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ROTATIONAL EFFECTS OF GRAIN LEGUMES ON MAIZE PERFORMANCE IN THE RIFT VALLEY HIGHLANDS OF KENYA

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ABSTRACT

High fertiliser costs and declining soil fertility are among the key factors contributing to low crop yields in Kenya. The contribution of five legumes grown in the short-rains season to soil nitrogen status and performance of a succeeding maize (*Zea mays* L.) was studied in an experiment at Njoro and Rongai within the Rift Valley Highlands of Kenya, from 1997 to 1999. Treatments included a weedy fallow, five grain legumes and maize (H513) grown during short-rains season followed by maize in the April-August long-rains season. The legumes were chickpea (*Cicer arietinum* L.), field bean (*Phaseolus vulgaris* L.), soybean [*Glycine max* (L.) Merril], garden pea (*Pisum sativum* L.), dolichos [*Lablab purpureus* (L.) Sweet]. The crop residues and vegetation of the weedy fallow were incorporated in the soil during seedbed preparation for the long rains season. The maize test crop was supplied with three levels of nitrogen, 0, 30, and 60 kg ha^{-1} as main factor whilst fallow management options were allocated as sub-factors in a split-plot treatment arrangement of a randomised complete block design replicated three times. Results show improved soil N status following legumes, with dolichos giving highest available N. Grain yield in maize succeeding legumes was 24-68% higher than maize succeeding weed fallow. In the absence of N fertiliser input, maize succeeding dolichos gave 20-40% higher yield than maize after weed fallow treated with recommended 60 kg N ha^{-1} fertiliser rate. The study has demonstrated that the use of grain legumes, particularly dolichos in rotation with maize, is a viable and preferable option to weedy fallows and maize-maize sequences.

Key Words: Chickpea, crop rotation, dolichos, fallow, field bean, garden pea, maize, soybean

RÉSUMÉ

Les coûts très élevés des engrais et le déclin de la fertilité du sol sont parmi les facteurs clés qui contribuent au faible rendement des cultures au Kenya. La contribution de cinq légumineuses cultivées durant la petite saison de pluie au status de l'azote du sol et la performance du maïs suivant (*Zea mays* L.) a été étudiée dans un essai à Njoro et Rongai dans les hautes Terres du Rift Valley du Kenya, de 1997 à 1999. Les traitements comprenaient une jachère sarclée, cinq légumineuses à graines et le maïs (H513) cultivés pendant la petite saison de pluie suivie par le maïs durant la grande saison pluvieuse d' avril-Août .Les légumineuses étaient le pois chiche (*Cicer arietinum* L.), le haricot (*Phaseolus vulgaris* L.), le soya {*Glycine max* (L.), Merril}, le petit pois (*Pisum sativum* L.), le lablab {*Lablab purpureus* (L.) Sweet}. Des residues des cultures et la végétation de la jachère étaient incorporées au sol pendant la préparation du semis pour de longues saisons pluvieuses. Le maïs test a été fourni avec trois niveaux d'azote, 0, 30 et 60 kg ha^{-1} comme facteur principal alors que les options de gestions de la jachère étaient des sous-facteurs dans un arrangement de traitement en split-plot des blocks complètement rendomisés avec trois répétitions. Des résultats ont montré le status de l'azote amélioré après des légumineuses, avec le lablab donnant de l'azote disponible très élevé. Le rendement grain du maïs suivant les légumineuses était 24-68% plus élevé que le maïs suivant la jachère sarclée. En l'absence des intrants d'engrais azoté, le maïs suivant le lablab a donné 20-40% de rendement supérieur à celui du maïs après la jachère sarclée traités avec le taux recommandé de 60 kg N ha^{-1}. L'étude a montré que l'utilisation des légumineuses, en particulier le lablab en rotation avec le maïs, est une option viable et préferable à la jachère sarclée et à la séquence maïs- maïs.

Mots Clés: Pois chiche, rotation des cultures, lablab, haricot, petit pois, maïs, soya

INTRODUCTION

Maize (*Zea mays* L.) is a primary food crop in Kenya and is cultivated country wide. Annual production is estimated to be 2.7 million tonnes which is slightly less than consumption (KARI and MIAC, 1993). Besides frequent unfavourable weather conditions, low input use has constrained maize production (Muriuki, 1998). Kenya's population is projected at 36 million in the year 2010, up from the current 27 million. Per capita arable land has declined over the years from 0.23 to 0.15 hectares in 1981 and 1996 respectively (World Bank, 1998) and increased productivity is therefore essential (KARI, 1992).

Maize yield is often constrained by inadequate nutrient supply as little fertiliser is used due to high costs. Nitrogen can be added to the soil through biological N fixation by legumes that are less expensive, and more readily available to farmers than inorganic fertilisers. Increased maize yield subsequent to legume production is attributed to improved N supply following mineralisation of legume plant residues (Onim *et al.*, 1990; Kwesiga and Coe, 1994; Wortmann *et al.*, 1994; Peoples *et al.*, 1995; Oike *et al.*, 1998).

The Kenya Highlands have a bi-modal rainfall pattern with the long rains (300-600 mm) in April-August and the short rains (250-400 mm) in October-December (Jaetzold and Schmidt, 1983). Most crops are produced during the long-rains season and much land is fallowed during the short-rains season due to low and erratic rainfall. It may be feasible to produce suitably adapted legumes during the short rains to produce manure for the subsequent crop. It has been reported (Tanner *et al.*, 1994) that traditional short fallows in Ethiopia were managed with legumes that improved grain yields of succeeding cereals. Adaptation of some legumes to the semi-dry fallow gap indicates that legumes can be integrated in cereal production with positive yield results (Mwandemele, unpublished data; Rheenen *et al.*, 1991; Guto, 1997; Onwonga, 1997). However, more information is needed on the potential of producing legumes during the short rains and on their effects on subsequent cereal crops. Such legumes must tolerate water deficits and produce crop residues of adequate C:N ratio to decompose rapidly and supply nutrients to the crops in the subsequent season. The study tested two hypotheses: that the growing of legumes during the short rains season in the Kenya Highlands increases grain yield of a subsequent maize crop and that this yield increase is associated with improved soil N contributed differentially by the legumes.

MATERIALS AND METHODS

Site description. The study was conducted in the central Rift Valley region of Kenya, at Egerton University near Njoro (0° 23' S and 35° 35' E) and on a farmer's field at Mangu in Rongai (0° 10' S and 36° 01' E), both within Nakuru District. The sites are in agriculturally high potential zone III(6) and III(5) respectively, within the Kenya Highlands (Jaetzold and Schmidt, 1983) and are about 30 km apart. Mangu is at an altitude of 1945 m above sea level and receives annual rainfall of about 900 mm with a mean annual temperature of 16-18°C. The soils are well drained sandy clay loams, classified as *Vitric Andosols*. Egerton University is at 2250 m above sea level and receives annual precipitation of about 1000 mm and has a mean annual temperature range of 14-16°C. The soils are well drained dark reddish clays, classified as *Mollic Andosols*.

Experimental design and sampling procedures. Twenty one treatments were arranged as a split-plot in a randomised complete block design (RCBD) replicated three times. Three levels of N-fertiliser (0, 30, and 60 kg N ha^{-1}), applied as Calcium Ammonium Nitrate, were assigned to whole plots measuring 4x21 m. The nitrogen was applied during the long rains to the subsequent maize crop at the V6 growth stage (Ritchie *et al.* 1986). The sub-plots measured 4x3 m and the treatments consisted of maize (Hybrid H513), a natural fallow and five grain legumes namely: chickpea (*Cicer arietinum* L.), field bean (*Phaseolus vulgaris* L.), soybean (*Glycine max* (L.) Merril), garden pea (*Pisum sativum* L.) and dolichos (*Lablab purpureus* (L.) Sweet). These sub-factor treatments were applied during the short-rains season of October-December in 1997 and then again in 1998.

Land was tilled with hand hoes for all treatments except the natural fallow which was left untilled. Fallow management crops (FM) were sown in October, at the recommended spacing; chickpea 30x10 cm, field bean 50x20 cm, soybean 45x15 cm, garden pea 45x15 cm, dolichos 60x30 cm and maize 75x30 cm. All legume seeds were inoculated with their specific strains of *rhizobia* prior to sowing in the first season only and sown without inoculation in the subsequent seasons. Inorganic-P was applied as basal treatment at the rate of 60 kg P_2O_5 ha^{-1} in Triple Superphosphate (TSP), $Ca(H_2PO_4)_2H_2O$ as recommended (KARI, 1997). Inorganic N was not applied to any crop during the short rains season, as most legumes were assumed capable of fixing their own nitrogen from the atmosphere (Marschner, 1995)

Data were collected from each subplot and included the following response variables; stand count, nodule count, nodule dry weight, above ground biomass, vegetative tissue N content; and seed production. Harvesting of the crops which seeded was done between January and February the following year depending on when each crop matured. The grains were taken while the rest of the vegetative material was left in the field for subsequent incorporation into the soil during land preparation for the long rains season. Three legumes in each plot were sampled by consistently picking the 6th plant from each of the three middle rows in each plot except for fallow and maize plots. This was done at the onset of flowering, approximately 80-85 days after emergence for most species. The nodules were dried at 65°C for 48 hours and the dry weights taken. To determine the DM , three plants were randomly sampled in each experimental unit except in fallow plots where a one meter quadrant was used and above ground vegetation taken. The sampling was done to coincide with R3 growth stage, when most plants were expected to be at the peak of dry matter accumulation (Ritchie, *et al.* 1986). The plants were dried at 65°C to constant weight and the dry weight measured. The dry samples were milled and stored for organic carbon and tissue-N analysis.

The seedbed for maize test crop was prepared in March for all treatments. Maize seed (Hybrid H513) was sown at the onset of long rains in mid-April in 1998 at a spacing of 75x30 cm. A blanket application of phosphorus at 60 kg P_2O_5 ha^{-1} was provided as TSP. Other crop management practices were done as recommended. Maize was harvested in October 1998 and the second cycle of the experiment repeated in 1999 in the same plots.

Soil samples were taken six weeks after fallow residue incorporation to coincide with estimated peak mineralisation of legume residues (Palm, 1995; Handayonto *et al.*, 1992), at 0-15 cm and 15-30 cm depth from each plot and refrigerated at 4°C, pending inorganic N analysis.

Maize sampling for DM determination was done at V6 and R2 growth stages as described by Ritchie *et al.* (1986). Three plants were sampled at the crown level in each plot. The 4th and 6th plants in the second row and a 5th in third row were picked for the V6 and the next plants in the same rows for the R2 sampling, respectivey. At each sampling the plant specimens were dried at 65°C for a minimum of 48 hours to constant weight. During vegetative development three plants were randomly selected in each plot and used to monitor Leaf Area Index (Norman and Campbell, 1989). At physiological maturity whole plants from the two middle rows were taken and separated into cobs and vegetative tissue, oven dried at 85°C to constant weight, and then shelled for grain yield determination and milled for tissue N analysis.

Plant tissue-N, organic carbon, and Soil inorganic N analysis. To determine total N in tissues, plant samples were digested with one tablet of 'Kjeltabs' (containing 3.5 g K_2SO_4 and 400 mg $CuSO_4$) and 5 ml of H_2SO_4, in a Tecator 1015 digester at 360°C for two hours. After cooling, each diggested sample was dissolved in

100 ml distilled water and a 10 ml aliquot taken for distillation (Page *et al.*, 1982; Okalebo *et al.*, 1993).

Inorganic N ($NH_4^+ + NO_3^-$) was determined by extracting 8g from soil of known moiture content with 80 ml 2M KCl for 1 hour and distilling a 10 ml aliquot with Magnesium oxide and Dervardas alloy. The distillate was collected over 5 ml boric acid and titrated with 0.002N H_2SO_4 (Page *et al.*, 1982; Okalebo *et al.*, 1993).

Organic carbon of the plant tissue was determined by the Walkley-Black wet oxidation method and the C:N ratio for each sample calculated by dividing the carbon content with the corresponding N content (Okalebo *et al.*, 1993).

Data analysis. Data were subjected to analysis of variance using the General Linear Model (GLM) and the means separated by Duncan's Multiple Range Test (DMRT) on a SAS software (SAS 1996; Steel *et al* 1997), with acceptable error limited to 5% (P=0.05). The analysis was separate for site and year due to significant interactions.

RESULTS

Fallow management treatment effects on soil and tissue N, nodulation and Carbon. Inorganic N was more following dolichos as compared to the weedy fallow (Table 1). However, inorganic N did not differ for crop fallows except in 1998 at Rongai where N was more following dolichos. During the short rains season, the weedy fallow generally produced more biomass than dolichos, garden pea and chickpea (Table 2), with soybean, field bean and maize producing intermediate amounts. N concentration for weeds was not less than that for legume crops except dolichos at Njoro but generally less compared to all other fallow treatments at Rongai (Table 3). Garden pea and dolichos residues had the highest N concentration, while soybean had a lower percent N than other legumes. The C:N ratios were consistently higher for weeds and maize than for legumes but were similar amongst all legume crops at both Rongai and Njoro. In 1997/98, nodulation was best for garden peas and field bean, intermediate for soybean and dolichos and poor for chickpea (Table 3). Nodulation was extremely poor in 1999/2000 probably because no inoculation was done and also due to severe water deficits that year; no nodules were found on chickpea, field bean and garden pea.

Fallow management effects on subsequent maize crop. Maize biomass was more following dolichos than for continuous maize and weedy fallow in all cases except for Rongai in 1999 (Table 5). While maize biomass was more following dolichos in two of four cases the other legumes and weedy fallow had less but similar influence. Maize leaf area index (LAI) was more

TABLE 1. Effect of fallow management treatments on soil inorganic-N at eight weeks after residue incorporation and four weeks after sowing maize

	Soil inorganic-N (μg N g^{-1})					
	Njoro (1999)		Rongai (1998)		Rongai (1999)	
Fallow treatments	0-15cm	15-30cm	0-15cm	15-30cm	0-15cm	15-30cm
Chickpea	32.5^{a*}	26.9^{ab}	8.9^{b}	9.5^{b}	39.0^{ab}	25.3^{ab}
Field bean	34.8^{a}	27.6^{ab}	7.2^{b}	10.6^{b}	37.6^{ab}	33.2^{a}
Soybean	37.5^{a}	33.4^{a}	9.0^{b}	8.6^{b}	30.6^{ab}	26.6^{ab}
Garden pea	32.6^{a}	28.9^{ab}	8.8^{b}	7.3^{b}	37.7^{ab}	32.3^{a}
Dolichos	38.2^{a}	32.9^{a}	13.9^{a}	15.5^{a}	44.2^{a}	36.1^{a}
Maize	40.2^{a}	30.5^{ab}	7.0^{b}	9.4^{b}	36.0^{ab}	28.3^{ab}
Weedy fallow	33.2^{a}	22.9^{b}	9.1^{b}	10.0^{b}	27.6^{b}	19.3^{b}

*Means followed by the same letter in the same column are not significantly different as per LSD test (α=0.05)

TABLE 2. Above-ground biomass production (Mg ha^{-1}) by the fallow management species during the 1997/98, 1998/99 and 1999/2000 short-rains cropping season in Njoro and Rongai

Fallow treatments	Above-ground biomass (Mg ha^{-1})							
	Njoro				Rongai			
	1997/98	1998/99	1999/00	Average (Njoro)	1997/98	1998/99	1999/00	Average (Rongai)
Chickpea	2.11^{cd}	1.40^{b}	1.47^{bc}	1.66	1.10^{c}	0.96^{a}	0.46^{b}	0.84
Field bean	3.63^{ab}	1.88^{a}	1.08^{c}	2.20	2.83^{ab}	0.52^{a}	0.45^{b}	1.27
Soybean	2.98^{bc}	2.22^{a}	1.56^{bc}	2.25	1.84^{bc}	1.10^{a}	0.69^{a}	1.21
Garden pea	1.36^{d}	0.92^{cd}	0.99^{c}	1.09	2.05^{bc}	*	0.35^{b}	1.20
Dolichos	1.44^{d}	0.57^{d}	0.83^{c}	0.95	1.19^{c}	0.50^{a}	0.32^{b}	0.67
Maize	4.64^{a}	1.11^{bc}	2.40^{b}	2.72	2.14^{bc}	1.72^{a}	0.49^{ab}	1.45
Weedy fallow	4.58^{a}	0.71^{cd}	4.08^{a}	3.12	3.68^{a}	0.48^{a}	0.51^{ab}	1.56

Means followed by the same letter in the same column are not significantly different as per LSD test (α=0.05)
*Biomass missing due to crop damage by Guinea fowls

TABLE 3. Tissue N, C/N ratio and nodules in fallow species at R3 at Rongai and Njoro, 1997/1998

Fallow	Njoro				Rongai			
	%N	C/N (Ratio)	Nodules (No/plant)	Nodules (gms/plant)	%N	C/N (Ratio)	Nodules (No/plant)	Nodules (gms/plant)
Chickpea	2.2abc	11.5bc	1.0c	0.0b	2.0^{b}	12.9^{b}	0.5c	0.0a
Field bean	1.8abc	12.2bc	25.6b	0.1b	2.0^{b}	14.1^{b}	10.7a	0.4a
Soybean	0.9c	15.8b	17.2bc	0.3a	1.8^{b}	14.7^{b}	3.4bc	0.1a
Garden pea	2.3ab	11.8bc	64.1a	0.1b	3.8^{a}	11.9^{b}	11.6a	0.1a
Dolichos	2.8a	9.0bc	13.7bc	0.4a	3.4^{a}	12.3^{b}	6.9ab	0.1a
Maize	2.0abc	15.3b	-	-	1.8^{b}	14.7^{b}	-	-
Weedy fallow	1.4bc	21.1a	-	-	0.9^{c}	21.7^{a}	-	-

Means followed by the same letter in the same column are not significantly different as per LSD test (α=0.05)

TABLE 4. Effect of fallow management treatments on maize dry weight at V6 growth stage in two locations

Fallow treatments	Njoro			Rongai		
	DM yield (Mg ha^{-1})			DM yield (Mg ha^{-1})		
	1998	1999	Mean	1998	1999	Mean
Chickpea	0.75^{ab}	0.49^{ab}	0.62	0.29^{b}	0.42^{a}	0.36
Field bean	0.86^{ab}	0.42^{ab}	0.64	0.24^{b}	0.42^{a}	0.33
Soybean	1.06^{ab}	0.33^{b}	0.70	0.27^{b}	0.28^{a}	0.28
Garden pea	0.93^{ab}	0.33^{b}	0.63	0.16^{b}	0.32^{a}	0.24
Dolichos	1.20^{a}	0.68^{a}	0.94	0.58^{a}	0.46^{a}	0.52
Maize	0.49^{b}	0.35^{b}	0.42	0.11^{b}	0.35^{a}	0.23
Weedy fallow	0.57^{ab}	0.20^{b}	0.39	0.19^{b}	0.30^{a}	0.25

Means followed by the same letter in the column are not significantly different as per LSD test (α=0.05) following chickpea, field bean, soybean and dolichos as compared to maize following maize at both locations, while LAI was not increased by weedy fallow. Generally, highest LAI values were associated with dolichos during both the V9 and R2 growth stages (Tables 5 and 6). Maize LAI did not increase with N rate at the V9 stage in both locations, however, high N supply resulted in large increases in maize biomass only at the R2 growth stage in Rongai particularly following dolichos. In general biomass yield was almost twice as large at Njoro when compared to Rongai.

Maize grain yield and yield components. Maize grain yield averaged 4.89 and 3.56 Mg ha^{-1} in 1998 and 1999, respectively (Table 7a and b) and varied with treatment only in 1998. During that year, maize yield following dolichos was more

TABLE 5. Influence of fallow management species and N fertilizer application on leaf area index (LAI) at V9 growth stage in maize during 1998 cropping season

Fallow treatment	Leaf area index (LAI) at V9							
	Njoro				Rongai			
	Nitrogen levels (kg ha^{-1})			Fallow species means	Nitrogen levels (kg ha^{-1})			Fallow species means
	0	30	60		0	30	60	
Chickpea	1.64	1.30	1.04	1.33^{a}	1.31	0.87	1.54	1.24^{b}
Field bean	1.95	1.20	1.29	1.48^{a}	0.98	1.19	1.34	1.17^{b}
Soybean	1.31	1.80	1.56	1.56^{a}	1.18	1.37	1.05	1.20^{b}
Garden pea	1.54	1.05	1.60	1.40^{a}	1.21	0.78	1.10	1.03^{bc}
Dolichos	1.73	1.76	1.36	1.62^{a}	1.69	2.09	1.70	1.83^{a}
Maize	0.62	0.78	0.91	0.77^{b}	0.71	0.68	0.53	0.64^{c}
Weedy fallow	0.86	0.70	0.88	0.81^{b}	1.00	0.96	1.10	1.02^{bc}

Fallow species means followed by the same letter in the column are not significantly different as per LSD test (α=0.05)
Nitrogen treatment means were not significantly different according to the Duncan means separation procedure (α=0.05)

TABLE 6. Effect of fallow management species and N fertilizer application on maize DM yields at R2 growth stage in Njoro and Rongai during 1998 cropping season.

Fallow treatment	Maize dry matter yield at R2 (Mg ha^{-1})							
	Njoro				Rongai			
	Nitrogen levels (kg ha^{-1})			Fallow species means	Nitrogen levels (kg ha^{-1})			Fallow species means
	0	30	60		0	30	60	
Chickpea	17.99	15.07	16.64	16.57^{ab}	5.80	9.04	13.00	9.28^{b}
Field bean	13.95	21.64	13.61	16.40^{ab}	6.90	7.04	13.84	9.26^{b}
Soybean	19.78	21.20	14.96	18.64^{ab}	5.90	7.23	11.86	8.33^{b}
Garden pea	17.91	13.30	25.63	18.95^{ab}	8.72	8.11	11.35	9.39^{b}
Dolichos	26.77	18.85	18.66	21.43^{a}	13.68	15.30	15.69	14.89^{a}
Maize	12.90	8.81	11.65	11.12^{b}	6.25	7.79	8.08	7.37^{b}
Weedy fallow	12.38	11.72	13.50	12.53^{ab}	7.28	7.79	9.80	8.29^{b}
N means (Mg ha^{-1})	17.38^{a}	15.80^{a}	16.38^{a}		7.79^{b}	8.90^{ab}	11.95^{a}	

Fallow treatment means followed by the same letter within a column and nitrogen means within a row are not significantly different as per LSD test (α=0.05) than continuous maize and weedy fallow at both sites, but the positive impact of other legumes was less conspicuous.

DISCUSSION

This study was undertaken primarily to investigate if a rotation of maize with selected grain legumes had the potential of improving maize grain yield through enhanced conditions of nutrient supply, particularly nitrogen. Except during extremely dry conditions that prevailed in 1999, the results of this study show that maize yields were limited by insufficient supply of nitrogen regardless of location (Table 7). Also, managing fallows with legumes resulted in increases in maize grain yield averaging 6.75 Mg ha^{-1} compared to 4.90 Mg ha^{-1} for continuous maize or weedy fallow. This reflects a 39% gain in yields associated with fallow improvement practice. These results are comparable to others (Bundy *et al.*, 1993; Badaruddin and Meyer, 1994; Horst and Hardter, 1996; Fischler and Wortman, 1999; Kasasa *et al.*, 1999).

Despite the large quantities of residue in the weedy fallow and continuous maize (Table 2), the impact of these fallow management options on maize dry matter accumulation and grain yield in

TABLE 7. Effect of fallow management species and applied N fertiliser on maize grain yield (Mg ha^{-1}) at Njoro and Rongai in (a) 1998 and (b) 1999 cropping seasons

Fallow treatment	Njoro				Rongai			
	Nitrogen levels (kg ha^{-1})			Fallow species means	Nitrogen levels (kg ha^{-1})			Fallow species means
	0	30	60		0	30	60	
a) Maize grain yield in 1998 (Mg ha^{-1})								
Chickpea	5.66	7.20	8.37	7.08^{ab}	4.45	4.75	6.38	5.19^{b}
Field bean	6.25	5.97	7.12	6.44^{abc}	4.05	4.39	7.19	5.21^{b}
Soybean	5.84	5.88	8.38	6.70^{ab}	4.33	5.26	5.68	5.09^{bc}
Garden pea	5.57	5.31	7.23	6.04^{bc}	4.28	3.59	4.50	4.12^{bc}
Dolichos	6.95	7.74	7.85	7.51^{a}	6.32	6.96	7.43	6.90^{a}
Maize	4.28	5.33	6.18	5.26^{cd}	3.49	2.27	4.55	3.60^{c}
Weedy fallow	5.05	2.79	5.75	4.53^{d}	3.33	4.49	4.48	4.10^{bc}
N means (Mg ha^{-1})	5.66^{b}	5.74^{b}	7.27^{a}		4.32^{b}	4.60^{b}	5.74^{a}	
b) Maize grain yield in 1999 (Mg ha^{-1})								
Chickpea	2.17	2.11	2.18	2.15^{a}	2.73	4.00	4.22	3.65^{a}
Field bean	1.78	2.59	3.13	2.50^{a}	3.79	2.76	4.07	3.64^{a}
Soybean	1.99	2.39	2.08	2.15^{a}	3.98	3.57	3.55	3.66^{a}
Garden pea	2.58	2.13	2.93	2.68^{a}	3.16	1.96	5.01	3.38^{a}
Dolichos	2.29	2.32	3.00	2.57^{a}	3.10	3.12	5.07	3.76^{a}
Maize	2.86	1.21	2.86	2.31^{a}	3.23	2.83	3.95	3.34^{a}
Weedy fallow	2.34	2.49	2.02	2.28^{a}	2.91	3.41	4.22	3.51^{a}
N means (Mg ha^{-1})	2.27^{a}	2.18^{a}	2.60^{a}		3.23^{b}	3.11^{b}	4.30^{a}	

Fallow species means followed by the same letter in the same column are not significantly different as per LSD test (α=0.05)
Nitrogen treatment means followed by the same letter in the row are not significantly different according to the LSD test (α=0.05)

the subsequent season was negligible (Tables 6 and 7). This is not suprising because the critical enhancing feature of fallow species appears to be residue quality as defined by levels of tissue-N and C:N ratio rather than biomass quantity *per se*. Thus, the improved maize yields associated with legumes, particularly dolichos, is as a result of high residue quality. The extend to which residue quality can impact on crop performance in tropical environments has been reported in several studies (Tian *et al.*, 1994).

Whilst the benefits of improved fallow are largely attributable to improved N supply, and low C:N ratio characteristics of the legume (Fox *et al.*, 1990; Maroko *et al.*, 1998; Ojiem *et al.*, 1998), other factors which this study did not quantify, may have played a part. These include improvement in soil physical and chemical properties such as bulk density, water holding capacity, and improved cation exchange capacities (McVay *et al.*, 1989). Maize may also be self incompatible (Yakie and Cruse, 1984) since maize residue often retards growth of seedling maize crop due to the presence of phytotoxins.

A second major observation from this study is that dolichos, in contrast to other legumes selected for fallow improvement, consistently induced faster canopy development (Table 5), higher biomass accumulation (Table 6) and more grain yield (Table 7) in the subsequent maize crop. The reasons that support this apparent superiority of doilchos may be several and complex. Dolichos sets seed late and partitions comparatively less dry matter to reproductive tissues (data not shown) and hence it has a low nitrogen harvest index (NHI). By the time legume residue was incorporated, dolichos had just poded but not seeded and hence most of the N accumulated was still in vegetative tissue. Also, available evidence suggests that most grain legumes typically remove more N from the soil than they leave behind inspite of capacities for atmospheric N_2 fixation (Table 3) and this is due to their high NHI (Giller and Wilson, 1991; Toomsan *et al.*, 1995).

Both the dry matter accumulation and grain yield (Tables 6 and 7) suggest that Njoro was a more favourable environment for maize growth than Rongai. This is probably because it is cooler in Njoro; the cool temperatures allowing for a longer period of post anthesis DM accumulation and grain development (Forbes and Watson, 1992). Njoro had also a lot more rain; the total precipitation during the long rains was 560 and 420 mm in 1998 at Njoro and Rongai, respectively, as contrasted with 366 and 264 mm at the two sites in 1999. In addition, baseline soil analysis data suggest that Njoro has more conducive soil environment, with an average 0.25 % total N, 20 ppm P and 4.63 % organic matter compared to 0.08 %N, 0.22 ppm P and 2.47 % organic matter at Rongai (data not shown). The grain yields although well above average farm levels at Njoro in 1998 (Table 7), did not march the large accumulation of DM by the maize crop that year (Table 6). This response is partly attributable to the dry conditions that prevailed during anthesis at this location, thus prolonging the anthesis-silking interval (ASI) beyond 10 days and inducing kernel abortion. This suggests that the reproductive tissue did not develop a strong enough sink to attract all the available photoassimilate from vegetative structures (Lorens *et al.*, 1987).

In conclusion, it is evident from this study that smallholder cropping enterprises could be improved if farmers rotate maize with grain legumes, particularly dolichos as a source of N on the proviso that the legume residue is left in the field and incorporated. It is also noted that the biological and economic buffering offered by multiple species in sequential cropping affords stability of harvest and income over time space against risk of crop failure. There is need for further study to determine the precise synchrony between the time of legume residue incorporation, peak release and crop demand, along the lines suggested by Yamoah *et al.* (1986)

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