Improved *Crotalaria* cover crop fallow system for sustainable maize production in the northern Guinea Savanna agroecological zone of Ghana

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ABSTRACT

An on-station trial was carried out at the Research Farm of the Faculty of Agriculture, University for Development Studies, Tamale, in the northern Guinea Savanna agroecological zone of Ghana. The study compared different seeding rates of leguminous cover crops, inorganic fertilization, and a combination of the two in a small-scale cereal-based production system. The experiment was conducted for 2 years within a 3-year fallow system to investigate the use of *Crotalaria ochroleuca* and *Crotalaria retusa* as 1 and 2 years' fallow systems. *Crotalaria ochroleuca* seed fallow at 50 kg ha^{-1} was more efficient in above-ground biomass production and nutrient accumulation than *Crotalaria retusa* seed fallow at 50 and 100 kg ha^{-1} of cover crop regrowth. The above-ground biomass production and nutrient accumulation by the *Crotalaria* species at 100 kg ha^{-1} of seeds was higher than at 50 kg ha^{-1} of seeds. The results showed that *C. ochroleuca* and *C. retusa* can accumulate higher soil nutrients at higher seed rates. The average grain yield increase for all the treatments between 2001 and 2002 were 4.6 and 3.0 per cent for "Dobidi" and "Okomasa" at 100 kg ha^{-1} of *Crotalaria* seeds, respectively. Grain yields from the *Crotalaria* fallow species plus fertilizer performed better, followed by fertilizer treatment and *Crotalaria* fallow systems. Two years' *Crotalaria* fallow systems at 100 kg ha^{-1} were more profitable than at 50 kg ha^{-1}.

Original scientific paper. Received 28 Jun 07; revised 09 Dec 08.

Introduction

Food production in the semi regions of sub-Saharan Africa, including Ghana, has not kept pace with population growth (UN, 1979; Eicher & Staaz, 1985; Eicher, 1986). Under the pressure of increasing population and other competing land use demands, long fallow periods are no longer possible in densely populated areas (Kang, Reynolds & Atta-Krah, 1990). Permanent crop growing in the tropics can only be maintained at a high productivity level if external resources are used and plant residues are returned to the field

(Sanchez *et al*., 1982; Kang *et al*., 1990). The possible effects of shortening the fallow cycles on soil productivity have been well illustrated.

Maintaining soil fertility may require introducing leguminous cover crops commonly known in the study area as fallow species in an attempt to optimize the soil internal cycling efficiency (Quainoo & Lawson, 2001). In recent years, increasing fertilizer cost and concern for sustainable soil productivity have emerged. Furthermore, heavy reliance on chemical fertilizer tends to favour economically those farmers with large hectares of land (FAO, 1994). These considerations have led to renewed interest in organic manure.

A series of research conducted across the northern agroecological zones of Ghana have indicated that the application of combined organic and inorganic fertilizers gave the highest yields in grain and tuber crop production (NARP, 1998). When green manure was used in the study, the results were similar. Inclusion of *Mucuna pruriens* in the rotation system, supplemented with low fertilizer rates, was used to maintain acceptable maize yields in Ibadan, Nigeria. Elsewhere, Herrera (1980) observed that maize-grain yield increases from applying leucaena leaves at 90 kg N ha^{-1} were comparable with those from an equal quantity of inorganic N supplied as ammonium sulphate. Also, grain yield of maize from treatments receiving 150 kg N ha^{-1} through leucaena leaves was comparable with treatments receiving 150 kg N ha^{-1} from urea. A way forward in tropical agricultural production should, therefore, be a balance between organic and inorganic farming. However, high seed rate is recommended for fallow species to delay the development of woodiness. Diekmann & De Datta (1990) found that *Sesbania rostrata* at a seed rate of 40 kg ha^{-1} accumulated 114 kg N ha^{-1} compared with a seed rate of 50 kg ha^{-1} (148 kg N ha^{-1}) in a 45-day growth period.

This paper presents results of a study on a comparison between the seeding rates of leguminous cover crops *(Crotalaria ochroleuca* and *Crotalaria retusa)*, inorganic fertilization, and a combination of the two in a small-scale cereal-based production system in the northern Guinea Savanna agroecological zone of Ghana.

Materials and methods

An on-station trial was carried out at the Research Farm of the Faculty of Agriculture, University for Development Studies, Tamale, Ghana (latitude 9°25'N and longitude 0058'W), in the northern Guinea Savanna. The experimental sites received between 900 and 1,300 mm of rain per annum (Table 1). The soils of the experimental sites were developed from the Voltanian sandstone, moderately drained and classified as Nyankpala series.

Physical and chemical analyses of the top soils (0 - 20 cm) showed the following constituents: sand, 57 per cent; silt, 28 per cent; clay, 15 per cent; organic carbon, 0.34 per cent; total N, 0.04 per cent; available P (Bray 1), 8.05 mg kg^{-1}; K, 58 mg kg^{-1}; Ca, 371 mg kg^{-1}; Mg, 76 mg kg^{-1}; CEC, 3.62 cmol (+) kg^{-1}; and soil, *p*H 5.63.

TABLE 1

Crotalaria *Cover Crop Fallow System for Sustainable Maize Production*

Treatment	*Treatment combination*
1	*Crotalaria ochroleuca* + dobidi
2	*Crotalaria ochroleuca* + okomasa
3	*Crotalaria retusa* + dobidi
4	*Crotalaria retusa* + okomasa
5	*Crotalaria ochroleuca* + fertilizer + dobidi
6	*Crotalaria ochroleuca* + fertilizer + okomasa
7	*Crotalaria retusa* + fertilizer + dobidi
8	*Crotalaria retusa* + fertilizer + okomasa
9	Fertilizer + dobidi
10	Fertilizer + okomasa

The experiment was conducted for 2 years (2001 and 2002) during 3-year (2000, 2001 and 2002) cropping seasons to investigate the use of leguminous shrubs, *C. ochroleuca* and *C. retusa* (improved 1 and 2-year fallow systems), in comparison with mineral fertilization. *Crotalaria ochroleuca* and *C. retusa* were used for the experiment because they are commonly found growing in the study area, especially during the dry season. The impact of the leguminous fallow species on the yields of two locally improved maize varieties ("Dobidi" 120 days and "Okomasa" 120 days) was evaluated. "Dobidi" and "Okomasa" belong to the same pedigree, but "Okomasa" has the gene resistance to streak virus disease.

Ten treatment combinations involving 50 and 100 kg ha^{-1} of *Crotalaria* seeds, respectively, were compared (Table 1). The seeding rates were chosen based on the findings of Diekmann & De Datta (1990) in which higher rates of *Sesbania rostrata* fallow system accumulated higher rates of N in the soil. The experiment was laid out in split-plot randomised complete block design with the 50 and 100 kg ha^{-1} *Crotalaria* seeding rates as the main treatment and the two *Crotalaria* species as sub-treatments. The experiment was replicated four times. An experimental site (10,000 m^2) divided into two blocks for the 1 and 2-year fallow systems was used. Each block was sub-divided into plots of 10 m × 10 m.

Soil samples for chemical and physical properties were collected from the experimental site in May 2000. In June 2000, *Crotalaria* species were broadcasted at the seed rate of 50 and 100 kg ha^{-1} on the fields after ploughing. (The leguminous fallow benefited from the late rains and remained green throughout the fallow period). In May 2001, the above-ground leguminous fallow for the 1-year fallow system was sampled for dry matter analysis and plant nutrient uptake before being ploughed into the soil. The field was planted with maize 3 weeks after ploughing in the plant materials. A controlled experiment, using the recommended fertilizer rates in the study area, was applied at 40 kg N ha^{-1}, 20 kg P ha^{-1} and 20 kg K ha^{-1}. In May 2002, the above experiment was repeated for the 2-year fallow system.

All data were subjected to Analysis of Variance at 5 per cent probability, using Genstat for windows ih edition. The projected cost of production was based on the assumption that land was free; and the costs incurred were cost of gathering and broadcasting of *Crotalaria* seeds, cost of fertilizer, and agronomic practices. Profit analysis of return to increments in variable costs from shifting from one fallow system to another and to inorganic fertilizer application was calculated for each fallow system based on the procedures of Black (1956) and Boehlje & Eidman (1984). The profit analysis of return was calculated separately for "Dobidi" and "Okomasa" at different *Crotalaria* seed densities (100 kg ha^{-1} of *Crotalaria* fallow species) as means for 2001 and 2002.

Results and discussion

Nutrient uptake and biomass production

Crotalaria ochroleuca was more efficient in above-ground biomass production and nutrient accumulation than *C. retusa* at a seed rate of 50 and 100 kg ha^{-1} of cover crop regrowth (Table 2). The fallow period allowed the accumulation of plant biomass with high mineral content that, when incorporated in the soil, can be absorbed by the cultivated crops.

The results showed that *C. ochroleuca* fallow had higher N, P, Ca and Mg than *C. retusa*. The 2-year fallow generally accumulated more nutrient than the 1-year fallow, despite the shortage in plant biomass production in the second year.

Further, above-ground biomass production and nutrient accumulation by the *Crotalaria* seeds at 100 kg ha^{-1} was higher than at 50 kg ha^{-1}. The results showed that *C. ochroleuca* and *C. retusa* can accumulate higher soil nutrients at higher seed rates, which conform to the findings of Diekmann & De Datta (1990). The 1 and 2-year fallows at 100 kg ha^{-1} of seeds generally

TABLE 2

Total Above-ground Plant Biomass Production (BM) and Nutrient Accumulation in 50 and 100 kg ha^{-1} of Cover Crop Regrowth 1 and 2 Years After Planting

Duration of growth (months)	*Treatment*	*Biomass yield tonnes/ha*	*N (%)*	*P*	*K*	*Ca*	*Mg*	*Biomass yield tonnes/ha*	*N (%)*	*P*	*K*	*Ca*	*Mg*
				50 kg ha^{-1}						*100 kg ha^{-1}*			
12	*Crotalaria ochroleuca*	7.3^b	1.34^b	20.1^b	217.7^a	73.7^b	93.6^b	8.2^b	1.42^b	22.3^b	234.1^b	87.57^b	113.6^b
	Crotalaria retusa	6.7^a	0.89^a	12.3^a	216.9^a	68.7^a	40.2^a	6.8^a	1.11^a	15.7^a	219.5^a	73.8^a	61.3^a
24	*Crotalaria ochroleuca*	6.9^a	1.36^a	21.0^b	221.6^b	75.0^a	93.5^b	7.5^a	1.59^b	24.0^b	250.8^b	103.3^b	139.4^b
	Crotalaria retusa	6.6^a	1.13^a	12.7^a	195.3^a	74.1^a	41.4^a	6.6^a	1.31^a	18.3^a	237.4^a	94.1^a	96.4^a

Means values followed by a common superscript in a row are not significantly different at $P = 0.05$.

accumulated more nutrient than the 2-year fallow at 50 kg ha^{-1} of seeds.

This may be due to the delay in development of woodiness in the *Crotalaria* spp. as reported for *Sesbania rostrata* by Diekmann & De Datta (1990). These findings suggested that 1-year fallow at 100 kg ha^{-1} of seeds was more efficient in above-ground biomass production and nutrient accumulation than the 2-year fallow at 50 kg ha^{-1} of seeds.

Therefore, higher seeding rate of cover crops for soil fertility was more beneficial for short fallow systems.

Grain yields

Generally, maize grain yields benefited significantly from the *Crotalaria* fallow species with fertilizer than the other treatments (Table 3). The average grain yield increase for all the treatments between 2001 and 2002 were 7.3 and 9.0 per cent for "Dobidi" and "Okomasa" at 50 kg ha^{-1} of *Crotalaria* fallow seeds, respectively. The average grain yield increase for all the treatments between 2001 and 2002 were 4.6 and 3.0 per cent for "Dobidi" and "Okomasa" at 100 kg ha^{-1} of *Crotalaria* fallow seeds, respectively. This indicates that at 100 kg ha^{-1} of *Crotalaria* fallow seeds, the yields of "Dobidi" and "Okomasa" increased by 20.5 and 21.7 per cent, respectively, over the 50 kg ha^{-1} of *Crotalaria* fallow seeds.

Grain yields from the *Crotalaria ochroleuca* fallow species plus fertilizer performed better, followed by fertilizer treatment, *C. ochroleuca* and *C. retusa* in that order (Table 4). These results conform to various reports of crop increases involving combined organic and inorganic fertilizer application, incorporation of herbaceous woody species in the farming systems (Herrera, 1980; NARP, 1998). "Okomasa" performed better than "Dobidi", which could be attributed to the resistance of "Okomasa" to the streak virus disease that was prevalent in the study area. The yields of "Okomasa" and "Dobidi" were better at 100 kg ha^{-1} of *Crotalaria* fallow seeds.

TABLE 3

Maize Yield (tonnes ha^{-1}) Under 50 and 100 kg ha^{-1} of Crotalaria *Fallow Species*

Treatment combination	*Dobidi*		*Okomasa*		*Dobidi*		*Okomasa*	
	2001	*2002*	*2001*	*2002*	*2001*	*2002*	*2001*	*2002*
	50 kg ha^{-1}				*100 kg ha^{-1}*			
Crotalaria ochroleuca	0.83^{a}	0.87^{a}	0.84^{a}	0.89^{a}	1.20^{a}	1.35^{a}	1.34^{b}	1.50^{b}
Crotalaria retusa	0.79^{a}	0.81^{a}	0.78^{a}	0.82^{a}	1.10^{a}	1.35^{a}	0.98^{a}	1.22^{a}
Crotalaria ochroleuca + fertilizer	2.72^{c}	2.96^{c}	2.76^{d}	3.10^{d}	3.37^{c}	3.45^{c}	3.42^{c}	3.47^{c}
Crotalaria retusa + fertilizer	2.68^{c}	2.98^{c}	2.53^{c}	2.87^{c}	3.29^{c}	3.47^{c}	3.28^{d}	3.42^{d}
Fertilizer	1.71^{b}	1.74^{b}	1.72^{a}	1.74^{b}	1.71^{b}	1.71^{b}	1.71^{c}	1.70^{c}
Total yield	8.73	9.38	8.63	9.42	10.67	11.33	10.73	11.31
Percentage yield increase	6.8%		9.3%		6.2		5.4	

Means values followed by a common superscript in a row are not significantly different at $P = 0.05$.

Economic analysis

Generally, the *Crotalaria* fallow species plus fertilizer recorded the highest profit margins than the sole *Crotalaria* fallow systems and fertilizer application alone, which may be attributed to the *Crotalaria* species in the fallow system. The higher *Crotalaria* seed fallow systems at 100 kg ha^{-1} resulted in higher grain yields; hence, higher profit margins than at 50 kg ha^{-1} (Table 4). Yields from the sole fertilizer application were higher than the yields from the sole *Crotalaria* fallow systems. This indicates that the sole *Crotalaria* fallow systems over two cropping seasons was less profiting for maize production in the study area.

Conclusion

The results showed that *Crotalaria ochroleuca* and *Crotalaria retusa* can accumulate higher soil nutrients at higher seed rates. *Crotalaria ochroleuca* and *C. retusa* were more efficient in total above-ground plant biomass production and nutrient accumulation. The *Crotalaria* species plus inorganic fertilizer application to the maize had the highest grain yields, resulting in higher profit margins than the other treatments. Crop production in the study area is declining as a result of poor soil fertility status. To increase food productivity, the need is for a careful balance between organic and inorganic fertilizer application. It is recommended that farmers in the study area could improve on the natural fallow system and income by oversowing with *Crotalaria* species in one or two fallow systems.

TABLE 4

Profit Analysis of Maize Output Under Crotalaria *Fallow Species for 2001 and 2002 Cropping Seasons*

	Average maize output under 50 kg ha^{-1} of Crotalaria *fallow species*							
	Dobidi				*Okomasa*			
Treatment combination	*Total output tonnes/ha*	*Total receipt at ¢1.5 million /tonne*	*Total expense in million (¢)*	*Profit in million (¢)*	*Total output tonnes/ha*	*Total receipt at ¢1.5 million /tonne*	*Total expense in million (¢)*	*Profit in million (¢)*
Crotalaria ochroleuca	0.850	1.275	0.468	0.807	0.870	1.305	0.468	0.827
Crotalaria retusa	0.800	1.200	0.468	0.732	0.800	1.200	0.468	0.732
Crotalaria ochroleuca + Fertilizer	2.840	4.260	1.131	3.129	2.980	4.470	1.131	3.339
Crotalaria retusa + Fertilizer	2.830	4.245	1.131	3.114	2.700	4.050	1.131	2.919
Fertilizer	1.730	2.595	0.663	1.932	1.770	2.655	0.663	1.992

	Average maize output under 100 kg ha^{-1} of Crotalaria *fallow species*							
	Dobidi				*Okomasa*			
Treatment combination	*Total output tonnes/ha*	*Total receipt at ¢1.5 million /tonne*	*Total expense in million (¢)*	*Profit in million (¢)*	*Total output tonnes/ha*	*Total receipt at ¢1.5 million /tonne*	*Total expense in million (¢)*	*Profit in million (¢)*
Crotalaria ochroleuca	1.280	1.920	0.468	1.452	1.420	2.130	0.468	2.662
Crotalaria retusa	1.18	1.770	0.468	1.302	1.500	2.250	0.468	1.782
Crotalaria ochroleuca + Fertilizer	3.410	5.115	1.131	3.944	3.450	5.175	1.131	3.819
Crotalaria retusa + Fertilizer	3.330	4.995	1.131	3.864	3.300	4.950	1.131	3.819
Fertilizer	1.730	2.595	0.663	1.932	1.730	2.595	0.663	1.932

* 1 US dollar = 8,000.00 Ghanaian cedis *(¢)*

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