Rotation of Maize with some Leguminous Food Crops for Sustainable Production on the Vertisols of the Accra Plains of Ghana

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Abstract

Five food legumes were grown, as cover/food crops, in rotation with maize, at the University of Ghana, Soil and Irrigation Research Centre, Kpong. The legumes were determinate cowpea (*Vigna unguiculata* (L.) Walper, var. soronko), indeterminate cowpea (*Vigna unguiculata* (L.) Walper, var. Adidome mottled), soyabean (*Glycine max* (L.) Merril, var. GMX 92–16-2M), bambara groundnut (*Vigna subterranea* (L.) Verd, var. Ada) and groundnut (*Arachis hypogea* L., var. goronga). The experimental treatments were: incorporated legume residues, recommended inorganic fertilizer application (100 kg N, 60 kg P_2O_5 and 40 kg K_2SO_4 ha^{-1}) and no fertilization as control. Soil samples (0-20 cm depth) were analysed for *p*H, organic carbon (OC) and nitrogen (N) contents before and after the experiments. Samples of the leguminous crops were also analysed for N content. The indeterminate cowpea continued growth after initial setting of pods and, therefore, had greater biomass (total dry weight – TDW) than the other leguminous crops. Its total N was relatively high in spite of lower N content. The TDWs of indeterminate cowpea, soyabean and groundnut were 2.80, 1.90 and 1.85 t ha^{-1}, respectively; the N contents were 2.7, 4.5 and 4.8% and the total N contents were 75.6, 91.2 and 83.3 kg ha^{-1}. Grain yields of maize were higher in the incorporated soyabean and groundnut treatments than the other leguminous crops. In the major rainy season in 2003, grain yield in the groundnut treatment was 3.3 t ha^{-1}, compared with 3.1 and 1.1 t ha^{-1} in the inorganic fertilizer treatment and the control, respectively. In the minor rainy season in 2004, grain yield was 3.0 t ha^{-1} in the soyabean treatment, compared with 3.0 and 1.6 t ha^{-1} in the inorganic fertilizer and control treatments.

Introduction

Maize requires a well distributed rainfall, well drained soil and adequate soil organic matter to give optimum growth and yield. Maize yields under typical subsistence management practice (with little or no technological input) are higher in the forest and forest-savanna transition agro-ecological zones (e.g. Kade and Ejura) than the savanna agro-ecological zone (e.g. Accra Plains). In a typical peasant farm, where maize is grown without fertilization, growth and yield of maize have been observed to be better in patches with higher organic matter (OM), as a result of the activity of termites or decomposed vegetative and animal waste (Nyalemegbe, unpublished).

Most soils in Ghana are of low inherent fertility (Benneh ***et** al*., 1990) and, therefore, require fertilization. Acquaye (1986) observed that soil fertility is closely associated with OM content of the soil, which was determined to be 1–2% (0–15 cm depth) in savanna soils, compared with 4.5–6% in forest soils. The Accra Plains of Ghana has low soil OM content because of the annual bush fires and slower rate of vegetative growth and decomposition, due to low and poorly distributed rainfall.

Of the various management practices, which can increase the productivity of crops, fertilizer application normally gives the highest returns (Chowdhury & Chetty, 1979). For maize production, NARP/CSIR (1998) recommended the application of: nitrogen (N) [100 kg N ha^{-1}], phosphorus (P) [60 kg P_2O_5 ha^{-1}] and potassium (K) [40 kg K_2O ha^{-1}]. However, fertilizer use in Ghana is low because most farmers cannot afford it and, therefore, do not use it or use less than the recommended rates.

Other approaches to remedy nutrient deficiency and declining soil productivity may be to explore organic sources of fertilizers (Gyamfi *et al*., 2001). With the rise in the cost of mineral fertilizer and the concern over sustainability of current cropping systems, green manures have attracted new research interest (Hikwa & Mukurumbira, 1995). However, green manure production requires land that could often be used for food and cash crops (Giller *et al*., 1997). On the other hand, a number of farmers cultivate food legumes, e.g. cowpea, bambara groundnut and groundnut in rotation with upland crops, and these have beneficial effects on soil fertility.

In a rice-based cropping system experiment on the Vertisols of the Accra Plains in Ghana (Nyalemegbe *et al*., 2011), cowpea in rotation with rice contributed highly to soil OM and N content and increased rice yield. Cowpea has also been grown in rotation with NERICA rice variety on farmers' fields, in the Hohoe and Kwaebibirem districts in Ghana, to demonstrate their potential as green manure/food crop (Nyalemegbe, unpublished).

Creamer & Baldwin (1998, 1999) reported that cowpea is a fast growing summer cover crop that is adapted to a wide range of soil conditions and has a taproot that can obtain moisture from deep in the soil profile. Asibuo & Osei-Bonsu (1999), in studies conducted at Ejura in the forest-savanna transition zone, observed that mean maize grain yields after mucuna, canavalia and soyabean, without fertilizer N, were 2.3, 1.6 and 1.0 t ha^{-1}, respectively.

The present study aims at determining leguminous food crops with profuse vegetative growth, good grain yield and the ability to nodulate well and fix nitrogen, which can provide food and also rejuvenate both the physical quality and fertility of the soil. This would encourage farmers on the Accra Plains to grow food legumes in rotation with maize.

Materials and methods

The experiments were conducted at the University of Ghana, Soil and Irrigation Research Centre, Kpong (lat. 6^0 00' and 6^0 10' N, long. 0^0 05' and 0^0 15' E), within the Accra Plains agro-ecological zone. The area has an annual rainfall of 800–1100 mm, which is bi-modal and made up of the major rainy season (March–July), a short period of drought in August, the minor rainy season (September–November), and a period of drought (December-February) between the minor and major rainfall seasons (Table 1).

The experimental design was randomised complete block, with four replications and plot size, 6 m × 4 m. On 2nd September 2002, five leguminous food crops were planted in designated plots, which had been ploughed and harrowed. The legumes were determinate cowpea (*V. unguiculata*, var. soronko), indeterminate cowpea (*V. unguiculata*, var. Adidome mottled), soyabean (*G. max*, var. GMX 92–16-2M), bambara groundnut (*V. subterranea*, var. Ada) and groundnut (*A. hypogea*, var. goronga). Three seeds each of the legumes were planted and thinned to two

TABLE 1
Monthly rainfall during the period of experiments (2002–2004)

	2002 (mm)	*2003 (mm)*	*2004 (mm)*	*Long-term average (1958–2010) (mm)*
January	29.3	24.8	4.9	15.7
February	41.0	28.2	33.3	35.3
March	57.2	101.0	4.2	83.5
April	223.1	147.0	47.4	117.3
May	128.3	183.6	182.6	146.7
June	147.4	96.7	91.1	166.9
July	72.1	0.0	45.5	83.3
August	23.6	9.8	46.6	51.3
September	118.6	32.4	182.0	114.0
October	125.8	92.2	42.7	119.2
November	72.6	82.0	79.5	70.1
December	20.3	36.2	71.5	22.7
Annual Rainfall	1059.3	833.9	831.3	1026.0

Source: University of Ghana, Soil and Irrigation Research Centre, Kpong

plants per hill, at planting distances of 40 cm × 60 cm, 40 cm × 80 cm, 30 cm x 60 cm, 20 cm × 40 cm and 40 cm × 60 cm, respectively.

There were a total of seven treatments, namely incorporated residues of *V. unguiculata* (L.) Walper, var. soronko, *V. unguiculata* (L.) Walper, var. Adidome mottled, *G. max* (L.) Merril, var. GMX 92-16-2M, *V. subterranea* (L.) Verd, var. Ada and *A. hypogea* L., var. goronga, recommended inorganic fertilizer application (100 kg, 60 kg P_2O_5 and 40 kg K_2SO_4 ha^{-1}) and no fertilization (control). The inorganic fertilizers were applied as 15-15-15 NPK and sulphate of ammonia.

In view of the variations in maturity period of the various legumes, plant samples were taken for N analysis as they attained 50% maturity (browning). Two plants were randomly sampled from each plot for the laboratory analysis. Biomass of the leguminous crops were also determined by taking two 1 m × 1 m samples, weighing them fresh and weighing again after drying in an oven at 75 °C for 48 h. Dropped leaves within the sample area were also weighed as part of the biomass. The crops were harvested and the residues spread on the soil surface and incorporated with hoe, after all the leguminous crops attained maturity. Soyabean had the longest maturity period of 120 days and that determined the time of incorporating all leguminous residues (20th February, 2003).

Maize (*Zea mais,* var. Obatanpa) was planted on all plots on 15th March 2003. Planting was at a spacing of 40 cm × 80 cm, with three seeds per hole, but thinned to two plants after germination, to give a planting density of 62,500 plants ha^{-1}. Twenty days after planting the maize (DAP), all the required P_2O_5 and K_2SO_4, plus 50% of the N requirement were applied, as basal application, in the plots earmarked for inorganic fertilizer treatment, using 15-15-15 NPK fertilizer, at a rate of 250 kg ha^{-1}. This was followed with the other 50% N as top dressing at 50 DAP, using sulphate of ammonia fertilizer, at a rate of 150 kg ha^{-1}. Weeds were controlled, using hoe, from 35 to 40 DAP. The mature maize was harvested on 14th August, 2003. Sample areas of 1 m × 2 m at the centre of the plots were harvested for dry matter and grain yield measurements. The shoot was weighed fresh and weighed again after drying in an oven at 75 °C for 48 h, while the grains were air-dried to 14% moisture.

The leguminous crops were replanted on same plots on 8th March 2004 and procedures were followed as in the earlier experiment. The legume residues were incorporated on 15th August 2004, and maize planted on 30th August 2004. The maize was harvested on 29th December 2004. Biomass and yield data were taken on the various legumes and the maize crop as in the initial experiment.

Soil samples were taken at 0–20 cm depth before commencement of the experiment and after harvesting the final maize crop, and analysed for *p*H, OC and N contents. The chemical analyses included soil *p*H (1:2.5, soil:water), as by McLean (1982); OC by the Walkley & Black wet digestion method, as by Nelson & Sommers (1982), and N by micro-Kjedahl digestion method (Bremner & Mulvanay, 1982). The leguminous plant materials were also analysed for N content.

The statistical analysis of data was by analysis of variance (ANOVA), using the Genstat analytical software.

Results

The determinate cowpea, groundnut and soyabean had higher N contents than the other leguminous crops, and also had high TDWs and grain yields; groundnut had the highest number of root nodules (Table 2). The determinate cowpea reached 50% maturity at about 55 DAP, while the indeterminate cowpea reached 50% maturity at about 65 DAP. The indeterminate cowpea continued vegetative growth after the initial pods were harvested and the aged leaves were shed while vegetative and reproductive growths continued to about 120 DAP. Both plants produced root nodules but the indeterminate cowpea continued to produce root nodules beyond the life cycle of the determinate cowpea. Soyabean, bambara groundnut and groundnut had maturity periods of about 115–120 DAP, and also produced root nodules. However, bambara groundnut had lower N content than soyabean and groundnut (Table 2).

In the major rainy season in 2003, cob weight of maize was higher under groundnut residue than the control, but was comparable to that under the recommended inorganic fertilizer application. On the other hand, grain yields under both groundnut and indeterminate cowpea residues were higher than the control and were comparable to grain yield under the inorganic fertilizer application (Table 3).

In the minor season in 2004, soyabean residue supported greater biomass, cob weight and grain yield than the control and was comparable to the recommended inorganic fertilizer application (Table 4).

Soil *p*H and N content did not differ between treatments but there were slight increases in OC content over the control (Table 5).

TABLE 2

The average biomass, grain yield and nitrogen content of leguminous food crops incorporated in the major rainy seasons of 2003 and minor rainy season of 2004

Leguminous food crop	*TDW ($t\ ha^{-1}$)*	*Grain yield ($t\ ha^{-1}$)*	*Number of nodules*	*N content of biomass (%)*	*Total N ($kg\ ha^{-1}$)*
Determinate cowpea	1.85	1.20	30	4.0	74.0
Indeterminate Cowpea	2.80	1.40	34	2.7	75.6
Soyabean	1.90	1.80	23	4.8	91.2
Bambara groundnut	1.89	1.60	13	3.7	69.9
Groundnut	1.85	1.50	55	4.5	83.3

TABLE 3

The growth and yield of maize after incorporation of leguminous food crops in the major rainy season of 2003

Leguminous food crop	*TDW ($t\ ha^{-1}$)*	*Cob weight ($t\ ha^{-1}$)*	*Grain weight ($t\ ha^{-1}$)*
Determinate cowpea	11.5	4.1	1.8
Indeterminate cowpea	11.1	5.3	2.5
Soyabean	12.0	4.9	2.1
Bambara groundnut	12.6	5.3	2.2
Groundnut	18.3	7.9	3.3
Inorganic fertilizer	16.6	6.9	3.2
No fertilization (control)	9.7	3.0	1.1
LSD ($P \leq 0.05$)	.ns	3.2	1.4

TABLE 4

The growth and yield of maize after incorporation of leguminous food crops in the minor rainy season of 2004

Leguminous food crop	*TDW ($t\ ha^{-1}$)*	*Cob weight ($t\ ha^{-1}$)*	*Grain weight ($t\ ha^{-1}$)*
Determinate cowpea	11.8	3.2	1.8
Indeterminate cowpea	5.8	1.8	1.4
Soyabean	15.5	4.9	3.0
Bambara groundnut	8.8	3.3	2.0
Groundnut	10.5	2.8	1.6
Inorganic fertilizer	17.6	4.9	3.0
No fertilization	9.2	2.6	1.6
LSD ($P \leq 0.05$)	5.0	2.2	1.4

TABLE 5

Chemical properties of soil before incorporation of leguminous crops and after harvest of maize crop in the minor season of 2004

Leguminous food crop	p*H*	*OC content (%)*	*N content (%)*
Pre-cropping	7.1	1.16	0.1
After-cropping			
Determinate cowpea	7.3	1.24	0.1
Indeterminate cowpea	7.3	1.20	0.1
Soyabean	7.3	1.19	0.1
Bambara groundnut	7.3	1.16	0.1
Groundnut	7.1	1.19	0.1
Inorganic fertilizer	7.3	1.17	0.1
No fertilization (control)	7.2	1.18	0.1
LSD ($P \leq 0.05$)	ns	ns	ns

Discussion

Biomass and grain yields of maize in the study area have been generally lower than expected (even under the recommended inorganic fertilizer application) because of low and poorly distributed rainfall. Eghball *et al*. (1995) found in a long-term manure and fertilizer trial that, although management practices can reduce temporary grain yield variability in some crops, variations in environmental factors dominated the yearly maize grain yield, regardless of soil fertility amendments. Wang *et al*. (2007) also found, in long-term effects of various combinations of maize stover, cattle manure and N and P fertilizer applications on maize that grain yields, and N, P, and K uptakes and use efficiencies were greatly influenced by the amount of rain during the growing season and by soil water at sowing.

Indeterminate cowpea, soyabean and groundnut gave fairly high growth and yield of maize, compared with the unfertilized and recommended inorganic fertilizer treatments. Soyabean and groundnut had higher N contents than the other legumes and also had fairly high TDWs. On the other hand, indeterminate cowpea (unlike the determinate cowpea) shed its leaves as fruits were harvested and continued vegetative growth, pod formation, nodulation and nitrogen fixation. In spite of its lower biomass N content, the indeterminate cowpea, due to its growth habit, had cumulatively higher TDW than the other leguminous crops, which resulted in its relatively high total N content. Profuse vegetative growth and high N fixation are important in the selection of leguminous plants for use as green manure (Nyalemegbe *et al.*, 2011).

Asibuo & Osei-Bonsu (1999) showed that maize grown after legumes responded to fertilizer N, giving indication that the legumes could not supply the entire N required by maize for optimum yield. Adediran *et al*. (2004) also found that complementary application of 50 kg N ha^{-1}, with incorporation of mucuna biomass, increased plant height, biomass weight and grain yield of maize by 18, 23, and 31 per cent, respectively, compared with incorporation of mucuna alone. These would be taken into consideration in future studies.

Conclusion

Vigna unguiculata, var. Adidome mottled, *Arachis hypogea*, var. goronga and *Glycine max*, var. GMX 92-16-2M), in rotation with maize, gave optimum growth and grain yield of maize. This was by virtue of their profuse vegetative growth and good nodulation and nitrogen fixation. In order for leguminous crops to be effective as cover crops, they should be suitable for the ecology, be able to produce enough biomass and fix substantial quantities of nitrogen.

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