

Effects of Legumes in a Cropping Rotation on an Infertile Soil in Machakos District, Kenya

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In agro-ecological zone LM4/5 there is a problem of low crop yields due to poor soil fertility after a long period of maize cropping. The soils are very sandy with very low organic matter (Aore and Gatahi 1990). Normal farming practice in the region involves little return of crop residues or use of manure. The particular terrace chosen for this experiment yielded only 80 kg grain/ha in the season prior to the experiment despite good rainfall. Similar problems confront many resource-poor farmers in semi-arid regions.

Farm resources do not allow the purchase of fertilizers, and the possibility of pronounced leaching of nutrients in wetter seasons means that fertilizers would, in any case, have to be used with care.

The major goal of this research was to identify whether a rotation of grain legumes or a fast-growing forage legume (lablab) could have a role in improving soil fertility and maize production, in a system where current productivity is extremely low. Grain legumes received emphasis because these farms are short of food grains in many seasons and there is considerable resistance to devoting crop land to non-food crops. Pigeon pea had been observed to grow well on the farm in previous seasons and is widely grown in the district. However, little information exists on its possible contribution to subsequent cereal crops.

Experimental Procedures

General

The experiment was conducted on the Kyengo farm, near Wamunyu (lat 1°25' S, long 37°34' E, altitude 1190 m) where the soil is a Haplic Alisol (Aore and Gatahi 1990).

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It was carried out during four growing seasons covering the period from October 1988 to June 1990 [Short rains (SR) 88, Long rains (LR) 89, SR89 and LR90]. In the first two seasons, appropriate plots of the experiment were planted with treatments consisting of (1) pure stands of maize, (2) intercropped pigeon peas with cowpeas and (3) intercropped pigeon peas and lablab. The whole terrace was planted with maize or sorghum in the third season and with maize in the fourth, as test crops. A basal application of soluble inorganic nutrients (excluding nitrogen) was applied to the entire terrace at first planting in the following amounts (kg/ha): P 48, S 20, Ca 85, Mg 25, Cu 2, Zn 2, B 0.5.

The experiment had five replicates of the three treatments (Table 1) set out as randomised complete blocks along the terrace.

Each plot was 10 m long and 8 m wide. However, maize growth was consistently much better on the first replicate than on the other replicates. This was associated with a much higher soil N status, probably due to its proximity to a cattle boma. The data from this replicate have been discarded in evaluating the treatment effects.

Cultural Details

Maize (cv Katumani composite B) was planted in both of the first two seasons in the maize treatments plots, and as a test crop on all plots in the third and fourth seasons. Plant spacing was 0.75 × 0.4 m (i.e. 33 300 plants/ha) in the first two seasons, and 0.9 × 0.3 m (37 000 plants/ha) in the third and fourth seasons. Sorghum was also grown as a test crop in the third season on sections of plots that had received treatments 1 and 2.

Pigeon pea (a local long-season variety) was planted in both the legume treatments in the first season and allowed to grow through to the second season. The spacing was 1.2 × 0.3 m but it was not rigorously thinned and resulted in about 40 000 plants/ha.

Cowpea (cv M66) was planted as an intercrop in both of the first two seasons in treatment 2. It was planted in single rows midway between the pigeon-pea rows (i.e. 0.6 m from the pigeon peas). Intra-row spacing was 0.15 m giving a plant population of 55 600 plants/ha.

Table 1. Details of treatments and test crops.

Treatment no.	Species grown (SR88, LR89)	Test crops	
		SR89	LR90
1	Maize	Maize, sorghum	Maize
2	Pigeon peas and cow peas	Maize, sorghum	Maize
3	Pigeon peas and lablab (retained)	Maize	Maize
	Pigeon peas and lablab (removed)	Maize	Maize

Lablab purpureus (cv Rongai) was planted only once — in the first season of treatment 3 — and allowed to grow on after cutting back at the end of the first season. Plant arrangement was the same as for the cow peas.

All species were over-planted and then thinned to ensure the desired stands. Grain legumes were sprayed to control insects as required.

Management of the Legumes

Cow peas. At harvest, pods were removed but stems and fallen leaves were left on the plots to decompose. In the second season (LR89) cowpeas were replanted between the now well-established canopy of pigeon peas.

Pigeon peas. Pods were harvested progressively during the long dry season and the total grain yield was calculated. Leaves were allowed to fall on the plots but woody stalks were removed after harvest of pods had been completed, and weighed.

Lablab. In the first season (SR88) lablab grew profusely and was not defoliated until late March 1989. At this stage it was cut back to 0.2 m height, yielding 2100 kg DM per ha. The prunings were retained in situ on one half of each plot, but removed from the other half plot for recording of yields and then discarded.

In late July 1989, the remaining lablab residues were removed on the appropriate half of each plot (as in March) while the residues were incorporated on the other half plot.

Assessment of Soil Fertility by Cereal Cropping

In October 1989 the whole site was cultivated using hand tools. Crops of maize (KCB) and sorghum (cv Serena) were planted at onset of the short rains 1989. All plots except those after lablab were split and planted half to maize and half to sorghum. The plots previously split for removal or return of lablab residues could not be split any further and so were planted to maize only.

Any possibility of complicating deficiencies of phosphorus or sulfur was avoided in the test crops by augmenting the basal nutrients already applied in 1988 with additional single superphosphate (100 kg/ha) placed along the rows soon after planting. The maize established well. Sorghum was more troublesome and slow to establish, but was planted as an assurance of obtaining some grain yield if the season was a poor one.

Soil sampling

The soil was sampled at the start of the experiment in November 1988, samples being collected from all plots for the depth intervals 0–15, 15–30, 30–60 and 60–90 cm. In October 1989, following cultivation, and again in March 1990, the following samples were collected:

- A composite from each plot of 10 cores to 20 cm depth taken with a 5 cm diameter auger.
- Profile samples from all half-plots for the same depth intervals as previously.

Sub-samples were taken for moisture and the remainder of each sample was frozen for later analysis.

Analytical Methods

Plant materials were dried at 70°C before weighing. Total nitrogen in plants and soils was determined by conventional Kjeldahl methods on the ground materials from dried samples. Total soil carbon was obtained by Walkley and Black digestion with a factor of 1.30 being applied to allow for incomplete recovery.

Mineral nitrogen was determined on soil extracts obtained after shaking a 25 g sample for 1 hour in 100 mL of 1M KCl containing 5 mg/L of phenyl mercuric acetate. After filtration, 50 mL of extract was steam distilled (after adding 5 mL of 12% water suspension of powdered calcined MgO) into 5 mL of 2% boric acid and indicator to collect the extractable ammonium-N. Powdered Devarda's alloy (0.2 g) was then added to the extract and distillation was repeated to obtain the nitrate-N. Ammonium and nitrate were determined separately by titrating the distillates with standard sulphuric acid. Nitrite-N was assumed to be negligible.

Results

Crops in the First and Second Seasons (SR88 and LR89)

Legume growth was excellent in the first season (SR88). Pigeon peas grew well after cowpeas (treatment 2) in the second season (LR89), but the cowpeas interplanted in this season failed due to competition. Lablab grew well in the first season but a number of plants died in the second season after defoliation. Approximately 2000 kg/ha of

lablab dry matter was achieved on healthy plots in both seasons, but the death of large patches of plants on some plots in LR89 reduced the average yield in the second season to about 1000 kg/ha. Cow peas yielded 1200 kg/ha of grain in the first season. Pigeon peas yielded 690 kg/ha after cowpeas but only 310 kg/ha in the presence of lablab (Table 2).

Maize yields on the continuous maize plots were very poor. In SR88 the average grain yield was 67 kg/ha and in LR89, due to the short abrupt season and extreme N deficiency, all plots failed to produce grain. The severity of N deficiency was highlighted by a neighbouring maize crop fertilised with complete nutrients (including nitrogen) which produced over 2000 kg/ha in LR89.

Soil Mineral Nitrogen

Soil profiles could be sampled consistently to only 90 cm because of stone lines at about 1 m depth. Analyses showed that at the start of the experiment there was 47 kg/ha of nitrate-N in the profile to 90 cm depth (mean across four replicates) with no difference between the treatment plots (Table 3).

Following the growth of legumes for two seasons, differences in mineral-N were marked in the composite surface (0–20 cm) samples. The difference between the continuous maize plots (16.5 kg N per ha) and the legume plots (30.4 kg/ha) was highly significant ($P < 0.001$).

Profiles taken from each plot showed that these differences existed throughout the 0–90 cm layer. Nitrate-N was quite evenly distributed throughout the 0–90 cm zone (Fig. 1). Ammonium-N also tended to increase after the legume treatments, but the amounts present were small (4–10 kg N per ha) and accounted for only about 10 per cent of the total mineral-N. Differences between the two legume treatments were not significant, but the legume plots contained significantly ($P < 0.05$) more mineral-N (88.3 kg N per ha) than the plots previously under maize (50.6 kg N per ha).

In March 1990, the soil mineral N content was low, with a mean of only 20 kg N per ha in the 0–90 cm depth and no obvious treatment effects. Total soil nitrogen analyses revealed no long term effects or differences between treatments. Averaged throughout the profile, total N was 0.029% and showed no trends with depth.

Table 2. Crop and nitrogen yields (kg/ha) in the first two seasons (SR88 and LR89).

		Treatment				
		(1)	(2)		(3)	
		Maize	Cow pea/ CP	Pigeon pea PP	Lablab/ LL	Pigeon pea PP
SR88	grain	67	1217	–	–	–
	total biomass	237	3275	–	2020	–
LR89	grain	–	–	694	–	309
	total biomass	(100) ^a	–	4785	994	2276
Estimated total N uptake (over 2 seasons)		5	92		85	
Estimated N removal		5	75		75	

^a Estimated (not measured)

Table 3. Mineral N (kg/ha) in soil.

Date/sampling type		Treatments			Significance of the difference between treatment (1) and the mean of the legume treatments
		(1)	(2)	(3)	
16.11.88	profiles (90 cm)	46	54	39	ns
7.11.89	composites (20 cm)	17	34	27	($P < 0.001$)
7.11.89	profiles (90 cm)	51	79	97	($P < 0.05$)
21.3.90	profiles (90 cm)	(24) ^a	28	21	ns

^a Very variable replicates

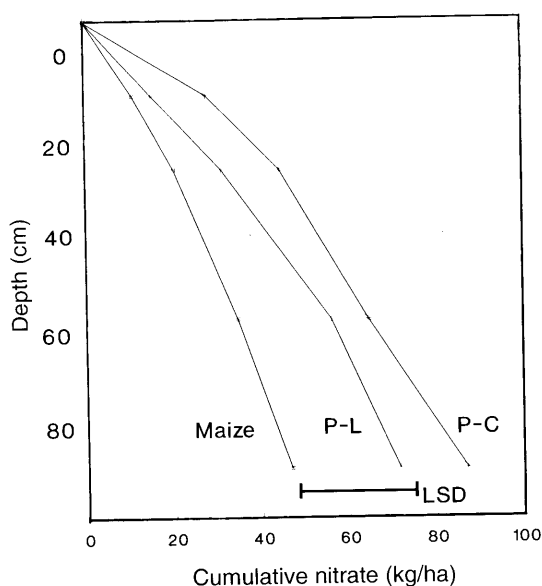


Fig. 1. Cumulative amounts of nitrate-N in soil profiles to 90 cm depth after two seasons of three different cropping treatments, viz. continuous maize, pigeon pea/cow pea (P-C) and pigeon pea/lablab (P-L).

Cereal Crops in SR89 and LR90

Despite the legume treatments, the indicator crops of maize and sorghum, planted in November 1989 at the onset of the short rains, looked severely N-deficient from an early stage.

However, the overall N-deficiency did not prevent differences in maize biomass from appearing after 2 months growth. Biomass after maize was 190 kg/ha compared with 470 kg/ha after legumes. Sorghum was still poorly established at this stage.

Differences increased over the remainder of the season, both in maize and sorghum. At final harvest, the differences were significant ($P < 0.05$) in maize total biomass and in grain (Table 4). Grain yield after maize was only 82 kg/ha compared with 485 kg/ha after legumes. The difference in sorghum yields was similar but the effect was more convincing statistically ($P < 0.001$ for biomass, $P < 0.01$ for grain). Grain yield of sorghum increased from 102 kg/ha following maize to 402 kg/ha after cow pea/pigeon pea. There were no significant differences between the two legume treatments, or between the subplots that compared the removal or incorporation of the lablab residues.

In the subsequent long rains (LR90), maize was replanted throughout and was severely N-deficient. The

crop was variable and yielded no significant treatment differences, but a trend in grain yields remained, from 54 kg/ha after maize to 175 kg/ha after legumes.

Discussion

The inclusion of legumes in the cropping rotation clearly gave a large increase in biomass and grain production over three seasons compared with continuous maize cropping on this low nitrogen site. The cow pea crop is estimated to have contained 45 kg N per ha in grain and hulls, and the subsequent pigeon pea crop contained another 30 kg N per ha. This nitrogen was removed from the plots and thus did not contribute to the subsequent increased growth of the cereal crops. The residual effect was due to a sparing of soil nitrogen by biological fixation and return of haulms and roots.

Similarly, the lablab/pigeon pea combination is also estimated to have produced an average of about 75 kg N per ha in lablab biomass (60 kg N per ha) and pigeon pea grain plus hulls. Surprisingly, the removal of lablab from one half of the plot did not produce a detectably different residual effect on cereal yields from that after returning all cut material. This could be partly explained by volatile losses and transport of dried plant residues across the site by termites or wind, or by the late removal of herbage after some leaf fall had occurred.

The residual effect of the legumes on subsequent cereal yields did not differ between legume species and amounted to an extra grain production of 300–400 kg/ha. Despite the slow establishment of the sorghum crop, the total biomass achieved after legumes by maize and by sorghum was very similar — about 1000 kg/ha.

Substantial amounts of mineral nitrogen, mainly nitrate, remained in the soil profiles after legumes, adding about 40 kg N per ha to that in the plots previously under maize. However, only about 30% of this extra nitrogen was recovered in the above-ground cereal biomass. The mineral nitrogen at planting was well distributed down the soil profile. It would be susceptible to leaching in this sandy soil and could evade being absorbed by the roots of a deficient, weak and widely spaced crop.

While legume crops are clearly very advantageous in this soil environment, their residual effects on cereal yields may be less per unit of nitrogen present than nitrogen fertiliser carefully placed near the plants at 30 days after planting, when a nitrogen recovery of > 50% could be expected.

One important observation on the site was that soil fertility was noticeably higher close to trees of *Acacia* and deciduous species. Within 30–50 m of a cattle boma surrounded by trees which deposited their leaf fall into the plots, cereal growth and yield were several times greater than those in plots further away from the trees.

Table 4. Cereal yields (kg/ha) in SR89 after rotation-cropping treatments.

Test crop	Treatment (1) (maize)		Treatment (2) (Cow pea/pigeon pea)		Treatment (3) (Lablab/pigeon pea)	
	Maize	Sorghum	Maize	Sorghum	Lablab removed	Lablab retained
					Maize	Maize
Total DM	289	274	983	940	1172	1063
Grain	82	102	464	402	562	449

These higher fertility patches occurred in two areas of the experiment site, and had to be avoided in the analysis of the data. Thus the use of perennial plants, as in agroforestry or alley cropping, may offer considerable advantages in enabling the recycling of soil nutrients back to the soil surface in organic matter. Even pigeon peas, intercropped in their first season and maintained for a whole year, have some advantages in this regard.

The present work in Kenya, though only a single experiment at one site, is consistent with studies elsewhere (Table 5). The positive residual effect of two seasons of legume providing about 40 kg N per ha of soil nitrate is typical of other observations made on an annual basis by various methods. This amount of nitrate was not nearly sufficient to provide the full N requirements of the maize or sorghum crops but it was a useful boost. The legume-cereal rotation was clearly many times more productive than continuous cereal cropping.

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Table 5. Residual effects of legumes on nitrogen available to cereal crops in semi-arid areas.

Authors	Legume (location)	kg N/ha/year	Method
Narain et al. 1980	Pigeon pea (India)	40	Leaf litter N
ICRISAT 1981	Pigeon pea (India)	40	N fert. equiv.
MacColl 1989	Pigeon pea (Malawi)	12-55	N fert. equiv.
Eaglesham et al. 1982 ^a	Cowpea (Nigeria)	36	N balance
Singh 1983	Cowpea intercrop (India)	46	N fert. equiv.
Singh 1983	Green gram intercrop (India)	31	N fert. equiv.
Reeves et al. 1984	Lupin (Australia)	41	Soil mineral N
Doyle et al. 1988	Lupin (Australia)	20-37	N uptake (wheat)
MacColl 1989	Lablab (Malawi)	36	N fert. equiv.
MacColl 1989	Groundnut (Malawi)	9	N fert. equiv.
MacColl 1989	Soybean (Malawi)	7	N fert. equiv.
Puckridge and French 1983 ^b	Legume pastures	30-150	Total soil N

Notes:

^a As calculated by Ofori and Stern (1987)

^b Review of studies in southern Australia

Explanation of methods

N fert. equiv. denotes the amount of fertilizer which had to be added to the test crop growing after a non-legume control crop to produce an equivalent yield to that after the legume.

Other methods depend on analyses of legume leaf litter, balance of soil and crop N, N uptake in the relevant test crops, and accumulated soil N, respectively.

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