Effect of Pre-Crop Type on Growth and Yield of Maize on Two Soils in the Guinea Savanna Zone of Ghana

B. D. K. Ahiabor*, M. Fosu and I. Tibo
CSIR-Savanna Agricultural Research Institute, P. O. Box 52, Tamale, Ghana
*Corresponding author; E-mail: bahiabor@yahoo.com

Abstract

Mucuna (black type) (*Mucuna pruriens* var. *utilis*), devil-bean (*Crotalaria retusa),* cowpea (*Vigna unguiculata*), maize (*Zea mays* L.) and sorghum (*Sorghum bicolor* Moench.) were grown as preceding crops to maize in a Ferric Luvisol and a Haplic Luvisol in the Guinea savanna zone of Ghana in June 2001. Their effects on growth, grain yield and arbuscular mycorrhiza formation of the following maize in a rotational system were assessed. A non-fertilized weedy fallow treatment was also included as control. Each of the legume pre-crops received 40 kg P ha^{-1} and 30 kg K ha^{-1} whereas the cereals received 60-40-30 kg N-P-K ha^{-1}. The legume biomasses were incorporated into the soil in June 2002, two weeks before maize was planted and grown to maturity. Each of the legumes produced over 5 t ha^{-1} of biomass within the cropping season. Devil-bean tended to be the most efficient in increasing maize grain yield (4.04 t ha^{-1} in the Ferric Luvisol and 1.2 t ha^{-1} in the Haplic Luvisol). This is probably due to its relatively higher mean shoot N accumulation across the two locations (214 kg N ha^{-1}) and its greater stimulation of mycorrhizal fungal colonization (25.5%) in the following maize, especially in the Haplic Luvisol. Devil-bean and mucuna generally enhanced maize stover growth. Devil-bean can, therefore, produce significant benefits when used as a preceding crop to maize in a rotational system.

Introduction

With the increasing population growth in Ghana, pressure on land has led to utilization of marginal lands resulting in wide deforestation, increased soil erosion, leaching and low organic matter content of the top soils. There is, therefore, an overall reduction of soil fertility and, consequently, reduction in levels of crop yield (Hubert, 1983). Reliance on long fallow periods has ceased to be an option for restoring soil fertility in Ghana. Widely used alternatives to the long fallow periods in-between the cropping phases involve the use of organic mulches of tree, shrub pruning or leguminous cover crops for improved fallows (Banful *et al*., 2007). The decomposition and nutrient release of the organic materials are key processes by which nutrients locked up in the plant residue eventually become available to crops (Nziguheba *et al*., 2005). These processes in the soil are influenced by biomass yield (Sanginga *et al*., 1996), chemical composition (Tian *et al*., 1992), residue placement (Mafongoya & Nair, 1997) and abiotic factors, such as climate and soil conditions (Mugendi & Nair, 1997), but also by other agronomic management practices. Inorganic fertilizers have also become so expensive that many small-scale farmers cannot afford them and apply them in cultivating cereals, especially maize.

In spite of the notable adoption of high-yielding maize varieties (33-50% of Africa's maize area), the national per hectare increase in maize productivity is disappointing, due to the low and declining soil fertility (Fosu *et al*., 2004). The need to develop alternative farming systems, which could build up organic matter levels and improve the physical and chemical conditions of the soils for sustainable agriculture at affordable costs, is, therefore, urgent.

The use of leguminous cover crops for fallow management is advocated mainly because of their biological nitrogen-fixing capabilities. For instance, when cowpea is used as a cover crop it helps to suppress weeds, control erosion and, sometimes, encourage populations of beneficial insects to defend cash crops from insect pests (Valenzuela & Smith, 2002). In soils with low phosphorus, the roots of cowpea develop effective arbuscular mycorrhizal associations, thereby, improving the available P content of the soil (Ahiabor *et al*., 2007). Also, legumes, managed as green manures, have the potential to furnish all or part of the N needed by a succeeding non-legume crop. Legume cover crops and green manures may contribute as much as 110 kg N ha^{-1} (Tian *et al*., 2000) to the subsequent cereal crop. The legume cover crops have been shown to increase grain yields of subsequent maize compared to continuously grown maize (Tian *et al*., 2000). These legumes are also involved in the cycling of other nutrients through the decomposition and mineralization of their biomass (Cheruiyot *et al*., 2003).

A number of studies has been done on mucuna, devil-bean and cowpea and their use as fallow crops (Agyenim Boateng, 1997; Fosu *et al*., 2004). Few of such studies involved ploughing back their biomass/residues into the soil apart from using them as mulch. In this study, therefore, a management system in which leguminous cover crops and cereals were grown as pre-crops and their biomass/residues ploughed back into the soil and maize cultivated in the subsequent year was assessed in the Guinea savanna agro-ecological zone of Ghana.

Materials and methods

The experiments were conducted on two soils, Ferric Luvisol and Haplic Luvisol, located at Nyankpala (09° 22.481' N and 000° 38.706' W) and Damongo (09° 02.652' N and 001° 48.308' W), respectively, in the Guinea savanna agro-ecological zone of Ghana. The mean annual temperature of this zone is about 28 °C, and the mean annual precipitation is about 1100 mm. The rainy season lasts for 5-6 months (May-October), and the rains are usually highly intensive and erratic.

Soil analysis was done at the soil and plant analytical laboratory of CSIR-Savanna Agricultural Research Institute, Nyankpala. Soil *p*H was determined in a 1:1 suspension of soil and 0.01 $CaCl_2$ using a HI 9017 microprocessor *p*H meter (Jackson, 1969). Organic matter was determined by a modified Walkley and Black procedure, as described by Nelson & Sommers (1982), and total nitrogen was measured by the Kjeldahl digestion and distillation procedure. Exchangeable bases (calcium, magnesium and potassium) in the soil were determined in 1.0 *M* ammonium acetate (NH_4OAc) extract (Black, 1986). Available phosphorus was estimated by the Bray-1 method, whereas cation exchange capacity (CEC), and base saturation were determined by the method of NAES (1985). Texture of the soil (sand, silt and clay) was determined by the hydrometer method.

During the cropping season of 2001, mucuna (*Mucuna pruriens* var. *utilis*) (black type), devil-bean (*Crotalaria retusa*) and cowpea (*Vigna unguiculata*) were grown as legume pre-crops on 6 m × 4 m plots and fertilized with P (as triple superphosphate) and K (as muriate of potash) at the rates of 40 and 30 kg ha^{-1}, respectively. Maize (*Zea mays*), sorghum (*Sorghum bicolor* Moench.) and weedy fallow treatments were also established. The cereals received 60 kg N ha^{-1} applied in two splits, 30 kg K ha^{-1} and 40 kg P ha^{-1} (maize), and 30 kg P ha^{-1} (sorghum). All the crops grew to their respective pysiological maturity stages when the grains of cowpea and the cereals and the seeds of mucuna were harvested. Apart from devil-bean, which was allowed to grow into the next season (being a perennial crop), the residues of all the crops were left on the field to decompose.

In 2002, the growing devil-bean plants were slashed and left on the plots for 30 days. The dry devil-bean biomass, the dry residues of the other legume crops and the biomass of the fallowed weed were ploughed back into the soil to a depth of about 10 cm using a hoe. Virtually all the maize and sorghum residues had been removed from the plots by the local women for fuel. The ploughed plots were then sown to a 120-day maize variety (*Okomasa*) at inter- and intra-row distances of 80 cm and 40 cm, respectively, 2 weeks after incorporation (WAI) and fertilized with 40 kg P and 30 kg K ha^{-1}.

Before incorporation of the legume materials into the soil, sub-samples of the materials were taken and finely homogenized with a mechanical grinder. These were digested with concentrated sulphuric acid and hydrogen peroxide. Concentrations of N and P in these tissues were determined by the micro-Kjeldahl distillation and ammonium-molybdenum blue methods, respectively. Their N and P contents (uptakes) were computed as the product of the N and P concentrations and the weight of the biomass/residue, respectively.

At 8 weeks after sowing (WAS), two maize stands were randomly sampled per plot for the assessment of extent of arbuscular mycorrhizal fungal (AMF) colonization, using the gridline intercept method (Giovanetti & Mosse, 1980). Simultaneously, AMF spore populations in the maize rhizosphere were also estimated using the wet-sieving and sucrose density-gradient centrifugation method (modified from Daniels & Skipper, 1984). After harvest, the grains were sufficiently sun-dried on a concrete platform for 5 days and their weights measured. The dry weight of the stover which had been left on the field for about 2 weeks to dry thoroughly was also measured using a field spring balance.

Results and discussion

Some physical and chemical characteristics of the soils are presented in Table 1. The soils of the two locations are almost similar except that the Ferric Luvisol was richer in N and organic carbon, whereas the Haplic Luvisol had higher exchangeable K and available P. The two soils are comparable in their clay and sand contents but whereas about 30% of the Ferric Luvisol was composed of silt, only 5% of the Haplic Luvisol was of this fraction. The two soils can be classified as sandy but a higher porosity is suspected in the Haplic Luvisol. The Haplic Luvisol is also expected to experience a higher rate of release of P into the available pool.

Whereas devil-bean and cowpea produced higher dry matter on the Ferric Luvisol than on the Haplic Luvisol, the growth of mucuna was higher on the latter soil than on the former (Table 2). The dry weights ranged between 2.6 t ha^{-1} (cowpea) on the Haplic Luvisol and 10.6 t ha^{-1} (devil-

TABLE 1
Some physical and chemical properties of the soils used

Property	*Soil type* *Ferric Luvisol*	*Haplic Luvisol*
% Sand	67.1	71.1
% Silt	28.2	5.2
% Clay	4.7	3.7
*p*H (0.01*M* $CaCl_2$)	5.07	5.13
% Organic carbon	1.59	1.33
% Total N	0.13	0.05
Available P (mg kg^{-1})	8.4	9.2
Exch. K (cmol(+) kg^{-1})	0.23	0.28
Mg (cmol(+) kg^{-1})	0.6	0.63
Ca (cmol(+) kg^{-1})	1.51	1.52
CEC ($cmol^{(+)}$ kg^{-1})	5.02	5.11
Base saturation (%)	46.2	47.2

bean) on the Ferric Luvisol. Despite the fact that devil-bean grew into the next growing season it did not accumulate much dry matter on the Haplic Luvisol as in the Ferric Luvisol. Whereas the trend in biomass yield generally reflected on the N and P uptakes, Tables 2 and 3 reveal that N and P uptakes in devil-bean on the Ferric Luvisol are mainly due to the high shoot concentrations of these nutrients. Cowpea grown on the Ferric Luvisol concentrated a lot of P (Table 3) which resulted in an almost equal accumulation of P as in devil-bean despite cowpea's lesser biomass (Table 2).

In a previous publication of an experiment carried out on the same soil type, Ahiabor *et al*. (2007) reported a similar higher concentration of P in the stems of cowpea compared with those of devil-bean, *Canavalia ensiformis*, and mucuna (both black and white types). Cowpea, therefore, took up P from the non-labile pool in the more P-rich (total P) Ferric Luvisol more efficiently than the rest of the legumes. Although this P-uptake ability is often attributed to an enhanced arbuscular mycorrhizal colonination (Ahiabor & Hirata, 1995), this appears not to be the case with cowpea in this work, as the degree of AMF colonization of cowpea is very low compared to most of the other pre-crop treatments.

The phenomenon of a high nutrient (e.g. P) uptake being associated with a low rate of AMF colonization, observed in cowpea in this study, is sometimes encountered as some AM fungi colonize poorly but are highly effective in enhancing nutrient uptake. On the other hand, the generally low rates of AMF colonization of the roots of the crops, especially in the Haplic Luvisol, is suspected to have been due to a possible suppressive effect of the 40 kg P ha^{-1} applied to the pre-crops. This phenomenon may have been compounded in the Haplic Luvisol by the higher rate of P release suspected in this soil type (Table 1). Mosse (1981) reported that application of phosphate fertilizers to soil decreases the degree of infection of roots with AMF.

TABLE 2

Dry weights of biomasses of mucuna, devil-bean and cowpea and the N and P uptakes in the biomasses incorporated into two soils (Ferric Luvisol and Haplic Luvisol) in the Guinea savanna zone of Ghana

	Biomass weight (t ha^{-1})		*N uptake (kg ha^{-1})*		*P uptake (kg ha^{-1})*	
Pre-crop	*Ferric Luvisol*	*Haplic Luvisol*	*Ferric Luvisol*	*Haplic Luvisol*	*Ferric Luvisol*	*Haplic Luvisol*
Mucuna	5.7	9.62	92.91	187.62	7.88	16.05
Devil-bean	10.55	5.83	282.74	145.83	20.6	10.19
Cowpea	8.47	2.58	138.9	50.89	18.92	5.47
LSD (5%)	2.04	1.09	50.48	21.4	5.19	1.83

TABLE 3

Concentrations of N and P in the biomasses of mucuna, devil-bean and the residue of cowpea incorporated into two soils (Ferric Luvisol and Haplic Luvisol) in the Guinea savanna zone of Ghana

	Biomass weight (t ha^{-1})		*N concentration (%)*		*P concentration (µg g^{-1})*	
Pre-crop	*Ferric Luvisol*	*Haplic Luvisol*	*Ferric Luvisol*	*Haplic Luvisol*	*Ferric Luvisol*	*Haplic Luvisol*
Mucuna	5.7	9.62	1.63	1.95	1382	1668
Devil-bean	10.55	5.83	2.68	2.5	1953	1747
Cowpea	8.47	2.58	1.64	1.97	2234	2118
LSD (5%)	2.04	1.09	0.47	ns*	556.7	ns

* Not significant.

The highest populations of maize rhizosphere spores were obtained when maize was grown after a weedy fallow (Table 4). This apparently contradicts Douds *et al*. (1990) who reported that higher numbers of VAM (vesicular-arbuscular mycorrhizal) fungal spores were present in fields maintained with a cover crop than in fields left fallow. The leguminous "weeds" (such as *Stylosanthes* and *Calopogonium*) observed growing in the weedy fallow might have contributed to the higher spore populations observed. Thompson (1991) reported that pre-cropping with legumes generated the highest densities of residual VAMF spores which resulted in the highest dry matter accumulations of linseed.

Mean grain yields of maize following mucuna, devil-bean and cowpea were 3.83, 4.04, and 3.61 t ha^{-1}, respectively, on the Ferric Luvisol, with mucuna and devil-bean performing better (Table 5). Similarly, in studies carried out at two locations, Agyenim Boateng (1997) observed that mucuna (*Mucuna pruriens* var. *utilis*) green manure applications, especially when incorporated, resulted in higher increases of maize grain. Non-significant yield values of 1.11, 1.20 and 0.68 t ha^{-1} were, however, recorded on the Haplic Luvisol (Table 5). Weedy fallow treatment produced statistically the same weight of maize grain as the legumes, especially on the Ferric Luvisol. This might be partly due to the high arbuscular mycorrhizal activity observed in the weed fallow treatment especially in the Ferric Luvisol (Table 4). In addition, the uncultivated legume components (*Stylosanthes* and *Calopogonium*) of the weedy fallow, whose populations were not sampled, might have contributed to the increased maize grain yield probably through their biological nitrogen fixation activities. This observation about the weedy fallow contradicts the findings of Fosu (1999) that maize dry matter accumulations under a weedy fallow were the least among the treatments with devil-bean, mucuna and *Calopogonium mucunoides* grown as pre-crops.

The incorporated biomass of the pre-cultivated legumes, especially mucuna and devil-bean might have enhanced maize stover production on the Ferric Luvisol

Table 4

Influence of pre-crop type on rhizosphere AMF spore population and AMFcolonization of maize grown on two soils (Ferric Luvisol and Haplic Luvisol) in the Guinea savanna zone of Ghana

	AMF spore population (no./50 g air dry soil)		*AMF colonization (%)*	
Pre-crop	*Ferric Luvisol*	*Haplic Luvisol*	*Ferric Luvisol*	*Haplic Luvisol*
Mucuna	175	70	15.6	6.6
Devil-bean	138	84	13.5	25.5
Cowpea	171	110	11.6	8.9
Maize	150	63	10.7	6.7
Sorghum	152	98	15.4	13.8
Weedy fallow	215	121	31.6	9
LSD (5%)	59	51	8.9	7.47

Table 5
Influence of pre-crop type on stover and grain yields of maize grown on two soils (Ferric Luvisol and Haplic Luvisol) in the Guinea Savanna zone of Ghana

	Stover yield (t ha^{-1})		*Grain yield (t ha^{-1})*	
Pre-crop	*Ferric Luvisol*	*Haplic Luvisol*	*Ferric Luvisol*	*Haplic Luvisol*
Mucuna	10.05	1.18	3.83	1.11
Devil-bean	9.56	1.35	4.04	1.2
Cowpea	8	0.79	3.61	0.68
Maize	4.89	0.59	2.43	0.72
Sorghum	3.37	0.7	1.56	0.72
Weedy fallow	6.56	0.91	2.95	0.89
LSD (5%)	2.94	0.54	1.3	ns*

* Not significant

(Table 5). Similarly, Agyenim Boateng (1997) obtained higher maize stover yields when mucuna biomass was incorporated as green manure than in the control. Preceding maize with a weedy fallow stimulated arbuscular mycorrhiza formation in maize on the Ferric Luvisol, and this might be responsible for the high AMF spore population observed with this treatment. Also, weedy fallow tended to influence AMF spore density in the rhizosphere of maize better than in the other treatments. This could be attributed to the phenomenon of cropping sequence effects on species composition of AM fungi (Johnson & Pfleger, 1992).

The diverse plant cultures in the weedy fallow plot might have selected for AM fungi species that were superior mutualists than those in the other (monoculture) legume plots. Johnson *et al.* (1992) reported that continuous corn and soybean monocultures, selected for AM fungi that were inferior mutualists, caused yield decline in crops. The stimulation of mycorrhiza by weedy fallow was better in the Ferric Luvisol than in the Haplic Luvisol probably because of the lower available P content of the former (Table 1) since AM colonization can be suppressed at higher soil P levels (Mosse, 1981). In the Haplic Luvisol, however, arbuscular mycorrhizal colonization of maize was greatly enhanced when devil-bean preceded it. This observation may suggest that even the monoculture phenomenon may be crop species-dependent.

Devil-bean had the highest tendency to increase maize grain yield (Table 5), and this performance could be due to the relatively higher mean N accumulation (214.3 kg N ha^{-1}) in its shoot across the two soil types (Table 2). This organic N would be made available to the following maize through decomposition and mineralization of its incorporated biomass (Cheruiyot *et al.*, 2003). This ploughed-in biomass serves as organic matter, which is known to play an important role in improving the fertility and productivity of soil as it provides the soil with nitrogen, phosphorus, sulphur and other nutrients. It is also used as a substrate by soil microorganisms whose activities improve soil productivity. The high accumulation of N in devil-bean shoots observed in this study strongly agrees with similar findings by Ahiabor *et al*. (2007) and Fosu *et al*. (2004).

The use of devil-bean as a short fallow herbaceous legume and ploughing-in its biomass for enhanced maize production, especially in the unimodal agro-ecology of northern Ghana is, therefore, recommended. This recommendation becomes more important when the crop's perennial nature, tolerance to drought and bushfires, as well as its non-palatability to animals (through long-term field observation) are considered. This zone is characterized by only a single rainy season, bushfires and grazing by free-range animals that feed on crop residues left in the field during the long dry season.

Conclusion

Grain and stover yields of maize can significantly increase when grown after a legume whose residue or biomass is ploughed back into the soil. The better performance of the maize grown on incorporated legumes in this study, especially devil-bean, is strongly suspected to be due to improved fertility of the soil as a result of nutrient release from the decomposed and mineralized biomass incorporated. Further studies to investigate the physical, chemical and microbiological dynamics in the soil, following plant residue incorporation are, however, required to confirm this assertion.

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