Integrated Soil Fertility Management for Increased Maize Production in the Degraded Farmlands of the Guinea Savanna Zone of Ghana Using Devil-Bean (*Crotalaria retusa*) and Fertilizer Nitrogen

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Abstract The native N and P of soils of the Guinea Savanna Zone of northern Ghana are only about 20 and 10% of the crops' requirements, respectively, and organic matter content is usually below 1%. Hence, cereal yields without soil amendments are usually below 500 kg/ha. Organic residue and mineral fertilizer combinations are necessary to increase nutrient use efficiency. Devil-bean is a very promising leguminous cover crop for this agro-ecology. The best time to intercrop devil-bean in maize, effect of P on the maize, and the effect of incorporated devil-bean biomass on grain yield of N-fertilized maize were investigated. In 2003, devil-bean was drilled in maize at 1, 3, and 4 weeks after planting (WAP) the maize which received 0, 20, and 40 kg P/ha. Phosphorus enhanced maize growth and yield. The devil-bean biomass was incorporated into the soil in the 2004 growing season. Maize was planted, fertilized with 0, 20, and 40 kg N/ha, and intercropped again with devil-bean as before. About 40 kg N/ha fertilized maize grown on incorporated devil-bean intercropped at 1 WAP in 2003 had the highest grain yield of 1.59 t/ha. In 2005, the devil-bean intercropped in the 2004 40 kg N/ha maize at 3 WAP produced the highest biomass containing 42–88, 4–11, and 25–52 kg/ha of N, P, and K, respectively. Maize grain yield significantly increased with incorporated biomass with the highest biomass producing the highest grain yield. The cumulative effect of the biomass applications was significant in this study.

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Introduction

Soils in the Savanna zones of northern Ghana are generally poor in nutrient status, especially in available nitrogen and phosphorus and have low organic matter content. The native N and P of soils of the Guinea Savanna Zone of northern Ghana are only about 20 and 10% of the crops' requirements, respectively, and organic matter content is usually below 1% (Tiessen, 1989). Crop production in this area must always be backed by nutrient amendments for economic yield but unfortunately the mostly resource-poor peasant farmers in this agro-ecological zone cannot afford to buy the mostly expensive chemical fertilizers to ameliorate the effects of poor fertility of their farmlands. Even where the application of such chemical fertilizers is possible, nitrogen is the most frequently applied fertilizer and often the only nutrient element added to the soil. There are even some indications from literature (Hayman, 1982) that increasing levels of N fertilizers may inhibit arbuscular mycorrhizal (AM) formation and may negatively affect AM fungal population in the soil, thereby adversely affecting phosphorus uptake.

An alternative that has been used by such farmers for ages is biological nitrogen fixation (BNF) which involves the use of legumes (grain, herbaceous, and tree) as components of the farming systems found in this area. Such legumes are grown as sole crops in rotation, relay crops, or intercrops with cereals (sorghum, millet, or maize). The promotion of herbaceous legumes as relay or rotation crops with

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cereals is currently on the increase. These herbaceous nitrogen-fixing cover legumes have been excellent ways to supply substantial amounts of organic carbon, N, and recycled nutrients to annual crop rotation systems by returning the total biomass produced to the soil prior to planting cereals. The direct N benefit from a well-developed leguminous cover crop on the subsequent crop has been estimated by a number of authors, and it ranges between 50 and 100 kg N/ha (Greenland, 1985). Fosu (1999) also observed a range of 40–76 kg N/ha. *Canavalia ensiformis, Mucuna pruriens, Glycine max,* and *Vigna unguiculata* have been reported to potentially contribute considerable amounts of N to succeeding crops (Sanginga et al., 1996; Ravuri and Hume, 1992). The residual effects on the following crops are less certain and depend on both the qualities (decomposition rate) and time of incorporation of the organic matter as well as the soil conditions influencing N mineralization rate from the young organic matter (Cheruiyot et al., 2007). Apart from being a source of N and other nutrients, cover crops also provide protection against soil erosion, improve soil structure, and interrupt the cycles of diseases and insect pests.

The nitrogen fixed by these cover crops becomes available to the subsequent or companion cereal crops which are high nitrogen feeders. The nitrogen-fixing efficiency of the legume depends on the legume type, the degree of nodulation, and the nitrogen-fixing capacity of the nodules. In screening four legume species, Ahiabor et al. (2007) obtained relatively high values of dry matter, N_2 fixation, and N accumulation for devil-bean (*Crotalaria retusa*) which is a perennial legume with high tolerance to drought and bushfires.

Experiments were therefore conducted to determine the most appropriate time of intercropping maize with devil-bean and to determine the optimum P level required by the intercropped maize. The effect of the biomass of the incorporated devil-bean on growth and grain yield of maize when ploughed into the soil in the subsequent year and planted to maize and fertilized with mineral nitrogen was also studied.

Materials and Methods

Experimental Site

The experiment was set up on-station in the experimental field of the Savanna Agricultural Research Institute of the Council for Scientific and Industrial Research, Ghana, situated at Nyankpala (9°25″N and 0°58″W) in the Tolon–Kumbungu district of the Northern region of Ghana. This area experiences a monomodal rainfall pattern (April–October) with a mean annual rainfall of 1000 mm and a variability of between 15 and 20% (Kasei, 1988). The mean annual temperature is about 28°C with the daily maximum sometimes being around 42°C during the hottest months of February and March, and the lowest temperatures (about 20°C) are recorded in December and January when the area comes under the influence of the cold dry North-Easterly Trade winds (‘Harmattan’ winds) from the Sahara Desert.

The soil was classified as Gleyi-ferric Lixisol (FAO/UNESCO) with a pH of 4.5. Base saturation was 32% and CEC was below 4 $cmol^{+}$/kg. Organic matter was below 1% and total N was less than 0.4%. Available P was 14 mg/kg and exchangeable K was less than 40 mg/kg.

Experimental Procedures

In 2003, the best time to intercrop maize (Dorke SR) with devil-bean and also the optimum P level to apply to the maize were investigated. The devil-bean was drilled at 40 kg seed/ha in two rows 40 cm apart in between two maize rows on 6 m × 4 m plots at 1, 3, and 4 weeks after planting the maize. The planting distance for the maize (2 seeds per hill) was 80 × 40 cm. The maize received P application rates of 0, 20, and 40 kg P/ha as triple super-phosphate (TSP) in addition to 40 kg N/ha (as sulphate of ammonia) and 30 kg K/ha (as muriate of potash). Half of the nitrogen and all of the potassium were applied 2 weeks after emergence. The remaining nitrogen was applied 4 weeks later. The fertilizers were deposited in bands about 5 cm away from the maize stands. The devil-bean was also given 40 kg P/ha (as TSP) and 30 kg K/ha (as muriate of potash) which were applied the same way as for the maize. At full maturity, the maize was harvested minus the outermost rows. The cobs were de-husked, shelled, and the grains were spread on a concrete floor and sufficiently dried in the sun for 5 days and weighed. The devil-bean stands were, however, left to grow into the following year.

At the beginning of the 2004 growing season, the devil-bean biomass (stems plus leaves) was harvested by slashing at the base of the plant. Sub-samples of this matter were dried in a forced-air oven at 80°C for 48 h and weighed. The rest of the biomass was chopped into pieces by cutlass and evenly spread on the plots and then incorporated into the soil 20 cm deep by hoe. After 2 weeks, the triplicate plots were hoe-harrowed, and the same maize variety was planted at the same spacing and fertilized with 0, 20, and 40 kg N/ha (sulphate of ammonia) as well as with 30 kg/ha each of P (TSP) and K (muriate of potash).

In 2005, 12 treatments (in triplicates) comprising devil-bean, N, and P combinations were tested on-station at Nyankpala as was in 2003 and 2004. Devil-bean was either intercropped in the maize at 1, 3, or 4 WAP the maize or not, and the latter was fertilized with 0, 20, and 40 kg N/ha and all treatments received 40 kg P/ha and 30 kg K/ha.

The dry matter of the devil-bean biomass incorporated was determined as stated earlier whereas the nitrogen, phosphorus, and potassium contents were, respectively, determined by the Kjeldahl digestion method (Tel and Hagatey, 1984), Bray I method (Bray and Kurz, 1945), and ammonium acetate method (Nelson and Sommers, 1982).

In 2006, a follow-up experiment was conducted to confirm the cumulative effect of incorporating small quantities of devil-bean into maize plots on maize growth and grain yield. All treatments were replicated three times. The 2005 devil-bean stands still growing on the respective plots were slashed, and small quantities of between 2.1 and 4.4 t/ha were ploughed into the soils of the respective plots 2 weeks prior to planting the maize variety Obatanpa (110-day maturity variety) which was fertilized with 60 kg N/ha, 30 kg P/ha, and 30 kg K/ha. No devil-bean was intercropped in the maize this time. The maize was grown to full maturity, and the cobs were harvested, shelled, and thoroughly sun-dried on a concrete floor for 5 days and then weighed.

Statistical Analysis

The data were subjected to analysis of variance using Statistix software (STATISTIX 7), and significance of treatment effects was tested at 5% level of Treatment means were separated using the least significant difference (LSD).

Results and Discussion

The yield of maize grain was not significantly increased by intercropping with devil-bean whose growth in the maize was not as good as expected (Table 1). Maize intercropped with devil-bean but without fertilizer P generally performed lower than those with devil-bean and applied P, or without devil-bean intercrop. Usually, an associated legume crop rarely has any beneficial effect on the cereal intercrop partner in the first season as any nitrogen that

Table 1 Effects of devil-bean intercrop and fertilizer P on grain yield, growth, shoot nutrient (N, P, and K) uptake, and arbuscular mycorrhizal formation of maize grown in a Gleyi-ferric Lixisol at Nyankpala in 2003

Treatment	Grain yield (t/ha)	Stover yield (t/ha)	AMF spore no. (/5 g a.d.s.)	AMF colonization (%)	N (kg/ha)	P (kg/ha)	K (kg/ha)
Maize/devil-bean 1 WAP + P0	1.57 b[a]	2.83 c	238	12.3 ab	99.6	6.8 ab	86.4 ab
Maize/devil-bean 1 WAP + P20	1.84 ab	3.78 a–c	125	10.8 ab	96.8	7.9 ab	71.5 ab
Maize/devil-bean 1 WAP + P40	1.77 ab	3.86 a–c	222	21.6 a	113.9	15.8 a	96.3 a
Maize/devil-bean 3 WAP + P0	1.71 b	3.02 c	174	4.9 b	103.8	6.9 ab	89.4 ab
Maize/devil-bean 3 WAP + P20	1.89 ab	4.23 ab	66	17.9 ab	85.7	8.1 ab	63.7 ab
Maize/devil-bean 3 WAP + P40	1.96 ab	4.22 ab	170	9.0 ab	83.9	11.1 ab	74.1 ab
Maize/devil-bean 4 WAP + P0	1.69 b	2.89 c	236	15.0 ab	76.1	6.3 b	64.2 ab
Maize/devil-bean 4 WAP + P20	1.87 ab	3.95 ab	125	10.2 ab	104.3	6.8 b	43.8 b
Maize/devil-bean 4 WAP + P40	2.16 ab	4.04 ab	124	13.1 ab	104	12.1 ab	96.2 a
Maize + P0	1.74 ab	3.04 bc	149	14.6 ab	67.9	5.6 b	66.0 ab
Maize + P20	1.74 ab	3.38 a–c	122	9.8 ab	100.1	12.0 ab	87.9 ab
Maize + P40	2.55 a	4.21 a	91	13.9 ab	70.8	10.3 ab	64.4 ab

[a]Means followed by the same letter(s) within a column are not significantly different at $P = 0.05$ by the least significant difference method

may have been fixed is not immediately accessible by the companion cereal crop. The intercrop partners therefore tend to compete with each other, and the degree of this competition largely depends on the intercrop arrangement and management practices adopted. The results here indicate that in the absence of an external supply of a vital nutrient like phosphorus to the maize, the effect of the competition on the growth and grain yield of the cereal was more pronounced than when P was present resulting in the decreased growth and lower grain yield in the former treatment. Maize fertilized with 40 kg P/ha and intercropped with devil-bean 1 week after planting (1 WAP) was generally the most colonized (22%) by arbuscular mycorrhiza (even though there was no significant effect of treatment on the AMF spore production) and tended to have the highest content of shoot P. Arbuscular mycorrhizal fungi (AMF) have been reported to enhance P nutrition in almost all agricultural crops (Atayese et al., 1993; Smith and Read, 1997). Mosse (1973) and Gerdemann (1975) reported increased nutrient uptake, especially that of phosphorus, in soils with low P content when plants were infected with arbuscular mycorrhizal fungi to produce mycorrhizas. Even though application of high rates of phosphate fertilizers to soil decreases the percentage of infection of roots with AMF (Hayman et al., 1975) and then inhibits the ameliorating effects of the fungi on plant growth (Thomson et al., 1986), the highest P rate of 40 kg/ha applied to the maize in this work rather produced the highest AMF colonization compared to the lower rates, thereby implying that this level might be just about the optimum for the maize and the AMF in terms of P nutrition. The relatively high AMF colonization rate and the enhanced P nutrition were not accompanied by any significantly improved plant growth (stover dry weight) which is contrary to the findings of Daft and El-Giahmi (1974), Mosse et al. (1976) and Atayese et al. (1993) that improved P uptake associated with arbuscular mycorrhizal plants is largely the result of enhanced shoot growth of such mycorrhizal plants. Devil-bean dry matter estimated at the beginning of the following growing season was very low, ranging between 2 and 4 t/ha (Table 2).

Results obtained in 2004 showed that maize grown on incorporated biomass of devil-bean that had been intercropped at 1 WAP and fertilized with 40 kg N/ha was tallest at 31, 42, 56, and 77 DAP (Table 2). Maize grain yield was also highest with 40 kg N/ha without devil-bean or when devil-bean was intercropped at 1 WAP compared with all the integrated treatments whereas the least grain yield was obtained with 1 WAP + 20 kg N/ha treatment (Table 2).

The dry matter and estimated nutrient content of devil-bean incorporated in 2005 are presented in Table 3. Devil-bean planted 3 WAP in the 2004 maize which received 40 kg N/ha produced the highest dry matter. This is similar to devil-bean intercropped 1 WAP in maize that received 20 kg N/ha. These treatments also produced the highest amounts of biomass N. Organic (biomass) N applied with the cover crop generally ranged from 88 to 42 kg/ha. The P applied

Table 2 Effects of incorporated devil-bean biomass (t/ha) and fertilizer N (kg/ha) on plant height (cm) at 31, 42, 56, and 77 DAP and grain yield of maize (t/ha) grown in a Gleyi-ferric Lixisol at Nyankpala in 2004

Treatments (crop combinations in 2003)	Devil-bean biomass incorporated in 2004	Fertilizer N	31 DAP	42 DAP	56 DAP	77 DAP	Grain yield
Maize/devil-bean 1 WAP	3.01	0	31.2 bcd[a]	60.2 cd	83.0 e	99.6	0.35 de
	3.15	20	32.5 abc	65.6 bc	99.4 cde	96.8	0.22 e
	3.53	40	41.1 a	90.8 a	142.4 a	113.9	1.59 a
Maize/devil-bean 3 WAP	2.49	0	31.2 bcd	59.6 cd	89.8 de	103.8	1.24 abc
	2.49	20	29.9 bcd	65.8 bc	105.0 b–e	85.7	0.87 b–e
	4.16	40	36.6 ab	85.3 a	136.3 ab	83.9	1.21 abc
Maize/devil-bean 4 WAP	2.04	0	24.4 cd	49.0 d	76.5 e	76.1	0.51 de
	2	20	28.1 bcd	60.0 cd	94.3 de	104.3	0.71 cde
	2.19	40	31.6 bcd	78.2 ab	130.2 abc	104	1.40 ab
Maize	0	0	23.8 d	54.1 cd	75.4 e	67.9	0.70 cde
	0	20	26.6 cd	64.8 bcd	106.7 b–e	100.1	0.92 bcd
	0	40	24.4 cd	67.6 bc	117.2 cd	70.8	1.81 a

[a]Means followed by the same letter(s) within a column are not significantly different at $P = 0.05$ by the least significant difference method

Table 3 Total devil-bean biomass (t/ha) and estimated nutrients (kg/ha) incorporated into the soil at the beginning of 2005 cropping season and their effects on grain yield of maize (t/ha) grown in a Gleyi-ferric Lixisol at Nyankpala in 2005

Treatments (crop combinations in 2004)	Devil-bean biomass incorporated in 2005	Fertilizer N	N	P	K	Grain yield
Maize/devil-bean 1 WAP	2.5	0	50	6.2	29.5	1.1
	4.1	20	82	10.1	48.3	1.2
	3.6	40	72	8.9	42.4	2
Maize/devil-bean 3 WAP	2.4	0	48	5.9	28.3	1.4
	2.5	20	50	6.2	29.5	1.9
	4.4	40	88	10.8	51.9	2.7
Maize/devil-bean 4 WAP	2.1	0	42	5.2	24.8	1.7
	2.2	20	44	5.4	25.9	1.3
	2.6	40	52	6.4	30.6	2.3
Maize	0	0	nd[a]	nd	nd	0.7
	0	20	nd	nd	nd	0.9
	0	40	nd	nd	nd	1.1
LSD (5%)	1.8		36	4.4	21.2	0.8

[a]Not determined

was between 11 and 5 kg/ha, and the K was between 52 and 25 kg/ha.

The devil-bean intercropped in the maize at 1 and 3 WAP might have had enough time to establish before the maize got fully established compared to the 4 WAP treatment, thereby experiencing a lesser degree of competition from the maize which may have resulted in a better growth of the former. Competition for space, light, soil water and nutrients has been known to be a major factor that influences the relative performance of partner crops in intercrop and relay cropping systems.

The yield of maize grain was significantly influenced by incorporating the biomass of devil-bean that was intercropped in the maize the previous year. The treatments having the highest devil-bean biomass production also resulted in the highest maize grain yield (Table 3). This observation agrees with the findings of Cheruiyot et al. (2001) who evaluated some legumes for short-rain conditions and identified dolichos [*Lablab purpureus* (L.) Sweet] as the most suitable legume for the fallow periods because of its production of a larger and higher quality aboveground biomass than the other legumes. It is commonly recognized that the amount of biomass generated by a pre-cereal legume crop greatly influences the growth, mineral nutrition, and yield effects of the legume on the cereal as a result of the high amounts of organic matter and mineralized N made available to the cereal (Cheruiyot et al., 2001, 2003). The high N contents of the biomass of the treatments that resulted in the highest grain yields may have enhanced the decomposition of the biomass leading to a relatively higher mineralization rate and more rapid nutrient release to the succeeding maize. Palm and Sanchez (1991), Palm et al. (2001), Wang et al. (2004), and Nziguheba et al. (2005) have linked the rate of nutrient release to biochemical properties, especially lignin, polyphenols, and N content from studies done on litter mineralization.

It should, however, be understood that the cumulative effect of devil-bean dry matter application also played a significant role. This can be deduced from the fact that in 2003, the treatments without devil-bean but with 40 kg P/ha (Table 1) gave the highest yield suggesting the presence of some competition of devil-bean with the maize. In the subsequent years, the cumulative effect of devil-bean biomass application on maize grain yield far exceeded the competitive effect, hence the increase.

The devil-bean intercropped in 2005 at either 1 or 3 weeks after planting (WAP) maize that received 40 kg N/ha and at 1 WAP maize supplemented with 20 kg N/ha tended to produce the highest shoot dry matter (biomass) when harvested in 2006 (Table 4), which confirms the conclusions drawn in 2005 on the effects of the same treatments. However, the growth and yield responses of the maize did not generally depend on the quantities of the devil-bean biomass ploughed in Table 4. This is explained by the fact that plots that had no devil-bean grown on them or incorporated into them for 2–3 years (especially those which even did not receive any N application) produced the same

Table 4 Cumulative effects of intercropping devil-bean and incorporating its biomass on stover dry weight and grain yield of maize grown in a Gleyi-ferric Lixisol at Nyankpala in 2006

Treatment combinations (in 2005)[a]	Devil-bean dry matter[b]	Stover yield	Grain yield
Maize/devil-bean 1 WAP + N0	2.6 a–d[c]	1.63 ab	4.13 ab
Maize/devil-bean 1 WAP + N20	4.1 a–c	1.63 ab	3.72 ab
Maize/devil-bean 1 WAP + N40	4.3 ab	1.78 ab	4.90 a
Maize/devil-bean 3 WAP + N0	2.3 bcd	2.16 a	3.73 ab
Maize/devil-bean 3 WAP + N20	2.5 a–d	2.05 a	4.70 ab
Maize/devil-bean 3 WAP + N40	4.4 a	1.92 ab	4.74 ab
Maize/devil-bean 4 WAP + N0	2.2 cd	1.59 ab	3.91 ab
Maize/devil-bean 4 WAP + N20	2.1 d	1.73 ab	4.53 ab
Maize/devil-bean 4 WAP + N40	2.2 cd	1.85 ab	4.68 ab
Maize + N0	nd[d]	1.63 ab	4.87 a
Maize + N20	nd	1.30 b	3.42 b
Maize + N40	nd	1.84 ab	4.21 ab

[a]In 2006, each plot was fertilized with 60 kg N/ha, 30 kg P/ha, and 30 kg K/ha
[b]Devil-bean biomass incorporated at the beginning of the 2006 growing season
[c]Means followed by the same letter(s) within a column are not significantly different at $P = 0.05$ by the least significant difference method
[d]Not determined

yields as the other treatments, thus indicating that the maize highly responded to the 60 kg/ha of N applied in 2006. The lack of dependency of the maize on the biomass applied might therefore be due probably to the sufficiency of the rate of fertilizer N applied for its growth and grain production under the conditions of this experiment. Even though supplementary N is required by maize when it follows legumes sequentially (Asibuo and Osei-Bonsu, 1999), it appears that the positive cumulative effects of the small quantities of the devil-bean biomass on growth and grain yield responses observed can be overshadowed when high rates of fertilizer N are introduced as the maize tends to depend on the fertilizer N rather than the organic N released from the decomposing legume biomass.

The use of devil-bean (as a short fallow herbaceous cover crop) as a nitrogen and organic matter source is therefore recommended in the absence of high doses of fertilizer nitrogen for enhanced maize production in the Guinea Savanna zone of Ghana.

Conclusions

Some farmers in the Guinea Savanna zone of Ghana express concern over the rotation of cover crops with maize as they obtain no economic gain from the land when it is under cover crop. This fear has been addressed in this study which has found out that devil-bean (a cover crop) can be intercropped in maize consecutively, say for 2–3 years, and when the devil-bean is repeatedly ploughed into the soil, the organic matter buildup and the associated release of N into the soil enhance maize growth and grain yield. Better yields of maize can be obtained when the maize is supplied with moderate rates of fertilizer N. This integrated system allows the farmer to obtain economic benefits from the cereal while simultaneously improving the fertility level and structural stability of his farmland.

From this investigation, the use of devil-bean as a short fallow herbaceous cover crop for nitrogen and organic matter supply is therefore recommended in the absence of high doses of fertilizer nitrogen for enhanced maize production in the Guinea Savanna zone of Ghana.

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