Enhancing Soil Productivity in Ghana through the Use of Leguminous Cover Crops and Tillage Practices

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Abstract

Soil fertility in Ghana is low and rapidly declining due to inappropriate soil management practices. This review examines the role of leguminous cover crops and tillage practices in building and sustaining the fertility of soils for enhanced productivity. A trial in the forest zone of Ghana evaluated the effect of two main tillage practices {minimum (MT); full tillage (FT)} and 4 cropping systems; maize/mucuna + 30-20-20kg N-P_2O_5-K_2O ha^{-1}(MMF1), maize/pigeon pea + 30-20-20 kg N-P_2O_5-K_2O ha^{-1} (MPF1), maize/cowpea + 30-20-20 kg N-P_2O_5-K_2O ha^{-1}(MCF1), sole maize + 60-40-40 kg N-P_2O_5-K_2O ha^{-1}(SMF2), sole maize + 30-20-20 kg N-P_2O_5-K_2O ha^{-1}(SMF1). After 4 years of continuous cultivation, MPF1 under MT (3.41t ha^{-1}) and FT (3.45 t ha^{-1}) gave the highest maize yield. SMF1 (0.48 t ha^{-1}) gave the lowest grain yield. A separate trial in the forest zone on a 5^o slope showed that FT with sole maize and removal of maize stover resulted in significant soil lost (4.61t ha^{-1}) and low maize yield. (2.33 t ha^{-1}). FT under maize/cowpea rotation and incorporation of maize and cowpea stover, soil lost was significantly low (0.75 t ha^{-1}) with higher grain yield (4.23 t ha^{-1}). Low soil lost (0.37 t ha^{-1}) and high grain yield (4.34 t ha^{-1}) was also obtained under MT with maize/cowpea rotation with plant residue used as mulch. MT under sole maize with maize stover as mulch gave very low soil lost (0.27 t ha^{-1}) but maize yield was also low (2.4 t ha^{-1}). At Nyankpala after a two year callopogonium fallow maize was grown in the third year. MT with residue applied as mulch gave similar maize grain yield (4.1 t ha^{-1}) as FT and residue removed with application of 40 kg N ha^{-1} (4.6 t ha^{-1}). In the Savanna zone, mucuna was intercropped with maize at three different stages. Maize grain yield was significantly higher for the control in the first year but the least in the third year. Maize yield was highest at 6 WAP in the third year. Inclusion of appropriate leguminous crops in cropping systems in Ghana with incorporation of plant residue or as mulch is recommended. Minimum tillage in combination with leguminous crops will minimize soil erosion and improve crop yields. These good options need scaling up for the improvement of soil productivity.

Keywords: agro-ecological zone, biological practices, cropping system, leguminous crops, residue management, tillage

Introduction

Sustainable agriculture aims at meeting the needs of the present population without compromising the productive potential for the next generations (Agovino et al., 2019). Smallholder farming practices are mostly not sustainable and currently do not achieve expected yields (MoFA, 2019 and 2015). According to MoFA (2019), over 60% of the Ghanaian population depend on agriculture for their livelihood. Most farmers are resource poor and unable to obtain the necessary inputs for their farming activities (Kumasi et al, 2019; Vlek et al., 2017).

Even though most soils in Ghana are low in plant nutrients, the situation is worse in the north, mainly occupied by the Sudan and Guinea savannah agro-ecological zones (Debpuur et al., 2021). According to Issaka et al (2008), soils of northern Ghana and parts of the Coastal Savanna are mostly *Savanna Ochrosols* (WRB: *Lixisols/Luvisols*). These soils are highly weathered and moderately to strongly acid in the top horizon. Organic matter is low and hence soil fertility is generally low (Abubakari and Abubakari, 2020). *Forest Ochrosols* (WRB: *Acrisols/Alisols/Lixisols/Ferralsols/Nitisols/Plinthosols*) are predominant in the forest zone and parts of the forest- savanna transition. These soils are deeply and highly weathered and generally moderately to strongly acid (Ibrahim et al., 2020) in the top horizon. They have high organic matter content in the top horizon, which may contribute significantly to the fertility status of these soils (Awoonor and Degbey, 2021). Soil fertility is low but slightly better than the *Savanna Ochrosols*. The *Forest Oxysols* (WRB: Ferralsols/Acrisols), however, occur in the high rainfall zone (south-west of Western Region). These soils are deeply and highly weathered but have high organic matter and hence a very high potential in influencing the fertility status of the soil. P fixation is very high due to the presence of large amounts of Al and Fe oxides (Ibrahim et al., 2020). Most soils in the country are inherently low in soil nutrients and are continually declining due to cultivation (Buri and Issaka, 2019).

To improve and sustain crop production, beside optimizing the use of inputs there is the need to develop improved and appropriate cultivation practices. Resource poor famers most often than not are able to obtain less than the recommended quantities of fertilizers for their activities. Use of biological materials (plant materials) have the potential to increase the organic matter content of the soil and many of the plant nutrients necessary to increase production (Adjei-Nsiah 2019; Quainoo et al 2008; Abunyewa and Karbo; Nyalemegbe and Osakpa, 2012). Use of these plant materials coupled with tillage practice have improved crop yields significantly (Kombiok et al, 2012, Issaka et al, 2016). Several authors have demonstrated the role leguminous cover crops and tillage practices play in improvement soil management leading to better crop yields (Begam et al., 2020; Kocira et al., 2020; Bacq-Labreuil et al., 2019; Nouri et al., 2020).

This paper reviewed some works on biological and tillage practices with high potential in improving soil fertility in Ghana. The paper aims to bring to scientists, agricultural trainers, farmers, NGOs and policy makers, (i) available and improved biologically soil fertility enhancing practices in Ghana and (ii) information as to the kind of practice to adopt/adapt considering the location and the objectives of the cropping system.

Materials and Methods

Both primary and secondary data were used in this study. Primary data comprised studies conducted by the authors in various parts of the country. Secondary data include published data from various works done in the country in books, journal articles, internet, annual and technical reports.

Results and Discussion

Biological Interventions in Improving Soil Fertility

Biological interventions include the use of leguminous cover crops, shrubs and other plant materials to improve the level of available nutrients for the benefit of the environment and ultimately improve the yields of crops. Critical factors for implementing a successful biological intervention management program is determined by the objectives and function of a chosen leguminous crop or shrub. Site specification, timing, and cropping history are all factors to consider in choosing the most appropriate leguminous crop/shrub species to introduce into a system.

Some specific reasons to implement leguminous crops/shrubs into a crop management regime include: to slow erosion, improve soil health, enhance water infiltration, smother weeds, control pests and diseases, and increase biodiversity.

Some of the common leguminous cover crops and shrubs used are presented in Table 1. The selection of a cover crop or shrub should take into consideration the agro-ecological zone and the farming system. *Pueraria* species, for

TABLE 1

Some leguminous crops and shrubs commonly used in Ghana

Crop	Growth Structure	Growth Type	Recommended Area
Mucuna pruriens	Cover crop	Annual	All agro-ecological zones
Pueraria sp	Cover crop	Biennial	Forest agro-ecological zone
Centrocema sp	Cover crop	Annual	All agro-ecological zones
Cowpea sp	Cover crop	Annual	All agro-ecological zones
Dolicus lablab	Cover crop	Annual	All agro-ecological zones
Canavalia ensiformis	Cover crop	Annual	All agro-ecological zones
Callopogonium sp	Cover crop	Annual	All agro-ecological zones
Pigeon pea sp	Shrub	Perennial	All agro-ecological zones
Groundnut	Cover crop	Annual	All agro-ecological zones

TABLE 2

Total dry weight, biomass produced and maize grain yield after incorporation of leguminous crop biomass compared to inorganic fertilizer

Leguminous crop	Total dry wt. (t ha^{-1})	Total biomass N (kg ha^{-1})	Maize grain yield after biomass incorporation (t ha^{-1})
Determinate Cowpea	1.85	74.0	1.8
Indeterminate Cowpea	2.80	75.6	2.5
Soybean	1.90	91.2	2.1
Bambara nuts	1.89	7 0.0	2.2
Groundnut	1.85	83.0	3.3
Inorganic fertilizer			3.2
LSD (5%)			*1.4*

Adapted: Nyalemegbe and Osakpa (2012)

example, is effective when used as a cover crop in oil palm plantation in the Forest agro-ecological zone but is less effective when grown in the Savannah agro-ecological zone.

Some biological interventions being practiced in the country include but not limited to the following:

Improved Fallow and Tillage Practices

Fallow generally describes a situation where the soil is put out of cultivation to allow for the fertility status to improve. This practice usually requires a long period ranging from at least 5 years to more than 10 years. However, land availability is of prime importance and determines the length of time the soil can be allowed to recuperate. Increasing pressure on land has resulted in the shortening of fallow duration (FAO, 2006).

Improved fallow requires the introduction of fast growing leguminous crops or shrubs that are capable of producing large amounts of biomass or can fix enough nitrogen within short periods. In areas with well-defined major and minor rainy season periods, rotations can be within a year. Under such cases, leguminous crops should be planted during the minor season. Leguminous cover crops have been used to improve the fertility of the soil resulting in increased crop yields particularly cereals. In the Semi-deciduous agro-ecological zone, Nyalemegbe and Osakpa (2012) evaluated the soil improving qualities of four (4) grain legumes (Table 2). They observed that all the legumes contain at least 70 kg ha^{-1} N in their biomass. After incorporating the plant biomass into the soil, maize grain yield was observed to be similar to maize yield when inorganic fertilizer was applied.

In the Savannah agro-ecological zone, Kombiok et al (2012) observed a significant increase in maize grain yield after a two-year *Callopogonium* fallow (Fig. 1). When the residue was applied as mulch with no addition of mineral fertilizer grain yield was similar to when the residue was removed and 40 kg N ha^{-1} was applied. The highest grain yield (> 5.0 t ha^{-1}) was obtained when in addition to the incorporation of plant residue, 40 kg N ha^{-1} was applied. These results clearly define the importance of legumes in improving the productivity of our soils, especially under resource poor farmer conditions.

Quainoo et al (2008) working in the Savanna agro-ecological zone observed that Crotalaria species produced large amounts of biomass and accumulated large amounts of nutrients at a high seeding rate of 100 kg ha^{-1}. This improvement of fertility levels translated into better maize yield. Similarly, studies by

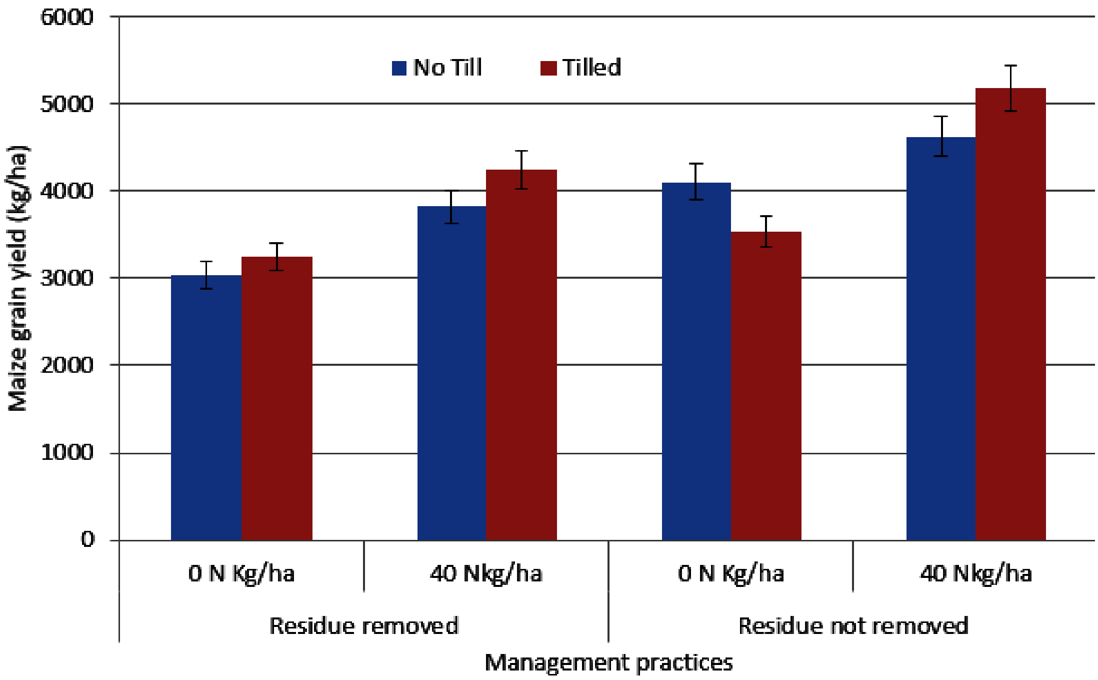

Figure 1 Maize grain yield after two years of *Callopogonium* fallow and four management practices

Abunyewa and Karbo (2005) using pigeon pea also resulted in an increase in soil organic matter over the control by 30.5%; 48.5% increase in total nitrogen and 17.8% increase in cation exchange capacity. Generally, soil organic matter status and nutrient accumulation occur when a leguminous crop is introduced into the fallow system.

Crop Rotation and Tillage Practices

Crop rotation may be described as the growing of different crops in a well-defined sequence on the same piece of land such that at least one crop benefits. In each growing season, a different crop is grown on the same land. For example, in southern Ghana maize and cowpea can be rotated on the same piece of land within the same year (maize-cowpea) as there are two growing seasons. However, within the savanna regions this will be done yearly since there is only one growing season/ cropping season in a year.

The key objective of crop rotation is to ensure that at least one of the crops benefits from the system. Some of the expected benefits may include nitrogen fixation, reduced pest and diseases, and reduction of nutrient competition due to different root structure and depth of exploitation. Rotation therefore ensures better exploitation of the soil and sustainable crop production. The most widely grown legumes in farming systems of Ghana are the grain legumes (groundnut, cowpea and soybean). These crops have advantage over other legumes in that they provide direct economic benefit (either yield for food or for cash). According to Kombiok et al (2012), despite these advantages, farmers only plant these crops when there is a ready market for the grain. Generally, farmers tend to grow grain legumes only on small proportions of their land, and certainly not sufficient to provide a rotation across the farm. According to the authors, analyses in northern Ghana, where farmers indicated that their normal rotation is cereal/legume, showed that the actual area sown to the legume was often less than 30% of the farm area. Further investigations indicated that crop rotations tended to be practiced more on the fertile 'home-fields' than on the poorer outfields.

The importance of crop rotation has been mentioned by several authors. According to Nsiah (2012), in the semi-deciduous, forest and forest/savanna transitional agro-ecological zones, pigeon pea/maize rotation significantly improved maize yield. According to the author maize yield increased by 75% in

TABLE 3

Effect of tillage, crop rotation and residue management on soil erosion and maize grain yield on a 5 ^{o} slope

Tillage	Cropping System	Residue Management	Eroded Soil (t ha^{-1})	Maize yield (t ha^{-1})
Full Tillage	Sole Maize	Removal	4.61a	2.33b
Full Tillage	Maize-Cowpea	Incorporated	0.75b	4.23a
Minimum Tillage	Maize-Cowpea	Mulch	0.37b	4.07a
Minimum Tillage	Sole Maize	Mulch	0.27b	2.41b

Within a column, numbers followed by similar letters are not significantly different at LSD 5% Issaka et. al (SRI annual report 2015)

the forest/savanna transition and 200% in the semi-deciduous forest. The author mentioned land tenure as one of the major reasons why the practice is not wide spread. Bonsu and Asibuo (2013) rotated three legumes (mucuna, canavalia and soybean) with maize at Ejura in the forest agro-ecological zone. They observed that the effect of the legumes on maize grain yield varied depending on crop type as follows: mucuna (2.3 t ha^{-1}), canavalia (1.6 t ha^{-1}) and 1.0 t ha^{-1} for soybean. The authors further stated that when 60 kg of urea was applied, maize grain yield increased significantly indicating that the legumes did not provide enough N for the maize crop. Dry matter produced by the legumes was more than 3.0 t ha^{-1}.

Horst and Härdter (1994) showed large maize yields in northern Ghana following cowpea. In a review on crop rotation in northern Ghana, Kombiok et al. (2012) stated that various field experiments have shown that crop rotation of maize with various legumes was beneficial for maize production and that maize following groundnut often had the greatest yields when compared with maize following other legumes. According to the review, yield response of cereal crops following a legume can be substantial. In Ghana, the grain yield of sorghum crop following groundnut averaged 30-40% higher than the yield of continuous sorghum. In all the studies, crop residue was not removed from the field after harvest. Nonetheless, under farmer conditions crop residues are often removed from the field at harvest so they do not provide the much needed mulch cover. Removal of crop residue reduces nutrient releases through decomposition and the soil improving effect of organic matter.

A study was conducted in the forest agro-ecological zone on a 5^{o} slope to evaluate the effect of rotating maize and cowpea in combination with tillage on maize yield and soil erosion. Continuous cultivation of sole maize coupled with the removal of crop residue resulted in significant high soil erosion and low maize grain yield (Table 3). Under sole maize with crop residue as mulch, eroded soil material was low with accompanied low grain yield. When maize was rotated with cowpea and crop residue were either incorporated (tilled) or left on the soil surface as mulch (no-till), soil erosion was low but grain yield was significantly higher than continuous maize cultivation.

The study showed that tillage, legume-cereal rotation and residue management have very strong influence on soil erosion and yield of cereals. The use of leguminous cover crops is more important when cereals are cultivated on steep slopes.

Intercropping and Tillage Practices

Intercropping is the growing of two or more crops on the same piece of land. The objectives for crop selection should include the avoidance/minimization of competition for nutrients or shade. The inclusion of a leguminous crop is to improve the fertility status and minimize soil erosion.

In the Forest agro-ecological zone, Issaka et al. (2016) observed significant yield differences

TABLE 4

Effect of tillage practice and cropping system on maize yield

Tillage practice	Cropping System	Grain Yield (t ha^{-1})			
		2011	**2012**	**2013**	**2014**
Minimum Tillage	Maize/M+F1	5.05a	3.23a	2.36bcd	2.30b
Minimum Tillage	Maize/Pp+F1	4.36a	2.88ab	3.34a	3.41a
Minimum Tillage	Maize/C+F1	6.18a	2.38ab	2.21cd	2.25b
Minimum Tillage	Maize + F2	4.84a	2.35ab	1.97de	2.09b
Minimum Tillage	Maize + F1	4.65a	2.15b	1.09e	0.48c
Full Tillage	Maize/M+F1	6.58a	2.48ab	3.12abc	2.08b
Full Tillage	Maize/Pp+F1	6.88a	2.80ab	3.31ab	3.45a
Full Tillage	Maize/C+F1	5.32a	2.58ab	2.21cd	1.74b
Full Tillage	Maize + F2	5.33a	2.68ab	2.20cd	2.11b
Full Tillage	Maize + F1	4.85a	2.28ab	1.80de	1.54b

M: Mucuna; Pp: Pigeon pea, C: Cowpea. F1:30-2020 kg N-P_2O_5-K_2O ha^{-1}, F2:60-40-40 kg N-P_2O_5- K_2O ha^{-1}

(Table 4) when maize was intercropped with three leguminous crops (mucuna, cowpea and pigeon pea). During the four (4) years of continuous cropping there was an initial decline in grain yield for all the treatment combinations, particularly in the second year. While grain yield became almost stable but improved in the third and fourth years for the maize-leguminous crop, the sole maize treatments showed continuous decline. In the fourth year, maize-pigeon pea intercrop gave the highest grain yield under both full and minimum tillage.

Studies also conducted on a 5^{o} slope in the Forest agro-ecological zone showed that maize grain yield was significantly higher when maize was intercropped with either mucuna or pigeon pea than under sole maize (Table 5a). While grain yield under sole maize declined in the following year, maize yield was similar for the two years when it was intercropped with mucuna or pigeon pea.

On the same slope, soil erosion was observed to be significantly higher under sole maize than when it was intercropped with mucuna or pigeon pea (Table 5b). Soil erosion generally declined in the second year due to accumulation of plant biomass, however,

TABLE 5a

Effect of intercropping maize and a legume on maize grain yield

Tillage Practice	Cropping System	Residue Management	2014	2015
			Maize grain yield (t ha^{-1})	
Full Tillage	Sole Maize	Incorporated	2.33b	1.20b
Minimum Tillage	Maize-Mucuna	Mulch	4.23a	3.97a
Minimum Tillage	Maize-Pigeon pea	Mulch	4.07a	3.42a

Within a column numbers followed by similar letters are not significantly different at LSD 5% Issaka et al (Unpublished)

TABLE 5b

Effect of intercropping maize with a legume on soil erosion on a 5^{o} slope

Tillage Practice	Cropping System	Residue Management	2013	2014
			Eroded soil(t ha^{-1})	
Full Tillage	Sole Maize	Incorporated	10.73a	8.26a
Minimum Tillage	Maize-Mucuna	Mulch	3.24b	1.53b
Minimum Tillage	Maize-Pigeon pea	Mulch	2.90b	1.00b

Within a column, numbers followed by similar letters are not significantly different at LSD 5% Issaka et al (Unpublished)

TABLE 6
Effect of time of Planting Mucuna on Maize Grain Yield

Treatments	Maize Grain Yield (kg ha^{-1})		
	1996	1997	1998
Control	1800 a	1180 b	1050 d
Six (6) Weeks After Planting	1500 b	1620 a	1850 a
Eight (8) Weeks After Planting	1130 c	1110 b	1650 b
Ten (10) Weeks After Planting	1100 c	1530 a	1250 c

Within a column, numbers followed by similar letters are not significantly different at LSD 5% Source: Kombiok et al 2012

eroded soil material under sole maize was still very high. The importance of intercropping with a legume especially on a slope is further confirmed.
In a similar manner, mucuna was intercropped with maize at three different periods: Six (6) weeks after planting (WAP) maize, 8 WAP, 10 WAP and a Control) at Nyankpala within the Guinea Savannah agro-ecological zone. Maize grain yield was significantly higher for the Control (1.8 t ha^{-1}) than the other treatments in the first year (Table 6). However, by the end of the third year maize grain yield was significantly higher for the 6 WAP (1.85 t ha^{-1}); followed by 8 WAP (1.65 t ha^{-1}) and 10 WAP (1.25 t ha^{-1}). The Control gave the lowest grain yield (1.05 t ha^{-1}) showing the role of the legume in enhancing and sustaining maize yield.

Limitations
The role of leguminous cover crops in improving soil productivity has been demonstrated and observed by many scientists to be effective in many parts of the country. Adoption of leguminous crops as soil improver or weed suppressor is rather low. Some of the limitations include:

Availability of seeds: Apart from the edible leguminous crops (cowpea, groundnut and soya bean) it is difficult to obtain seeds from the market or input dealers. Interested farmers may get some from their colleagues.
Economic value of the crop: Most farmers shy away from leguminous crops that do not give them immediate economic value. Generally, the edible leguminous cover crops are preferred to crops that do not have immediate economic value.
Problems associated with poor management: Most leguminous cover crops that produce large amounts of plant biomass are aggressive and can easily become pest. When maize is intercropped with mucuna, the yield of maize will decreased dramatically as the mucuna smothers the maize unless the mucuna is planted six weeks after planting the maize.

Conclusion and recommendations

From the above review, the following conclusions were arrived at:
(i) Most soils in the country are inherently low in plant nutrients.
(ii) To improve and sustain crop productions it is important to raise the fertility levels of these soils.
(iii) That these soils can be improved through proper management of leguminous crops and the appropriate tillage practices.
(iv) Selection of a particular management practice and/or leguminous crop should be based on a clearly stated objective.

Some of the recommendations include the following:
(i) Policy directive from the District Assemblies to facilitate the adoption of the aforementioned good agronomic practices by smallholder farmers;

(ii) Clear identification and selection of practices appropriate for the agro-ecological zone;
(iii) Encourage seed production of some important leguminous crops to ensure availability and affordability.

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