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Farmers' agronomic and social evaluation of productivity, yield and N_2-fixation in different cowpea varieties and their subsequent residual N effects on a succeeding maize crop

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Abstract Cowpea–maize rotations form an important component of the farming systems of smallholder farmers in the forest/savannah transitional agro-ecological zone of Ghana. We evaluated five cowpea varieties for grain yield, N_2-fixation, biomass production, and contribution to productivity of subsequent maize grown in rotation. We further analyzed the interrelationship between these technical dimensions and the social acceptability of these cowpea varieties for farmers. Cowpea grain yield ranged between 1.1 and 1.4 t ha^{-1} with no significant yield differences among the different varieties. Using the ^{15}N natural abundance technique, the average proportion of N_2 fixed ranged between 61% for Ayiyi and 77% for Legon prolific. This resulted in average amounts of N_2 fixed in above-ground biomass ranging between 32 and 67 kg N ha^{-1}, respectively. Variation in estimates due to differences in $\delta^{15}N$ among reference plants were larger than differences between cowpea varieties. The amount of soil-derived N ranged from 15 to 20 kg N ha^{-1}. The above-ground net N contribution of the cowpea varieties to the soil (after adjusting for N export in grains) was highest for Legon Prolific (31 kg N ha^{-1}) due to high N_2-fixation and high leaf biomass production. Maize grain yield after cowpea without application of mineral N fertilizer ranged between 0.4 t ha^{-1} with maize after maize to 1.5 t ha^{-1} with Legon Prolific. The N fertilizer equivalence values for the cowpea varieties ranged between 18 and 60 kg N ha^{-1}. IT810D-1010 was ranked by the farmers as the most preferred cowpea variety due to

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its white seed type, short-duration, ease of harvesting and good market value. Despite the high leaf biomass production and high amount of N_2 fixed by Legon Prolific, it was generally the least preferred variety due to lower market price, late maturity, least potential cash income (due to the red mottled seed type) and difficulty in harvesting. Although farmers recognized the contribution of cowpea to soil fertility and yields of subsequent maize, they did not consider this as an important criterion for varietal selection. Soil fertility improvement must be considered as an additional benefit rather than a direct selection criterion when designing more sustainable smallholder farming systems.

Keywords ^{15}N natural abundance · Forage cowpea · Marketability · Crop rotations

Introduction

The potential of the forest/savannah transitional agro-ecological zone of Ghana for the production of food crops is limited by poor soil fertility, and in particular, deficiencies of nitrogen (N) and phosphorus (P). Although mineral fertilizers can improve crop nutrition, they are sparingly used by farmers in this part of Ghana, as in many regions in sub-Saharan Africa, partly due to the prohibitive cost as a result of removal of government subsidies (Gerner et al. 1995). Preliminary field experiments in Wenchi revealed N to be the most limiting nutrient (unpublished results), supporting farmers' observations that grain legumes, including cowpea (*Vigna unguiculata* (L.) Walp.), play an important role in maintaining and improving soil fertility.

Cowpea is grown by most farmers due to its short growing cycle. The grain can be used both for food and for sale. In addition cowpea improves N availability for subsequent crops. The net N-contribution varies with the amount of N_2 fixed and the proportion of the plant N that is harvested. Cowpea can fix more than 50% of its N from N_2-fixation (Ofori et al. 1987; Awonaike et al. 1990). In Ghana, Dakora et al. (1987) estimated that cowpea can contribute up to 200 kg N ha^{-1} through N_2-fixation. Positive effects of grain legumes on yields of cereals grown in rotation may also be due to other, non-nitrogen effects such as breaking of cereal pest and disease cycles (Francis and Clegg 1990), soil structure improvement (Peoples and Craswell 1992), enhanced P-availability through secretion of enzymes and acids in the legume rhizosphere (Schlecht et al. 2006), and enhanced arbuscular mycorrhizal colonization (Harinikumar and Bagyaraj 1988).

Traditionally, in the forest/savannah transitional agro-ecological zone of Ghana with two growing seasons, farmers grow cowpea in the major growing season between April and July and follow it with maize (*Zea mays* L.) during the minor growing season between September and January. The acceptability of different cowpea varieties to farmers in that region and the reasons on which they base their varietal selection are not fully understood. Cowpea varieties that combine a reasonable grain yield with a large volume of leaf biomass could offer a useful compromise to meeting farmers' food security concerns and improving soil fertility (Giller and Cadisch 1995).

The yield of five cowpea varieties developed by the National Agricultural Research System (NARS) in Ghana and their effects on the yield and N uptake of a subsequent maize crop grown in rotation were assessed on farmers' fields. N_2-fixation in the various cowpea varieties was measured using the ^{15}N natural abundance technique, and the net N benefits to the soil and subsequent maize crop were calculated. We also analyzed farmers' preferences and criteria for selecting different cowpea varieties for use in their crop rotations.

Materials and methods

Study area

A trial was conducted in three neighboring communities namely Asuoano (7°41′ N, 2°05′ W), Beposo (7°42′ N, 2°05′ W) and Droboso (7°43′ 2°05′ W) in Wenchi district of Brong Ahafo region of Ghana in both researcher-managed and farmer-managed experiments. The soils are Lixisols which developed over Voltaian sandstone (Asiamah et al. 2000). The chemical and physical properties of the surface soil of the experimental plots are presented in Table 1. The site has a bimodal rainfall pattern with a 30-year annual mean of 1,271 mm with 127 rainy days. Total rainfall during the 1 year trial period was 1,350 mm.

Table 1 Some chemical and physical soil properties of surface soil (0–20 cm) of experimental plots before the planting of cowpea in 2003

Experiment	pH (H_20)	Organic C (%)	Total N (%)	Bray 1 P (mg kg^{-1})	Sand	Silt (%)	Clay
Researcher-managed plots							
	6.1	0.58	0.06	4.3	84	3	13
Farmer-managed plots							
Asuoano	5.9	0.63	0.08	6.8	79	4	17
Beposo	5.8	1.15	0.08	5.2	66	12	22
Droboso	5.2	0.45	0.07	6.4	84	5	11

Fields were selected for the experiments by local farmers specifically to represent soil conditions where repeated cropping had led to nutrient depletion and poor soil fertility for crop production.

Researcher-managed experiment

The land where the experiment was situated had been left fallow for 2 years and was dominated by speargrass (*Imperata cylindrica* (L.) Beauv.); yam had been grown in this field earlier. The grass was cleared by slashing with a cutlass and removing the standing biomass. About 4 weeks later the land was ploughed and harrowed. After a further four weeks, herbicide (glyphosate) was applied at the rate of 900 g a.i. ha^{-1}. Five cowpea varieties namely Ayiyi, Asontem, Adom, IT810D-1010 and Legon Prolific, and local maize (var. Dorke SR) were planted 8 days later at the end of May, 2003. The six treatments were randomized within four replicate blocks. Four of the cowpea varieties compared in this experiment (Ayiyi, Asontem, Adom, and IT810D-1010) were selected by farmers from 10 varieties that had been sown in a participatory varietal selection trial. Legon Prolific, a dual-purpose variety was not initially selected by the farmers because of its late maturity period, but we decided to include it in the experiment because it produced much more biomass than the other varieties. Plot size was 12 × 12 m with 2 m paths between the plots. Cowpea rows were spaced at 60 cm and two seeds per hill were sown at 20 cm intervals within the rows. Maize was planted at 80 × 40 cm with two seeds per hill.

Plots were weeded by hand 4 weeks after planting. Insecticide (containing cypermethrin and dimethoate) was applied at 4 weeks after planting and at flowering to control insect pests. An area of 1.8 m^2 was harvested at late pod filling from all plots for N_2-fixation measurements. Maize from the plots and some non-legume reference plants (*Croton lobatus* L., *Eclipta alba* Hassk., *Imperata cylindrica*, and *Celosia trigyna* L.) growing around the plot borders were sampled and used as reference plants for estimating N_2-fixation using the $\delta^{15}N$ technique (Peoples et al. 1989). The reference plants were bulked block by block.

An area of 10.8 m^2 (three rows of 6 m) was harvested when the crops were mature. The vines and pods were separated and the pods were dried and shelled. The fallen leaf litter was collected from the harvest area of cowpea. Maize was harvested 96 days after planting: plants were counted; stover, cobs, and grain were separated and weighed. Sub-samples of all harvested samples were taken and oven-dried at 70°C for 2 days to determine dry matter contents.

In August 2003 after the cowpeas and the first season maize were harvested, the stover comprising the litter and vines were ploughed into the soil by hand using a hoe. The maize stalks were cut into 20 cm pieces and incorporated into the soil. A maize variety, Dorke SR was planted on all plots at a distance of 80 × 20 cm with three seeds per hole. The maize pockets without germination were replanted 10 days after the first planting. The stand was thinned to one plant per hill 2 weeks after planting. All plots were split into five sub-plots, which received 0, 30, 60, 90, and 120 kg N ha^{-1} as ammonium sulfate in two split applications: half 14 days and half 42 days after planting. No further fertilizers or lime were used in the researcher-managed and farmer-managed plots. Weeding was done at 4 weeks after planting.

At maturity, maize ears and stalks were harvested from the two central rows of each sub-plot, leaving a 1 m border at both ends, and weighed. A sub-sample of 10 cobs per plot was taken and grain removed and weighed.

Sampling handling and analysis

Cowpea was separated into pods and shoots and maize into cobs and shoots; sub-samples (500 g) were oven-dried at 70°C for 48 h to determine dry matter contents. All grain yield data are presented with a correction for 12% moisture content. After weighing, all plant samples were ground to pass to 1 mm and sub-samples taken for N analysis. Samples from cowpea and reference plants were analyzed for %N and δ^{15}N using a 20–20 stable isotope mass spectrometer, coupled to a CN auto-analyzer. %N in maize samples from the second season was determined by Kjeldahl digestion and colorimetric analysis of NH_4–N in the digests.

Calculations

The %N derived from N_2-fixation was calculated from the δ^{15}N values as:

$$\%\text{N from N}_2\text{-fixation} = \left\{\left[\delta^{15}\text{N}_{\text{ref}} - \delta^{15}\text{N}_{\text{leg}}\right] / \left[\delta^{15}\text{N}_{\text{ref}} - \text{B}\right]\right\}100$$

where $\delta^{15}N_{ref}$ and $\delta^{15}N_{leg}$ are the isotope signatures of respectively the non-N_2-fixing reference plant(s) and the cowpea varieties, and B is a measure of isotopic fractionation during N_2-fixation. The B value used for cowpea was –1.51‰ (Nguluu et al. 2002). The amount of N_2-fixed was calculated from the total N accumulated by the cowpea varieties.

The net contribution of N_2-fixation to the overall N balance was calculated as:

$$\text{Net N-balance} = \text{Nb} - \text{Ng}$$

where Nb = proportion of N from fixation (as assessed from the δ^{15}N values) × total biomass N and Ng = grain N exported (modified from Peoples and Craswell 1992).

Farmer-managed experiment

Collaborative farmers in each of the communities were made up of migrant and native farmers. We included both migrants and natives in the study because a previous study (Adjei-Nsiah et al. 2004) indicated that migrants and natives use different soil fertility management practices due to differential land tenure arrangements. Selection of farmers was based on interest and preparedness to spend 1 day each week on the experimental field. The composition of farmers in the various groups was as follows: Asuoano (nine natives, eight migrants); Beposo (six natives, six migrants) and Droboso (eight natives and seven migrants). The experiment was conducted on collective plots in each of the three communities, as suggested by the farmers.

Land preparation on farmers' fields consisted of ploughing by tractor followed by harrowing using hoes. Planting, field management, and harvesting decisions were made by farmers. All participating farmers in each of the communities met with the researcher and decided when to plant, spray with insecticide, and harvest. Under normal farmers' practice cowpea is sprayed when insects are observed on the plants. However, in this experiment cowpea was sprayed only when insect damage was observed, therefore the fields were sprayed only twice instead of normal farmers' practice of three or more sprays before harvest. Each experiment comprised one complete block of treatments, giving three replicate blocks.

Litter traps measuring 50 cm by 50 cm were placed under the canopies of cowpea to trap litter falling from the cowpea varieties. The litter was examined together with the farmers to illustrate the amount of litter produced by each of the varieties and returned to the soil. At 50% flowering five plants each were removed from each of the plots to study the nodulation potential in each cowpea variety. In each of the three communities farmers assessed the performance of the cowpea varieties through ranking and scoring at harvest. Each variety was compared directly against the others until they were ranked from the variety the farmers liked best to what they considered the least useful. In August 2003, a local maize variety (Dorke SR) was planted on all the cowpea plots to assess the beneficial effects of the cowpea varieties on the subsequent maize yield.

Economic analysis

Costs of production were divided into inputs and labor costs. Costs of inputs were determined using prices of local planting materials and plant protection chemicals. Labor costs for field operations (land preparation, planting, weeding, collecting water and spraying, harvesting, and threshing) were determined together with the collaborative farmers based on existing labor rates in the communities. All amounts of money are expressed in US dollars at the average exchange rate between December, 2003 and June, 2005: ¢9000 to US$1 (Bank of Ghana 2005). Prices for cowpea and maize were based on the average of the national average wholesale price between 2002 and 2004 (ISSER 2005). The cowpea price was adjusted to reflect the relative prices for the different varieties in the local market using the average for the 2000–2004 prices.

A simple financial analysis was performed to evaluate the profitability of each cowpea variety and maize. The analysis included total revenue and cost of production per hectare for each cowpea variety and maize during the first season and that of the succeeding maize in the second season when no N fertilizer was applied to the maize. From these, the net revenues for each crop as well as the full rotation were determined. The net revenue from the investment was given by:

$$\mathrm{NR} = \mathrm{TR} - \mathrm{TC}$$

where NR is the net revenue; TR, total revenue; and TC is total cost.

Returns on investment (RI) were also computed:

$$\mathrm{RI} = \mathrm{NR}/\mathrm{TC}$$

where an RI > interest rate on capital implies profitability.

Statistical analyses

Data were subjected to analysis of variance (ANOVA) using the general linear model (GLM) procedure (SAS 1996). We used Friedman's test to address the question whether different farmer groups assessed the cowpea varieties differently (Werner 1993).

Results

Grain and stover yield, N accumulation and N_2-fixation in cowpea

Grain yield of the five cowpea varieties ranged from 1.1 to 1.4 t ha^{-1} in both the researcher-managed and farmer-managed fields (Table 2) with no significant difference in yield between varieties, despite large differences in growth habit and duration between the determinate, erect varieties (Asontem, Adom, Ayiyi, and IT810D-1010) which matured in 65–70 days and the indeterminate, creeping variety (Legon Prolific) which matured only after 90 days. By contrast, twice the amount of stover (2.6 t ha^{-1}) was harvested from Legon Prolific, as from the erect varieties (1.2–1.3 t ha^{-1}). While there were no significant differences in grain N between the varieties, which ranged from 26 to 36 kg N ha^{-1}, N in stover ranged from 23 kg N ha^{-1} in Asontem to 50 kg N ha^{-1} in Legon Prolific. Observations of excavated root systems confirmed that all cowpea plants were well-nodulated (data not shown). All five cowpea varieties had similar δ^{15}N suggesting that they were fixing similar proportions of their N (Table 2). Estimates of the %N from N_2-fixation ranged from 46% to 68% in Ayiyi to 68–81% in Legon Prolific depending on the reference plant used. There were significant differences in δ^{15}N signatures among reference plants (Table 3). The dicotyledonous non-fixing reference plants had higher δ^{15}N abundance than the monocotyledonous reference plants. This resulted in higher estimates of N_2-fixation.

The contribution of N by the different cowpea varieties to the overall soil N economy

The total amount of N accumulated by the varieties ranged from 49 kg N ha^{-1} in IT810D-1010 to 86 kg N ha^{-1} in Legon Prolific (Table 4), and the amount of N_2 fixed in the above-ground biomass from 32 (Ayiyi) to 67 (Legon Prolific) kg ha^{-1}, with significant differences ($P < 0.01$) among varieties (Table 4). The amount of N accumulated from soil was similar (15–20 kg N ha^{-1}) for all varieties (Table 4).

Calculations of the net N balance indicated that all cowpea varieties were contributing N to the system (Table 4). The largest net N contribution, assuming that all above-ground foliage biomass is retained and incorporated into the soil, was made by Legon Prolific (31 kg N ha^{-1}). The net N contribution from the erect varieties was relatively small (6–11 kg N ha^{-1}). Assuming 30% of the total plant N is contained in the roots (Rochester et al. 1998; Khan et al. 2002), then the roots potentially recycle between 21 and

Table 2 Yield, nitrogen contents and δ ^{15}N values of grain and stover of five cowpea varieties grown in Wenchi, Ghana

Variety	Grain yield (t ha^{-1})	Grain N (kg ha^{-1})	Stover N (kg ha^{-1})	Grain δ ^{15}N (‰)	Stover δ ^{15}N (‰)
Researcher-managed experiment					
Adom	1.1	30	26	0.22	0.29
Asontem	1.1	35	24	0.32	0.33
Ayiyi	1.1	26	26	1.01	1.34
IT810D-1010	1.1	26	23	0.64	0.21
Legon prolific	1.3	36	50	0.32	–0.21
SED	0.15	6	5	0.54	0.55
Pr > F	NS	NS	0.001	NS	NS
Farmer-managed experiment					
Adom	1.4				
Asontem	1.2				
Ayiyi	1.1				
IT 810D-1010	1.2				
Legon prolific	1.1				
SED	0.25				
Pr > F	NS				

Table 3 Proportion of nitrogen in cowpea varieties derived from N_2-fixation using the ^{15}N natural abundance technique and the nitrogen difference method

Cowpea variety	%N derived from N_2-fixation estimated using the ^{15}N natural abundance technique	
	Average for all five reference plants	Range for individual reference plants
Adom	75	64–79
Asontem	73	63–78
Ayiyi	61	46–68
IT810D-1010	71	60–77
Legon prolific	77	68–81
SED	8	
Pr > F	NS	

Means of δ ^{15}N values for reference plants: *Celosia trigyna* = 6.78‰; *Croton lobatus* = 6.26‰; *Eclipta alba* = 4.80‰; *Imperata cylindrica* = 3.38‰; *Zea mays* = 5.49‰. SED = 0.25; Pr > F 0.001

37 kg N ha^{-1}. Allowing for this root contribution leads to a total net N balance in the soil of between 19 and 60 kg N ha^{-1} for the cowpea varieties.

Response of maize succeeding different cowpea varieties

On the plots where no mineral fertilizer was applied, maize grain yields ranged from 0.4 t ha^{-1} for plots previously cropped with maize to 1.5 t ha^{-1} for plots previously cropped to Legon Prolific (Fig. 1a). Application of N fertilizer to maize following cowpea further increased maize grain yield except in the case of maize after Legon Prolific. Application of mineral N fertilizer above 30 kg N ha^{-1} to maize following cowpea resulted in no further maize grain yield, whereas 60 kg N ha^{-1} mineral fertilizer were required to achieve similar yields (±1.2 t ha^{-1}) when maize was grown after maize (Fig. 1a).

N-fertilizer equivalence of the cowpea residues was derived by comparing maize N uptake after the cowpea varieties with no fertilizer applied with the linear N fertilizer response of maize between 0 and 60 kg N ha^{-1} (Fig. 1b). This gave an N fertilizer equivalence of 18–23 kg N ha^{-1} for the erect varieties and 60 kg N ha^{-1} for Legon Prolific. There was a highly significant relation between maize grain yield and maize N uptake (internal use efficiency) across all previous cowpea cropping and N fertilizer treatments ($r = 0.90$; $n = 30$; $P < 0.001$)—indicating a value of 26.6 kg of grain for each extra kg N taken up by maize (Fig. 1c).

Farmers' preferences and perceptions of cowpea varieties

The criteria used by farmers to rank the varieties were similar among natives and migrants, with market

Table 4 N sources and net N contributions (kg N ha^{-1}) to the overall soil N economy of five cowpea varieties when only above ground N is considered or when a correction factor for root N is included assuming that 30% of total N is in the roots

Variety	Total biomass N	N sources		N in roots	Litter N content	Vine N content	Grain N removed	N recycled	Net N contribution
		N_2-fixation	Soil						
Only above ground N considered									
Adom	56	41	15	–	12	14	30	26	11
Asontem	59	43	16	–	9	15	35	24	8
Ayiyi	52	32	20	–	10	16	26	26	6
IT810D-1010	49	34	15	–	13	10	26	23	8
Legon prolific	86	67	19	–	30	20	36	50	31
SED	8	7	6	–	3.0	2.5	6	5	6.5
Pr > F	0.01	0.01	NS	–	0.001	NS	NS	0.001	0.01

value, short time to maturity, yield, and labor demand being the four most important criteria in order of decreasing importance. Farmers in the different villages had different preferences (Friedman's $\chi^2 = 6.4$, $n = 1$; $0.01 < P < 0.025$; Table 5). The shorter duration varieties were preferred by farmers at Asuano and Beposo, and Legon Prolific was the variety they liked least. At Droboso, by contrast, Legon Prolific was ranked as the most preferred variety by migrant farmers and as second-best variety by the native farmers.

Economic analysis

In the first season, the cowpea varieties gave net revenues ranging from US$ 143–396 ha^{-1}. The highest return on investment (RI) was made with IT810D-1010 (181%), while the least return was made with Ayiyi (66%). The maize crop gave negative net revenue of US$ 26 ha^{-1} (RI = –19%) (Table 6a). The net revenues in the second season ranged from US$ 53 ha^{-1} (RI = –44%) with the plot previously cropped to maize to US$ 126 (RI = 92%) ha^{-1} with the plot previously cropped to Legon Prolific (Table 6b).

When the net revenues of both seasons were combined, all cowpea/maize rotations gave positive net revenues while the continuous maize cropping resulted in a negative net revenue. The overall net revenues for the different cowpea/maize rotations ranged from US$ 191 ha^{-1} (RI = 55%) with the Ayiyi/maize rotation to US$ 449 ha^{-1} (RI = 130%) with IT810D-1010/maize rotation (Table 6c). Continuous maize cropping resulted in negative net revenue of US$ 79 ha^{-1} (RI = –30%).

Discussion

Measurements of N_2-fixation

The δ^{15}N enrichments of the different reference plants varied from 3.38‰ in *Imperata* to 6.78‰ in *Celosia* (Table 3). The variation in the δ^{15}N values might be due to differential uptake of N sources with different isotopic signatures or isotopic discrimination during assimilation as a consequence of differences in mycorrhizal symbioses (Spriggs et al. 2003) or internal plant physiological mechanisms. However, there is no way at present to judge which plant species is the better reference plant. The amounts of N_2-fixed varied from 32 to 41 kg N ha^{-1} in the erect cowpea varieties to 67 kg N ha^{-1} in Legon Prolific (Table 4), but the amounts of soil N differed little between the varieties (range of 15–20 kg N ha^{-1}). The absence of significant differences in soil N uptake suggests they had equal access to the same soil N pool and that there were no significant differences in their rooting depths.

In Ivory Coast, Becker and Johnson (1998) reported that cowpea fixed between 38% and 86% of its N within 180 days. Using the ^{15}N-isotope dilution method, cowpea fixed between 52% and 70% of its N (Awonaike et al. 1990). Ofori et al. (1987) in contrast reported a narrower range of values (69–74%) for cowpea, similar to the values found in our experiments (Table 3).

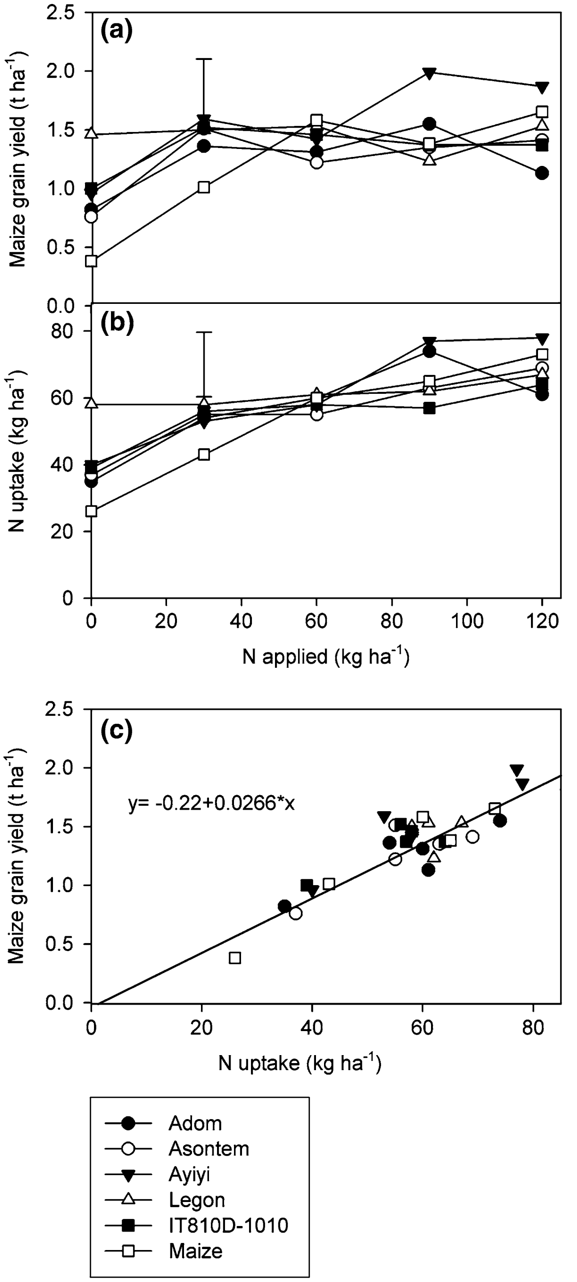

Fig. 1 Relationships between (**a**) N applied and maize grain yield (**b**) N applied and N uptake, and (**c**) N uptake and maize grain yield. Vertical error bars represent SED

N recycling and residual effects of cowpea varieties on maize yield and N uptake

The net N contribution after Legon Prolific (31 kg N ha^{-1}) was much greater than that from the erect cowpea varieties (6–11 kg N ha^{-1}) when only above-ground plant biomass was considered. When allowing for a 30% below-ground N contribution from the roots and nodules, the estimated contribution from Legon Prolific (60 kg N ha^{-1}) was still double that of the other varieties (19–28 kg N ha^{-1}; Table 4).

Maize yields after the erect cowpea varieties (0.8–1.0 t ha^{-1}) were better than maize yield after maize (0.4 t ha^{-1}), but yield after Legon Prolific was much greater (1.5 t ha^{-1}; Fig. 1a). The residual effects on maize yield were proportional to the net N contributions (cf. Table 4), and equivalent to 18–23 kg N ha^{-1} with the erect cowpea varieties and 60 kg N ha^{-1} with Legon Prolific (Fig. 1b). Estimates of N recycled including a contribution from roots are therefore more realistic. The maize variety used is a local variety not particularly N responsive compared with hybrid varieties. Furthermore, drought during the grain filling period (latter part of November—early December) contributed to the low yields, even after high N additions. Maize yields were further increased with N fertilizer, except after Legon Prolific, indicating that supplementary N fertilizer is required to maximize maize yields when preceded by short-duration, erect cowpea varieties. In similar studies in West Africa comparable N fertilizer equivalence values of 10–72 kg N ha^{-1} have been estimated for cowpea (Dakora et al. 1987; Carsky et al. 1999).

Economic analyses and farmers' evaluation of the cowpea varieties

Farmers at Asuoano and Beposo rejected Legon Prolific on the grounds that it took the longest time to reach maturity and was difficult to harvest, although they were aware that it might improve soil fertility. However, both native and migrant farmers from Droboso ranked Legon Prolific highly. Legon Prolific is similar to a local variety, which is grown by the migrants in Droboso as a leaf vegetable. Legon Prolific also produced the highest grain yield in their farmer-managed experiment. Native farmers at Droboso, who initially ranked Legon Prolific as a preferred variety, changed their preference after planting it in their own individual fields, partly because of its long duration and partly because of its lower market value. Legon Prolific, when planted in October, matures in January, which is a dry period not favorable for grain

Table 5 Farmers' preference raking for five cowpea varieties grown at Wenchi in the three villages; Asuano, Beposo and Droboso. (N.B. the lowest scores indicate the most preferred variety)

Variety	Natives			Average rank	Migrants			Average rank
	Asuoano ($n = 9$)	Beposo ($n = 5$)	Droboso ($n = 7$)		Asuoano ($n = 5$)	Beposo ($n = 5$)	Droboso ($n = 7$)	
Group experiment								
Asontem	2	2	1	1.7	4	3	3	3.3
Adom	1	3	3	2.3	2	4	4	3.3
Ayiyi	4	4	4	4.0	3	3	5	3.7
IT810D-1010	3	1	4	2.7	1	1	2	1.3
Legon prolific	5	5	2	4.0	5	5	1	3.7

Table 6 Estimated costs of production, gross revenue and returns on investment of: (a) cowpea and maize in the first season; (b) maize (without fertilizer) following cowpea and maize in the second season; and (c) cowpea/maize rotations and continuous maize cropping (sum of costs and revenues in both seasons) in Wenchi

Cowpea variety or maize crop	Economic yield (t ha^{-1})	Price/tonne (US$)	Total revenue (US$ ha^{-1})	Production costs (US$ ha^{-1})		Total cost (US$ ha^{-1})	Net revenue (US$ ha^{-1})	Returns on investment (%)
				Input	Labour			
(a) *Cowpea and maize* (first season)								
Asontem	1.1	375	405	47	171	219	186	85
Adom	1.1	449	512	47	173	220	292	132
Ayiyi	1.1	338	361	47	171	218	143	66
IT 810D-1010	1.1	564	614	47	171	219	396	181
Legon prolific	1.3	338	442	47	183	230	212	92
Maize	0.6	181	114	11	129	140	–26	–19
(b) *Maize following cowpea and maize* (second season)								
Asontem	0.8	181	138	11	114	125	13	10
Adom	0.8	181	149	11	114	125	23	19
Ayiyi	1.0	181	174	11	115	126	48	38
IT 810D-1010	1.0	181	181	11	116	127	54	42
Legon prolific	1.5	181	264	11	127	138	126	92
Maize	0.4	181	69	11	111	122	–53	–44
(c) *Cowpea/maize rotation and continuous maize cropping*								
Asontem			542	58	285	343	199	58
Adom			660	58	287	345	315	91
Ayiyi			535	58	286	344	191	55
IT 810D-1010			795	58.	288	346	449	130
Legon prolific			707	58	310	368	338	92
Maize			183	22	240	262	–79	–30

filling. In addition, owing to its creeping habit, harvesting of Legon Prolific is laborious and requires extra labor for harvesting. The migrants' varietal preference for IT810D-1010 is supported by the economic analyses (Table 6).

Farmers noted that yields of maize after cowpea were consistently better than yields after maize. The farmers also observed a stronger effect of Legon Prolific in improving the yield of the subsequent maize crop compared with the other cowpea varieties.

The economic benefits of Legon Prolific due to its residual soil fertility effects on improving the yield of the subsequent maize crop were demonstrated by the simple economic analysis (Table 6). Despite the larger benefit to subsequent maize, none of the farmer groups included this as an important criterion. When asked whether or not soil fertility improvement should be added to the list of criteria, the farmers responded negatively. Our findings confirm the conclusions of Kitch et al. (1998) who reported that in Cameroon farmers' acceptance criteria and preferences for cowpea varieties were strongly influenced by market preferences.

In the northern Guinea savanna of Nigeria, multi-purpose varieties of cowpea that combine characteristics of a good yield with prolific biomass production were found to be highly popular among farmers and rapidly spread from village to village (Inaizumi et al. 1999). Multi-purpose varieties of other legumes such as soybean have also been rapidly adopted by farmers in both west (Sanginga et al. 1999) and southern Africa (Mpepereki et al. 2000). Reasons often stated for farmers' interest in such multi-purpose varieties is the provision of fodder for livestock, improved soil fertility as well as grain for food or sale (for a detailed discussion see Chapt. 13 of Giller 2001). In the Wenchi region, livestock play a minor role and are poorly integrated in the farming systems.

Conclusions

Our results clearly demonstrate the direct benefits of N_2-fixation in cowpea and the increased residual soil fertility benefits of a creeping forage cowpea variety above the erect varieties. However, farmers did not include this as a criterion in making their variety choice. The overriding criteria for selecting cowpea varieties were related to marketability, early harvest, yield, and ease of production (low labor demand). Our results thus confirm the suggestion (Giller 2001) that soil fertility benefits of legumes must be considered as an 'additional benefit' rather than a primary criterion when designing more sustainable cropping systems together with smallholder farmers in Africa.

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References

Adjei-Nsiah S, Leeuwis C, Giller KE, Sakyi-Dawson O, Cobbina J, Kuyper TW, Abekoe M, Van der Werf W (2004) Land tenure and differential soil fertility management practices among native and migrant farmers in Wenchi, Ghana: implications for interdisciplinary action research. NJAS Wageningen J Life Sci 52:331–348

Asiamah RD, Adjei-Gyapong T, Yeboah E, Fening JO, Ampontuah EO, Gaisie E (2000) Report on soil characterization and evaluation at four primary cassava multiplication sites (Mampong, Wenchi, Asuansi and Kpeve) in Ghana. Technical Report No. 200. Soil Research Institute, Kumasi

Awonaike KO, Kumarasinghe KS, Danso SKA (1990) Nitrogen fixation and yield of cowpea (*Vigna unguiculata*) as influenced by cultivar and *Bradyrhizobium* strain. Field Crops Res 24:163–171

Bank of Ghana (2005) Periodic economic reports: half year economic review 2005 (Provisional Data) http://www.bog.gov.gh accessed on 2nd June, 2006

Becker M, Johnson DE (1998) Legumes as dry season fallow in upland rice-based systems of West Africa. Biol Fert Soils 27:358–367

Carsky RJ, Oyewole B, Tian G (1999) Integrated soil management for the savanna zone of W Africa: legume rotation and fertilizer N. Nutr Cycl Agroecosyst 55:95–105

Dakora FD, Aboyinga RA, Mahama Y, Apaseku J (1987) Assessment of N_2-fixation in groundnut (*Arachis hypogaea*) and cowpea (*Vigna unguiculata* L. Walp) and their relative N contribution to a suceeding maize crop in Northern Ghana. MIRCEN J Appl Microb Biotech 3:389–399

Francis CA, Clegg MD (1990) Crop rotation in sustainable production systems. In: Edwards CA, Lal R, Madden P, Miller RH, House G (eds) Soil and Water Conservation Society, Ankeny, pp 107–122

Gerner H, Asante EO, Owusu Bennoah E, Marfo K (1995) Ghana fertiliser privatization scheme. Private sector role and public sector responsibilities in meeting needs of farmers. IFDC-Africa, Lome Togo

Giller KE (2001) Nitrogen fixation in tropical cropping systems. CAB International, Wallingford

Giller KE, Cadisch G (1995) Future benefits from biological nitrogen fixation: an ecological approach to agriculture. Plant Soil 174:255–277

Harinikumar KM, Bagyaraj DJ (1988) Effect of crop rotation on native vesicular arbuscular mycorrhizal propagules in soil. Plant Soil 110:77–80

Inaizumi H, Singh BB, Sanginga PC, Manyong VM, Adesina AA, Tarawali SA (1999) Adoption and impact of dry-season dual-purpose cowpea in the semiarid zone of Nigeria. IITA, Ibadan, Nigeria

ISSER 2005. State of the Ghanaian economy for 2004. Institute for Social, Statistical and Economic Research, University of Ghana, Legon

Khan DF, Peoples MB, Chalk PM, Herridge DF (2002) Quantifying below-ground nitrogen of legumes. 2. A comparison of ^{15}N and non-isotopic methods. Plant Soil 239:277–289

Kitch LW, Boukar O, Endondo C, Murdock L (1998) Farmer acceptability criteria in breeding cowpea. Exp Agric 34:475–486

Mpepereki S, Javaheri F, Davis P, Giller KE (2000) Soyabeans and sustainable agriculture: 'Promiscuous' soyabeans in southern Africa. Field Crops Res 65:137–149

Nguluu SN, Probert ME, McCown RL, Myers RJK, Waring SA (2002) Isotopic discrimination associated with symbiotic nitrogen fixation in stylo (*Stylosanthes hamata* L) and cowpea (*Vigna unguiculata* L). Nutr Cycl Agroecosyst 62:10–13

Ofori F, Pate JS, Stern WR (1987) Evaluation of N_2-fixation and nitrogen economy of a maize/cowpea intercrop system using ^{15}N dilution methods. Plant Soil 102:149–160

Peoples MB, Craswell ET (1992) Biological nitrogen fixation: investments, expectations and actual contributions to agriculture. Plant Soil 141:13–39

Peoples MB, Faizah AW, Rerkasem B, Herridge DF (eds) (1989) Methods for evaluating nitrogen fixation by nodulated legumes in the field. ACIAR, Canberra

Rochester IJ, Peoples MB, Constable GA, Gault RR (1998) Faba beans and other legumes add nitrogen to irrigated cotton cropping systems. Austr J Exp Agric 38:253–260

Sanginga PC, Adesina AA, Manyong VM, Otite O, Dashiell K (1999) Social impact of soybean in Nigeria's Southern Guinea Savanna. IITA, Ibadan, Nigeria

SAS 1996. SAS user's guide: statistics. SAS Institute, Cary, NC

Schlecht E, Buerkert A, Tielkes E, Bationo A (2006) A critical analysis of challenges and opportunities for soil fertility restoration in Sudano-Sahelian West Africa. Nutr Cycl Agroecosyst 76:109–136

Spriggs AC, Stock WD, Dakora FD (2003) Influence of mycorrhizal associations on foliar $\delta^{15}N$ values of legumes and non-legume shrubs and trees in the fynbos of South Africa: implications for estimating N_2 fixation using the ^{15}N natural abundance method. Plant Soil 255:495–502

Werner J (1993) Participatory development of agricultural innovations: procedures and methods of on-farm research. GTZ, Eschborn, 251pp