	14.23	1.98	18.87	0.09	0.18	2.51	0.99	2.65	6.42	586
4	4.45	4.49	8.61	1.50	22.76	0.09	0.17	2.72	2.22	2.70	7.90	659
5	4.22	12.91	22.46	1.53	14.08	0.12	0.18	2.63	1.53	3.65	8.11	549
6	4.08	11.23	19.54	2.78	9.70	0.09	0.17	2.85	2.01	4.20	9.32	543
7	4.31	6.30	10.96	1.55	10.47	0.11	0.93	3.51	2.69	4.10	11.34	614
8	4.29	6.38	7.46	1.55	13.24	0.08	0.15	3.18	2.87	3.10	9.38	671
Mean	4.38	7.41	13.36	1.78	15.94	0.08	0.25	2.57	1.94	3.21	8.04	57.79
SD	0.21	2.69	5.25	0.43	4.97	0.03	0.27	0.75	0.65	0.67	2.02	5.77
CV %	4	36	39	24	31	38	108	29	33	21	25	9

SOC = soil organic carbon; SOM = soil organic matter; TN = total nitrogen; Av P = available phosphorus; Ca = calcium;
Mg = magnesium; Na = sodium: K = potassium; EA = exchangeable acidity; ECEC = exchangeable cation exchange capacity; BS = base saturation.

Soil physical properties and fertility status of soil of Sudano-Sahelian zone of Ghana

Table 3 presents the physical properties of cultivated fields in the Upper East Ghana, the Sudon- Sahelian zone of West Africa. Particle size distribution showed a preponderance of sand fraction (746 g kg^{-1}of sand fraction). The soil was sandy loam in texture. The specific surface area (SSA) of sand is small and few compared to clay giving the soil limited sites for cation exchange. Therefore, nutrient retention by the soil is expected to be low (Oku *et al.*, 2020). Soil with predominant sand fraction will be easily detached under heavy rainfall (Oku and Babalola, 2009; Oku *et al.*, 2011). According to (Oku and Edicha, 2009), nutrient and water retention in such soil will also be low.

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Table 3. Physical properties of some farmers field in villages in Upper East Ghana, Sudano-Sahelian belt of West Africa

Cultivated Field	Sand	Silt	Clay	Texture	WP	FC	Sat	SHC	BD	Porosity
		g kg^{-1}				% Vol		cm hr^{-1}	g cm^{-3}	%
A	752	112	136	sl	9.8	17	42.5	38.67	1.52	43
B	752	112	136	sl	9.3	16.2	41.2	36.8	1.56	41
C	752	112	136	sl	9.5	16.6	41.8	37.72	1.54	42
D	652	192	156	sl	10.9	19.9	42.2	26.99	1.53	42
E	752	112	136	sl	9.3	16.2	41.2	36.8	1.56	41
F	792	152	56	sl	5.0	11.7	44.0	83.61	1.48	44
G	652	292	56	sl	5.1	14.8	43.4	64.59	1.50	43
H	757	131	102	sl	8.4	15.7	43.9	53.29	1.49	44
I	757	134	109	sl	7.8	14.9	42.6	50.78	1.52	43
J	797	154	49	sl	3.8	10.3	43.0	90.75	1.51	43
K	797	114	89	sl	6.0	12.1	41.7	62.27	1.55	42
Mean	746	147	105		7.71	15.03	42.5	52.93	1.52	42.54
SD	50.37	54.34	38.28		2.35	2.74	0.99	20.56	0.02	1.03
CV %	6	36	36		30	18	2	38	1	2

WP = wilting point; FC = field capacity; Sat = degree of saturation; SHC = saturated hydraulic conductivity;
BD = bulk density

The Wilting Point (WP) is the moisture status in the soil at which plant will permanently wilt or fail to regain its turgor pressure on wetting or irrigation. The WP of sandy soil is expected to fall between 5 – 10 % and that of loam soil is expected to range from 10 – 15 % (Cornell University Northeast Region Certified Crop Adviser (2018). Field capacity (FC), the amount of water available for crop growth was within the 15 - 25 % volume expected of sandy soil except for three fields where the FC were below the critical values. The space available for water and air in the soil expressed as the total porosity were in the "satisfactory agricultural soil" porosity class (40 - 45 %) (Kachinskii, 1970). The saturated hydraulic conductivity (SHC) of seven fields were in the "moderately slow" class (2.1 – 6.0 cm hr^{-1}), two fields in the "moderately rapid" class (6.1 – 8 cm hr^{-1}). Two fields were in the "rapid" conductivity class (8.1 – 25 cm hr^{-1}). The PSD, WP, FC and SHC values of the soil shows the field should be continuously supplied with water during the growing season as dry spell of short duration will negatively affect the moisture status and water availability to crops.

Soil physical properties and fertility status of soil of Humid Forest zone of Nigeria

The physical characteristics of an erosion prone Inceptisols fields in Obubra, South East Nigeria are presented in Table 4. The particle size distribution was predominantly sand (> 700 g kg^{-1}), clay fraction had a mean value of 105 g kg^{-1} of the soil. The texture was sandy loam in all the eight fields sampled. The WP of the soil were within 5 – 10 % of the volume expected of sandy soils and below 10 – 15 % expected of loam soils % (Cornell University Northeast Region Certified Crop Adviser (2018). The FC of sandy soils varies from 15 – 25 % and for loam it varies from 35 – 45 %. With the WP and FC values obtained for the fields in the humid forest zone, crops will suffer from frequent incipient wilting with breaks in irrigation

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or rainfall (short dry spell). Similar observation of moisture stress has been made for tropical soils of Africa (Sanchez and Salinnas, 1981).

Table 4. *Physical properties of some farmers field in villages in South East Nigeria the humid forest z belt of West Africa.*

Culitvated Field	Sand	Silt	Clay	Texture	WP	FC	Sat	SHC	BD	Porosity
	g kg^{-1}				% Vol			cm hr^{-1}	g cm^{-3}	%
1	738	168	94	ls	7.	15	45	6.27	1.46	45
2	758	148	94	ls	7	15	45	6.45	1.46	45
3	782	127	91	ls	7	14	45	6.64	1.46	45
4	797	114	89	ls	6	13	45	7.35	1.45	45
5	757	174	69	ls	6	14	45	7.56	1.45	45
6	782	119	94	ls	7	15	45	6.63	1.46	45
7	828	74	98	ls	8	14	45	6.42	1.47	45
8	825	84	91	ls	7	14	45	7.02	1.45	45
Mean	783	126	90		6.93	14.25	45	6.79	1.45	45
SD	32.31	36.28	8.91		0.67	0.70	0	0.46	0.01	0
CV	4	28	9		9	4	0	6	0	0

WP = wilting point; FC = field capacity; Sat = degree of saturation; SHC = saturated hydraulic conductivity; BD = bulk density

Saturated hydraulic conductivity (SHC) of all the fields were in the "moderately rapid" conductivity class. This water transmission class is expected for the soil given that the cultivated fields were predominantly sand. The possibility of applied nutrient moving down fast beyond the rooting zone is high. Therefore, inorganic fertilizer when applied should be split applied. The porosity values indicate the bulk density does not constitute a hindrance to crop growth and development. Total porosity of the soil puts all the farmers' fields in the "satisfactory agricultural soil" class (Kachinskii, 1970). However, the bulk density could be further lowered and total porosity increased. Practices as the use of green mulch, organic fertilizer, cover cropping and ploughing of stubbles into the soil will be a good soil management strategy for the farms in this zone.

Recommended soil management strategies

Biological land management practices crop mixtures. Crop mixtures or intercropping, a cropping system that involves cultivation of different crops or in combination of trees species simultaneously in the same field. (Zhang and Zhang, 2013). It is a common cropping system in both the Sudano-Sahelian and Humid Forest zones. However, there is the need to retool the mixture to include variety of crops that meets human food needs, animal feed needs, soil nutrient enrichment and climate resilient needs (Oku *et al.*, 2017). Leguminous crops and trees can be combined with cereal of choice depending on the culture and tradition as in the Sudano-Sahelian region of Ghana (Odoh, *et al.*, 2017). Legumes in the mixture improves soil fertility. Also acts as soil conservation crop protecting the soil from the impact of raindrop and slowing sediment movement in the farm (Megersa, 2011). In the rainforest zone, leguminous crops can be combined in the field with root and tuber crops (cassava and yam) and vegetables. The advantage of this system is the availability of nutritious food from different crops, insurance against climate induced failure of one crop and soil nutrient enrichment. Thus, crop mixture is an agricultural intensification technology suitable for a changing climate. A cooler microclimate from increased leaf cover of intercropping system will further reduce the soil temperature and water evaporation (Miao *et al.*, 2016). Land under legume intercrop have been reported to provide higher C sequestration, N storage and enriched microbial diversity (Gan *et al.*, 2011; Layek *et al.*, 2018).

Vetiver grass buffer strip and agroforestry practice. Vetiver grass buffer strips (VGBS) planted along the contour at intervals of 3 m to 5 m will adequately protect the soil against wind and water losses. As an additional benefit, it provides adequate mulch material and improves water economy within the rooting zone. Improvement in soil structure and general soil health of farmers' fields under VGBS had been reported Layek *et al.*, 2018). In the long-term, vetiver improve soil carbon, N, P, K, Ca, Mg Na (Oku, 2011). The VGBS act as a barrier that intercepts water, reduce the velocity of runoff, cause more water to infiltrate the soil and trap eroded sediments (Oku and Aiyelari, 2014; Oku, 2018). The uniqueness with vetiver hedge is, it continues to act as a continuous natural filter to running water and sediments while continuously producing mulch material for the farmer (Oku *et al.,* 2014). The long-term effect of VGBS is that vetiver will improve soil chemical, physical and biological qualities of the farmers' fields (Oku *et al.,* 2011).

Agroforestry practice combines multipurpose tree species (MPT) and field crops in the same field. The practice helps to protect the soil against water and wind erosion and fruit trees can be grown in narrow strips along the contour (Megersa, 2011). The canopies of the trees intercept raindrops and reduce its impact on the soil. Leguminous trees in the system add nitrogen to the soil through its leaves litters and nitrogen fixing process. The leaves or prunes from the trees is a good source of organic mulch, green manure and feeds for cattle and domestic animals. The waste from the animals is returned to the soil as an amendment to increase fertility of the fields. On slopes, the trees stabilize slumping or sliding land. Agroforestry practices, though not common in the Sudano-Sahelian zone need to be encouraged as it will provide an alternative firewood source thus reducing the destruction of existing vegetation.

Mycorrhizae for rehabilitation of low productivity soils of Sudano-Sahelian and Humid Forest Zones. Arbuscular mycorrhizal fungus (AMF) is one of the nature's ecological engineers living and working in the soil. When present in the soil it has the inherent potentials to aid and accelerate the recovery of degraded lands across. The benefits of AMF to the soil and the farmer are numerous (Godfray *et al.*, 2010). Mycorrhizae improves nitrogen fixation, alleviate Al and Mn toxicity and aid increase uptake of P by crops (Barea, *et al.*, 1991; Cardoso and Kuyper, 2006). The fungus contributes immensely to improving the chemical, physical and biological soil health status and enhance ability of the plant to absorb nutrients. It has been observed that AMF traps carbon and sequester it in the soil (Miller and Jastrow, 2000). Increase in SOC is directly proportional to increase in the SOM. Mycorrhizal symbiosis has been noted to effectively suppress plant biotic and abiotic stress (Cameron *et al.*, 2013; Odoh and Oluwasemire, 2015). This is besides, the reduced dependence on inorganic fertilizer when the nature's engineer is adequately present in the soil.

Soil of both the Sudano-Sahelian and Humid Forest zone is sand in texture thus, behaving as sieve. The rainfall for Sahelian zone is inadequate to support a full cropping cycle. The inclusion of mycorrhizae in the soil management will curb the adverse effect of moisture stress on the crops. The AMF ramifies the soil holding soil particles together and tighter. This action improves the stability of soil, with the binding of soil particles together (Mardhiah, *et al.*, 2016). Continuous tillage and overuse of inorganic fertilizer could adversely affect the population and diversity of soil fungi such as mycorrhizae (Mardhiah, et al., 2016). The challenges of inoculation in terms of cost and the effectiveness of exotic inoculums could be averted with good

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soil management in farmers' fields (Nyamwange, *et al.*, 2018). Exploitation of indigenous AMF in these degraded soils could be carried out through the incorporation of appropriate cropping systems such as conservation tillage, legume-based intercropping, reduced use of pesticides as well as improved organic inputs (Verbruggen, *et al.*, 2010). Also, through mulching, green manuring, organic manure and compost using available agricultural waste and animal manure.

Physical land management practices

Use of contour farming and use of organic mulch. Contour farming is a low input soil conservation and water management technology for curtailing and controlling erosion on sloping farmland. Contour farming consists of making ridges across the slope instead of up and down (parallel) the slope (Megersa, 2011). In contour farming or cultivation, contour acts as barriers to runoff while the furrow acts as a small basin that traps and store water and improve infiltration. The trapped water gradually infiltrates the soil thus improving water economy within rooting zone for plant use. This water otherwise would run over the field, carrying away soil particles and nutrients away from the farmers' field. Mulch materials on the soil surface reduces or prevents moisture evaporation, protects the soil surface from destructive raindrops. Organic mulch and mulching also creates a favourable microclimate within the soil surface and subsoil for macro and micro biological activities. In the humid forest zone, organic materials are readily available as mulch and farmer need to be tutored and encourage to practice the act of mulching. In the Sudano-Sahelian belt of Ghana having adequate biomass for use as mulch remains a major challenge (Oku *et al.*, 2017). This is because the biomass competes as animal feed to cattle and domestic ruminant animals, firewood, thatch house construction and roofing materials for the community (Verbruggen, *et al.*, 2010). Similar observation had been made in some communities in the middle altitude and lowland areas of Woreda of Ethiopia (Megersa, 2011). However, introduction of VGBS in farms is a sustainable solution to production of organic mulching material.

Conclusions

The native fertility of the soils of Sudano-Sahelian and Humid Forest zones of West Africa is unable to sustain crop production and meet SDGs 1, 2, 13 and 15 and will require a combination of chemical, physical and biological soil management strategies to contribute to achievement of SDG. The soils are dominated by sand fractions. This makes soil aggregation, nutrients and water retention difficult. The SOC in all the fields were low. Soil pH values were acid to near neutral. TN were high in Sudano-Sahelian zone while it was low in the Humid Forest area characteristics of the high rainfall zone. The ECEC puts both soils in the medium fertility class indicating it will response to amendments and wise management practices. The introduction or increase in the population of Arbuscular mycorrhizal fungus (AMF), a natural soil engineers will enhance and speed the recovery of degraded lands. The mix of use of minimal chemical inputs, physical and biological management strategies will give a comprehensive sustainable soil management package.

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