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Yield and Nitrogen Fixation Response by Drought Tolerant Tepary Bean (*Phaseolus acutifolius* A. Gray var. latifolius) in Sole and Maize Intercrop Systems in Semi-Arid Southeast Kenya

Chris A. Shisanya
Department of Geography, Kenyatta University, P.O. Box 43844, Nairobi, Kenya

Abstract: Tepary Bean (TB), a drought tolerant bean variety has become popular among poor small-scale farmers in semi-arid Kenya, where it is predominantly intercropped with maize. The nitrogen fixation and yield of intercropping tepary bean-maize in comparison to sole crops as affected by nitrogen fertiliser application and inoculation were investigated during two successive growing seasons. Experimental design was randomised complete block with eight treatments: TB sole crop not inoculated with Rhizobium (R3254) and without N fertilizer (N), TB sole crop not inoculated with R3254 with or without N, TB sole crop inoculated with R3254 without N, TB with maize intercrop not inoculated with R3254 with or without N and maize sole crop with or without N. Each treatment was replicated four times. Significant differences ($p \leq 0.05$) were observed in total plant dry between inoculated and uninoculated treatments at both 21 and 42 Days after Emergence (DAE). TB yields were significantly reduced in uninoculated intercrop. Inoculated TB treatments had significantly higher seed dry weights and yields ha^{-1} compared to uninoculated. Intercropping TB and maize suppresses the yield of the former under semi-arid conditions. Inoculating TB with *Rhizobium* strain R3254 was infective, effective and significantly improved TB yields in sole and intercrop. Soil analysis after the two cropping seasons indicated enhancement of soil N in sole TB plots above pre-planting levels. Maize plots exhibited a decline in soil N. Total N concentration in plant tissues was significantly enhanced in treatment R3254. There was a marked increase in soil P in all treatment plots following amendment.

Key words: Cropping systems, N in the crops, N and P fertilization, nodule formation, residual N, *Rhizobium* R3254 inoculation, seed yield

INTRODUCTION

For a long time the Government of Kenya has underscored the important role played by the Arid and Semi-Arid Lands (ASALs) of Kenya[1] in food production. Currently, food production has been declining in these ASALs as population growth increases[2-4] and also because long periods of fallow are no longer practiced and the land is cropped continuously after clearing. Fertilizer use is low because of socio-economic constraints, its unavailability at the right time, its high cost and risks from erratic rainfall. As a result, yields of cereals do not exceed 1 t ha^{-1} and legumes 0.5 t ha^{-1} per crop season[5]. It is therefore a major challenge to sustain crop yields and economic returns in such low input agricultural systems, predominantly by small-scale farm.

Various researchers have emphasized the importance of research on drought tolerant crop species of short cycle as a priority in addressing the food deficit problem in the ASALs[4,6]. Unfortunately, this has not received adequate attention[7]. Most smallholder farmers in the ASALs cannot afford the required external inputs in the form of chemical N fertilizer to improve their food production. Researchers in Kenya have exploited the legume *Rhizobium* symbiosis as a substitute for the expensive N fertilizers in these ASALs[2,3,6,8]. Nitrogen (N) contribution by legumes to other crops in the system depends on the species, biological N_2 fixation and growth of legumes as determined by climate and soil and management of residues.

In semi-arid Kenya, maize (*Zea mays* L.) is commonly intercropped or rotated with bean (*Phaseolus vulgaris* L.), pigeon pea (*Cajanus cajan* L. Millsp.) or cowpea (*Vigna unguiculata* L. Walp), although the relative proportion of the legume in these mixed systems is small. Tepary bean (*Phaseolus acutifolius* A. Gray var. latifolius), a drought tolerant legume[9] has recently assumed importance in the intercrop farming systems of semi-arid Kenya[4]. The N removed by maize in this region is estimated to be as much as 25-40 kg ha^{-1} per season, which means that a matching amount of N needs to be supplied for long term sustainability of production [2].

Nitrogen fixation by bean is notoriously inconsistent, with or without inoculation[3], but cowpea nodulates well by the ubiquitous *Bradyrhizobia* sp. and fixes up to 20 kg N ha^{-1}[10]. Recently, Shisanya[4] found that tepary bean (TB) nodulates very well with *Rhizobium* sp. strain R3254 and fixes up to 260 kg N ha^{-1}. However, this study by Shisanya[3,6] did not investigate the effect of intercropping maize and TB on nitrogen fixation by the latter under the semi-arid conditions. Earlier studies[3,8] investigated the effect of intercropping on nitrogen fixation by common bean and green gram (*Vigna radiata* L. Wilczek) under semi-arid conditions. The main objective of this study was, therefore, to investigate the effect of intercropping maize and tepary bean on nitrogen fixation and yield under the semi-arid conditions of southeast Kenya.

MATERIALS AND METHODS

Experimental site: The experiments were carried out at KARI Kiboko sub-centre (latitude 02° 12' S, longitude 37° 43' E, altitude 975 m a.s.l.), located at about 160 km southeast of Nairobi, the capital town of Kenya. The climate of the experimental site is described as hot and dry [6]. The soils of the study area are well drained Fluvisols, Ferralsols and Luvisols[11]. The soil pH (0.01 m $CaCl_2$) of the experimental field is 7.9. Rainfall is bimodally distributed, with median monthly maximum in April (126 mm) and November (138 mm). The median annual rainfall is about 582 mm $year^{-1}$. The short rains (SR) (October-January) generally have more rainfall and are more reliable than the long rains (LR) (March-June)[6]. The lengths of the agrohumid periods for drought-adapted crops are 50-55 days (LR) and 65-70 days (SR) (Jaetzold and Schmidt, 1983). Average monthly temperatures are highest in February (24.3°C) and October (23.4°C) (KMD, 1984), prior to the onset of the rains in March and November, respectively.

Maize, TB seeds and Rhizobium culture: Seeds of maize (M) and tepary bean were obtained from local farmers. Undamaged seeds were carefully selected to ensure uniformity in size. Commercial *Rhizobium leguminosarum* biov. *phaseoli* strain R3254 used to inoculate TB was obtained from the Microbiological Resource Centre (MIRCEN), University of Nairobi. The infectivity of this strain had been determined in an earlier study[4].

Soil and plant samples analyses: Soil samples were collected to a depth of 60 cm using a soil auger before planting. Five sub-samples were collected from each plot, mixed thoroughly in polythene bags and transported to the laboratory. Sub-sample was air-dried while the remainder was refrigerated at 4°C. The air-dried sub-samples were ground and sieved (< 2 mm) for total carbon (C) and N analyses. The colorimetric method described by Anderson and Ingram[13] was used for soil organic C. Total soil N was measured colorimetrically following Kjeldahl digestion[14-15]. Available soil P was determined following the method of Forster[16]. Analyses of soil N and P were 7 mg N kg^{-1} and 13.0 mg P kg^{-1} soil, respectively. These values are above the threshold of 2.0 mg N kg^{-1} soil and 4.5 mg P kg^{-1} soil for optimum crop growth in tropical soils[17]. The C/N ratio and CEC were 11.7 and 7.8 cmol (+) kg^{-1}, respectively. Nitrogen concentration in plant tissues was determined using the high sensitivity nitrogen-carbon analyser (sumigraph nc-90). Soil N and P changes in treatment plots over the growth period were calculated using the following equation:

$$\delta\,(N/P) = (N/P)_h - (N/P)_{pp} / (N/P)_{pp} \times 100 \quad (1)$$

where:
δ = % change in N/P in treatment plots
N = total soil nitrogen in treatment plots
P = available soil phosphorus in treatment plots
h = harvesting period
pp = pre-planting period

Field experiments: The experiments were conducted over two successive seasons, i.e. LR 2000 (March-June) and SR 2000/2001 (October-January). The field experiments were made up of eight treatments as follows:

1. tepary bean as sole crop without N fertiliser and no inoculation (control) (TB-N-INOC)
2. tepary bean as sole crop with N fertiliser and no inoculation (TB + N-INOC)
3. tepary bean as sole crop and inoculated with *Rhizobium* strain 3254 and without N fertiliser (TB + INOC-N)
4. tepary bean-maize intercrop without N fertiliser and no inoculation (control) (TB + M-N-INOC);
5. tepary bean-maize intercrop with N fertiliser and no inoculation (TB + M + N-INOC)
6. tepary bean-maize intercrop inoculated with *Rhizobium* strain 3254 and without N fertiliser (TB + M + INOC– N)
7. maize as sole crop without N fertiliser (M-N)
8. maize as sole crop with N fertiliser (M + N)

Each plot was replicated four times in a complete randomised block design. A replicate constituted a 3x3 m plot size. Land preparation was done by tractor ploughing followed by harrowing. A basal dose of triple superphosphate granules (TSP; 50% P_2O_5) fertiliser was applied at the rate of 40 kg ha^{-1} to all plots to minimise plant phosphorus deficiencies. Before planting, TB seeds for inoculation treatment were rinsed in 10% sucrose solution to help the inoculant carrier material (filtermud) to stick on the seeds as described[8]. Inoculation with rhizobia was carried out by addition of 6.7 g of filtermud based inoculant for every kg of moistened sucrose coated TB. This was followed by thorough mixing of the seeds with the inoculant until the seeds were uniformly coated. The inoculated seeds were kept covered in a container to avoid exposure to direct sunlight. The crops were planted just before the onset of the rains in both seasons. This is a common practice in the study area[18]. Maize was sown in rows of 75 cm apart with spacing of 30 cm between plants in the row yielding a plant density of 44,400 plants ha^{-1}. Tepary beans were sown 50 cm between rows and 20 cm within rows, giving a density of 100,000 plants ha^{-1}. The intercrop plots consisted of alternating maize/tepary bean rows with planting densities same as those in the respective pure crops. These are the recommended plant densities for semi-arid Kenya[18]. For each of the treatments 3 seeds/hole were planted. During the first weeding, i.e. 7 days after emergence (DAE), plants were thinned to 2 seeds/hole. The resulting plant densities for TB and M were 10 plants m^{-2} and 4.4 plants m^{-2}, respectively. At 10 DAE, when plants were about 20 cm above ground, calcium ammonium nitrate (can) powder (26% N) was top-dressed on N treatment plots at a rate of 40 kg N ha^{-1}. Tepary bean plants were sampled 21 DAE, 42 DAE and 70 DAE. These periods corresponded approximately to first nodule formation, full flowering and full maturity, respectively. The physiological maturity period for maize was 90 DAE. Four plants were randomly sampled from each treatment replicate and various parameters assessed. The plant material was partitioned into roots, stems and leaves. The TB plants were dug up for nodule counting and determination of below and above ground biomass at 21 and 42 DAE, respectively. Plant samples and nodules were oven dried at 70°C to constant weight. Dry weights of the various parts of the plant samples were determined and recorded using a high precision Sartorius balance. From the final harvest, the following data were collected: pod number and pod dry weight of TB per plant, cob dry weight per plant in maize, seed (grain) dry weight per plot, 100 seed dry weight and yield per treatment plot. Data obtained were subjected to analysis of variance using the statistical computer package statgraphics version 6.0 and treatment means separated using Duncan's Multiple Range Test (DMRT) at $p \leq 0.05$ level[19].

RESULTS

The LR 2000 and the SR 2000/2001 season field results: There were significant differences ($p \leq 0.05$) in nodule number, nodule dry weight and plant dry weights between the inoculated treatments and the other treatments, 21 DAE (Table 1). Generally, the nodule and plant dry weight of inoculated sole and intercropped TB was significantly ($p \leq 0.05$) higher from the other treatments at this growth stage, respectively. The effect of fertiliser N treatment on total dry matter of intercrop plants or sole crops was not significant, 21 DAE.

At second harvest (42 DAE), inoculated treatments also had significantly ($p \leq 0.05$) higher nodule and pod number and dry weights, whether in sole or intercrop, but still significantly greater in sole crop (Table 2). The effect of fertiliser N at this stage was not significant too.

At physiological maturity (70 DAE), sole crop inoculated TB showed significantly ($p \leq 0.05$) higher dry weights of all parameters than the other treatments (Table 3).

Inoculation also had a significant effect on the TB yield (Table 4). The yield of sole crop TB was significantly ($p \leq 0.05$) higher than that in intercrop (Table 4). Sole crop maize yield response to N fertiliser application was significantly greater than maize yield in intercrop system (Table 4).

The results of the SR 2000/2001 season were very similar to those of the LR 2000 season in many aspects. Like in the previous season, significant differences ($p \leq 0.05$) were observed in nodule number, nodule dry weight and plant dry weight between inoculated and other treatments, 21 DAE (Table 1). At 42 DAE, treatment R3254 was significantly different from the rest in all parameters (Table 2). The effect of inoculation at this stage was significant though higher in sole cropped TB than in intercrop. At final harvest (70 DAE), significant effects of inoculation were observed in all parameters (Table 3). However, inoculation of TB with R3254 under sole crop had significantly ($p \leq 0.05$) higher dry weights of the parameters compared to intercrop (Table 3). Like in previous season, N fertiliser application effect was significant in sole cropped maize than in intercrop system (Table 4).

Results of plant tissue N concentration, soil N and P: The data in Table 5 show the N concentration in various plant tissue parts at final harvest over the two seasons. Inoculated TB plants had consistently higher N concentration over N and control treatments in both seasons.

The analysis of total soil N at harvest over the two seasons showed that plots with TB as pure crop had significantly ($p \leq 0.05$) higher soil N values compared to

Table 1: Effect of different tepary bean (TB)-maize (M) cropping systems on total dry weight per TB plant during the LR 2000 and SR 2000/2001 season, at 21 DAE[1]

	Nodule number per plant		Nodule dry weight (mg plant^{-1})		Total plant dry weight (g plant^{-1})	
Treatments	LR	SR	LR	SR	LR	SR
Control	11^{b}	14^{b}	5.4^{b}	5.7^{b}	2.5^{b}	2.9^{b}
TB+N* - INOC	16^{b}	18^{b}	7.8^{b}	8.0^{b}	2.9^{b}	3.2^{b}
TB-N+INOC	30^{a}	38^{a}	14.7^{a}	15.2^{a}	3.8^{a}	4.5^{a}
TB+ M - N - INOC	12^{b}	14^{b}	5.9^{b}	6.0^{b}	2.7^{b}	2.9^{b}
TB+M+N - INOC	15^{b}	16^{b}	7.4^{b}	7.6^{b}	2.6^{b}	2.8^{b}
TB+M-N+INOC	26^{a}	34^{a}	12.7^{a}	14.8^{a}	3.6^{a}	4.1^{a}

[1]Means (n = 24) followed by the same letter down the column are not statistically different ($p \leq 0.05$) by Duncan's multiple range test *Nitrogen (N) fertilizer was top-dressed 10 DAE at the rate of 40 kg n ha^{-1} of (26% n) powder

Table 2: Effect of different tepary bean (TB)-maize (M) cropping systems on total dry weight per TB plant during the LR 2000 and SR 2000/2001 season, at 42 DAE[1]

	Nodule number per plant		Nodule dry weight (mg plant^{-1})		Pod number (plant^{-1})		Pod dry weight (g plant^{-1})		Total plant dry weight (g plant^{-1})	
Treatments	LR	SR	LR	SR	LR	SR	LR	SR	LR	SR
Control	35^{d}	38^{d}	17.2^{c}	17.6^{c}	35^{c}	38^{c}	37.0^{c}	39.5^{c}	25.0^{b}	28.5^{b}
TB+N* - INOC	44^{c}	47^{c}	21.6^{c}	21.9^{c}	39^{c}	42^{c}	41.1^{c}	42.0^{c}	26.8^{b}	29.0^{b}
TB-N+INOC	78^{a}	85^{a}	39.2^{a}	45.0^{a}	60^{a}	75^{a}	63.3^{a}	65.8^{a}	32.8^{a}	38.0^{a}
TB+M - N- INOC	32^{d}	35^{d}	15.7^{c}	16.2^{c}	30^{c}	35^{c}	31.6^{c}	34.0^{c}	19.6^{b}	20.3^{b}
TB+M+N-INOC	38^{d}	42^{c}	18.6^{c}	19.2^{c}	34^{c}	39^{c}	35.8^{c}	37.0^{c}	22.4^{b}	25.4^{b}
TB+M-N +INOC	62^{b}	70^{b}	30.4^{b}	34.2^{b}	48^{b}	55^{b}	50.6^{b}	53.5^{b}	24.5^{b}	25.6^{b}

[1]Means (n = 24) followed by the same letter down the column are not statistically different ($p \leq 0.05$) by Duncan's multiple range test *Nitrogen (N) fertilizer was top-dressed 10 DAE at the rate of 40 kg n ha^{-1} of (26% n) powder

Table 3: Effect of different tepary bean (TB)-maize (M) cropping systems on total dry weight per TB plot and 100 seed weight at physiological maturity (70 DAE) during the LR 2000 and SR 2000/2001 seasons[1]

	Total seed dry weight (g plot^{-1})		Total plant dry weight (g plot^{-1})		100 seed weight (g)	
Treatments	LR	SR	LR	SR	LR	SR
Control	2220.8^{b}	2380.5^{b}	420.5^{c}	450.7^{c}	12.9^{b}	13.0^{b}
TB+N* - INOC	2467.5^{b}	2497.0^{b}	496.6^{c}	500.6^{c}	13.2^{b}	13.3^{b}
TB+INOC-N	3210.6^{a}	3500.5^{a}	735.5^{a}	750.0^{a}	16.4^{a}	16.6^{a}
TB+M - N-INOC	2160.0^{b}	2270.5^{b}	465.0^{c}	480.6^{c}	12.8^{b}	12.9^{b}
TB+M+N - INOC	2480.0^{b}	2590.0^{b}	570.4^{c}	590.5^{c}	13.0^{b}	13.2^{b}
TB+M-N+INOC	2560.0^{b}	2650.5^{b}	600.8^{b}	610.5^{b}	13.6^{b}	13.8^{b}

[1]Means (n = 24) followed by the same letter down the column are not statistically different ($p \leq 0.05$) by Duncan's multiple range test *Nitrogen (N) fertilizer was top-dressed 10 DAE at the rate of 40 kg n ha^{-1} of (26% n) powder

Table 4: Effect of different tepary bean (TB)-maize (M) cropping systems on yield during the LR 2000 and SR 2000/2001 seasons[1]

	TB yield (kg ha^{-1})		Maize yield (kg ha^{-1})	
Treatments	LR	SR	LR	SR
Control	850^{c}	996^{c}	-	-
TB+N* - INOC	990^{c}	1010^{c}	-	-
TB+INOC-N	1530^{a}	1650^{a}	-	-
TB+M - N-INOC	950^{c}	1000^{c}	2560^{c}	2670^{c}
TB+M+N - INOC	970^{c}	980^{c}	3850^{b}	3900^{b}
TB+M-N+INOC	1180^{b}	1200^{b}	3960^{b}	3900^{b}
M+N	-	-	4250^{a}	4380^{a}
M-N	-	-	2450^{c}	2600^{c}

[1]Means (n = 24) followed by the same letter down the column are not statistically different ($p \leq 0.05$) by Duncan's multiple range test *Nitrogen (N) fertilizer was top-dressed 10 DAE at the rate of 40 kg n ha^{-1} of (26% n) powder

intercrop plots Fig. 1a and b. Available soil P content in treatment plots increased overall, regardless of whether sole or intercrop over the two seasons Fig. 2a and b. The analysis of soil N before and after the growing season (using equation 1) showed that TB legume plots had enriched their N content over the two seasons by between 15-70% Fig. 1a and b. Available soil P content in the soil was enhanced in all the plots by between 10-66 %

Table 5: N concentration at harvest in TB plant tissues during the LR 2000 and SR 2000/2001 seasons[1]

	N concentration (mg g^{-1})					
	LR			SR		
Treatments	Shoot	Root	Seed	Shoot	Root	Seed
Control	1.1^{b}	0.5^{b}	22^{b}	1.4^{b}	0.8^{b}	26^{b}
TB+N* - INOC	1.3^{b}	0.6^{b}	25^{b}	1.7^{b}	0.9^{b}	28^{b}
TB-N+INOC	2.8^{a}	2.0^{a}	40^{a}	2.9^{a}	2.5^{a}	44^{a}
TB+M - N-INOC	1.8^{b}	0.4^{b}	29^{b}	1.9^{b}	0.9^{b}	30^{b}
TB+M+N - INOC	1.9^{b}	0.5^{b}	30^{b}	2.0^{b}	0.8^{b}	29^{b}
TB+M-N+INOC	1.5^{b}	0.6^{b}	26^{b}	1.6^{b}	0.8^{b}	29^{b}

[1]Means (n = 4) followed by the same letter down the column are not statistically different (p=0.05) by Duncan's multiple range test *Nitrogen (N) fertilizer was top-dressed 10 DAE at the rate of 40 kg n ha^{-1} of (26% n) powder

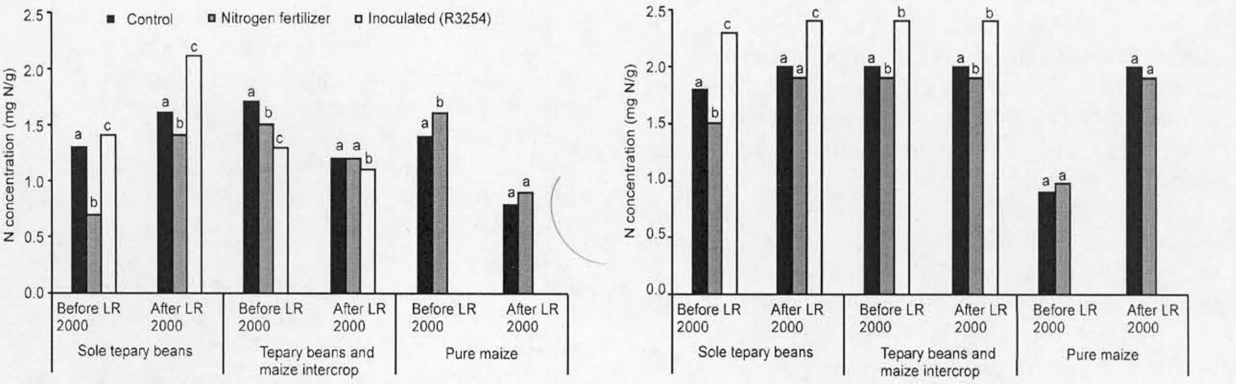

Fig. 1: (a) Soil nitrogen (N) concentration in cropping systems with tepary beans and maize intercrop at Kiboko (0-60 cm soil depth, LR 2000). Bars followed by the same letter are not significantly different by DMRT at $p \leq 0.05$ (b) Soil nitrogen (N) concentration in cropping systems with tepary beans and maize intercrop at Kiboko (0-60 cm soil depth, SR 2000/01). Bars followed by the same letter are not significantly different by DMRT at $p \leq 0.05$

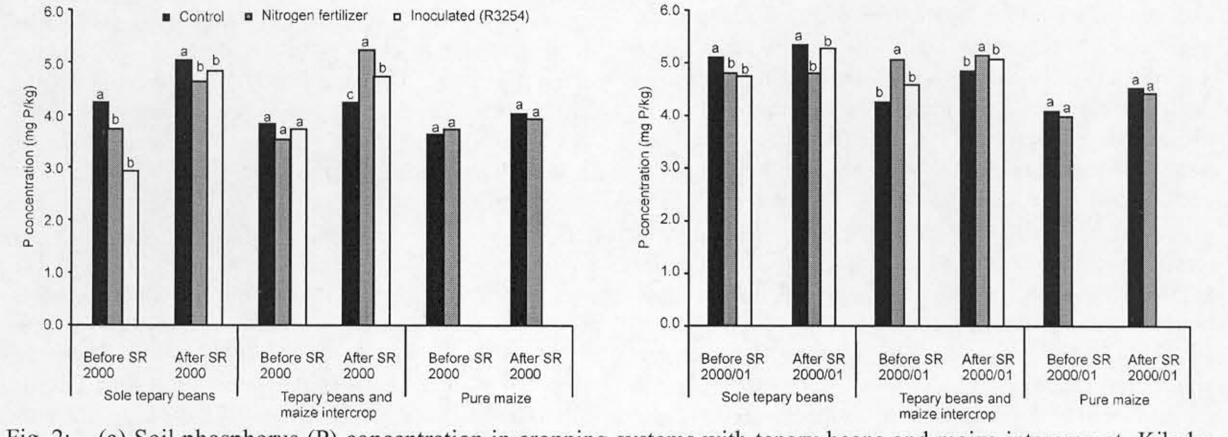

Fig. 2: (a) Soil phosphorus (P) concentration in cropping systems with tepary beans and maize intercrop at Kiboko (0-60 cm soil depth, LR 2000). Bars followed by the same letter are not significantly different by DMRT at $p \leq 0.05$ (b) Soil phosphorus (P) concentration in cropping systems with tepary beans and maize intercrop at Kiboko (0-60 cm soil depth, SR 2000/01). Bars followed by the same letter are not significantly different by DMRT at $p \leq 0.05$

over the two seasons Fig. 2a and b.

DISCUSSION

Plant dry weight was used indirectly to estimate N_2 fixation in the present study. In field experiments, at 21, 42 and 70 DAE, the effect of inoculating TB with R3254 had positive significant effects over the two seasons. This confirmed earlier findings[4] that *Rhizobium* strain R3254 is infective and effective on TB in the study area. For common bean in the same area, Pilbeam *et al.*[10] reported that both N-fertilisation and inoculation did not significantly improve yield over the control. N_2 fixation by common bean has been reported to be variable due to many biotic and abiotic factors[3]. High soil temperatures, as found in the study area and the incompatibility of some commercially available rhizobia strains are contributory factors in the failure of beans to nodulate and fix N_2 under semi-arid conditions of Kenya[4,20].

During all plant sampling stages, N fertilised plots had significantly lower dry weights of the parameters measured than inoculated TB sole crop treatments over the two seasons. Deficiencies in soil mineral N are a major constraint to crop growth and eventual productivity. Studies have shown that beans fertilised with moderate amounts of fertiliser N nodulate well during the early stages of growth and fix substantial amounts of N [21]. Apparently, this was not observed in the present study since N application had no significant effect on dry matter production or grain yield over the two seasons. This appears to be in agreement with earlier findings of Pilbeam *et al.*[10] with common bean in the study area. A plausible explanation for this is that uptake of N may have been constrained by low rooting density of tepary bean [22] and inadequate soil moisture within the rooting zone that could have inhibited the mineral N moving to the plant through the plant roots[22]. In addition, the aspect of slow mineralisation of soil N cannot be ruled out under such semi-arid conditions[6,11]. Studies[23] have demonstrated that under arid, temperate and cold environments, very little N is available for plant uptake in the short-term period, up to 6 months, because mineralisation must take place.

At 42 DAE over the two seasons, there was a significant difference ($p \leq 0.05$) in all measured plant parameters between sole cropped and inoculated TB and intercrop inoculated TB (Table 2). The other treatments had similar total plant dry weights, which were significantly lower ($p \leq 0.05$) than the sole cropped and inoculated TB and intercrop inoculated TB. At final harvest, N fertilised plots and intercrop inoculated TB had significantly lower grain yield compared to sole crop inoculated TB treatment over the two seasons (Table 3). Soil mineral N is often a major limitation to crop growth and productivity in the study area[18]. Apparently this was not the case in the present study since N application had no significant effect on dry matter production or grain yield in both seasons. However, uptake of N may have been constrained by low root length density, which is characteristic of TB[22] and/or inadequate soil moisture content by which mineral N can move to the plant root [10].

The analysis of total soil N at harvest over the two seasons showed that plots with TB as pure crop had significantly ($p \leq 0.05$) higher soil N-concentration values compared to intercropped plots Fig. 1(a) and 1(b). Available soil P content in treatment plots increased overall in all the plots, regardless of whether sole or intercrop over the two seasons(Fig. 2a and b). The higher values of total soil N and available soil P at pre-planting during the SR 2000/2001 (Fig. 1a and b) could be attributed to the carry over effect from the previous LR 2000 season.

Analysis of different plant tissues in different treatments showed that inoculated TB plants were significantly enriched with tissue N during the vegetative cycle over the two seasons (Table 5). The conclusion from this result is that *Rhizobium* strain R3254 is very infective and effective in N_2 fixation in TB under the semi-arid conditions of Kenya. Soil analysis of N indicated that inoculated treatment plots under sole crop and intercrop had enhanced soil N by between 15-70% (Fig. 1a and b). This is an indication that R3254 does fix nitrogen in both sole and intercrop. There was a general increase in P by between 10-66% in all the plots following the initial amendment (Fig. 2a and 2b). Soil P improvement has been reported in the study area in tepary bean-sorghum intercrop[24]. The increased available soil P could also be attributed to microbial activity, especially mycorrhiza that facilitates the release of insoluble P into the soil thus making it available for plants[11,25].

CONCLUSION

The results of this study show that inoculation is necessary if high yields of TB are to be realised in semi-arid southeast Kenya. However, the advantages of inoculation are not harnessed in intercrop system. Results showed that intercrop inoculated TB had significantly lower grain yield compared to sole crop inoculated TB over the two seasons. Intercropping maize and TB is thus not economically advantageous under the prevailing semi-arid conditions of southeast Kenya. It has been documented elsewhere[24] that common bean produced only 40% of their optimum yields when intercropped with sorghum in the study area. Inoculation of TB with the commercially *Rhizobium* strain 3254 was infective and effective under sole cropping system.

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REFERENCES

1. Republic of Kenya, 1993. National Development Plan 1993-96. Government Printer, Nairobi.
2. Rao, M.R. and M.N. Mathuva, 2000. Legumes for improving maize yields and income in semi-arid Kenya. Agric., Ecosys. Envron., 78: 123-137.
3. Maingi, J.M., C.A. Shisanya, N.M. Gitonga and B. Hornetz, 2001. Nitrogen fixation by common bean (*Phaseolus vulgaris* L.) in pure and mixed stands in semi-arid south-east Kenya. Eur. J. Agron., 14: 1-12.
4. Shisanya, C.A. 2002. Improvement of drought adapted tepary bean (*Phaseolus acutifolius* A. Gray var. latifolius) yield through biological nitrogen fixation in semi-arid SE-Kenya. Eur. J. Agron., 16: 13-24.
5. Tiffen, m., M. Mortimore and F. Gichuki, 1994. More People, Less Erosion.ACTA Press, Nairobi, pp:170.
6. Hornetz, B., C.A. Shisanya and N.M. Gitonga, 2000. Studies on the ecophysiology of locally suitable cultivars of food crops and soil fertility monitoring in the semi-arid areas of southeast Kenya. Materialien zur Ostafrika-Forschung, Heft Nr. 23. Universitaet Verlag, Trier.
7. Shisanya, C.A., 1999. Farming systems characteristics in semi-arid SE-Kenya: resource base, production dynamics and the way forward. Chem. Chemi., 1: 56-74.
8. Gitonga, N.M., C.A. Shisanya, J.M. Maingi and B. Hornetz, 1999. Nitrogen fixation by *Vigna radiata* L. Wilczek in pure and mixed stands in Southeast Kenya. Symbiosis, 27: 239-250.
9. Hornetz, B., 1990. Vergleichende Stressphysiologie von Tepary Bohnen als 'Minor crop' und Mwezi Moja Bohnen als Hochleistungsleguminose im tropischen Landbau. J. Agron. Crop Sci., 164: 1-15.
10. Pilbeam, C.A., M. Wood and P.G. Mugane, 1995. Nitrogen use in maize-grain legume cropping systems in semi-arid Kenya. Biol. Fert. Soils, 20: 57-62.
11. Eichinger, M., 1999. Die Applikation von Gesteinmehlen als Alternative Dungemittel in den Trockenregionen SE-Kenias: Eine Untersuchung Mittels Bodenmikrobiologischer Feld- und Labormethoden. M.Sc. Thesis, University of Trier, pp: 140.
12. KMD (Kenya Meteorological Department), 1984. Climatological Statistics for Kenya. Meteorology Department, Nairobi.
13. Anderson, J.M. and J.S.I. Ingram, 1993. Tropical Soil Biological and Fertility: A Handbook of Methods 2nd Edn. CAB International, Wallingford, UK, pp: 232.
14. Forster, J.C., 1995a. Soil nitrogen. In: K. Alef and P. Nannipieri (Eds.). Methods in Applied Soil Microbiology and Biochemistry. Academic Press, London, pp: 79-87.
15. Bremner, J.M. and C.S. Mulvaney, 1982. Nitrogen-total. In: Page, A.L., Miller, R.H., Keeney, D.R. (Eds.), Methods of Soil Analysis, Part 2. Chemical and Biological Properties. Am. Soc. Agron., 9: 595-624. Crop Sci., 28: 106-110.
16. Forster, J.C., 1995b. Soil phosphorus. In: Alef, K., Nannipieri, P. (Eds.), Methods in Applied Soil Microbiology and Biochemistry. Academic Press, London, pp: 105-117.
17. Kapkiyai, J.J., N.K. Karanja, J.N. Qureshi, P.C. Smithson and P.L. Woomer, 1999. Soil organic matter and nutrient dynamics in a Kenyan nitisol under long-term fertiliser and organic input management. Soil Biol. Biochem., 31: 1773-1782.
18. Shisanya, C.A., 1996. Chances and risks of maize and bean growing in the semi-arid areas of SE-Kenya during expected Deficient, Normal and Above Normal rainfall of the short rainy seasons. Materialien zur Ostafrika-Forschung, Heft 14, Trier, pp: 401.
19. Steel, R.D.G. and J.H. Torrie, 1981. Principles of Statistics: A Biometrical Approach, second Edn. McGraw-Hill, London, pp: 150-190.
20. Hornetz, B., C.A. Shisanya and N.M. Gitonga, 2001. Crop water relationships and thermal adaptation of Kathika beans (*Phaseolus vulgaris* L.) and green grams (*Vigna radiata* L. Wilczek) with special reference to temporal patterns of potential growth in the drylands of SE-Kenya. J. Arid Envron., 48: 591-601

21. Musandu, A.A.O. and J.O. Ogendo, 2000. Effect of *Rhizobium* Inoculation and Fertiliser Nitrogen and Phosphorus on the Grain Yield of Beans in Western Kenya. In: Karanja, N., Kahindi, J.H.P. (Eds.), Challenges and Imperatives for Biological Nitrogen Fixation Research and Application in Africa for the 21st Century. Proceedings of the Ninth Congress of the African Association for Biological Nitrogen Fixation, 25-29th September, 2000., Nairobi, pp: 86-93.
22. Shisanya, C.A., 1998. Phenology and diurnal course of leaf water potential of three bean varieties under a semi-arid environment in South-East Kenya. E. Afri. J. Sci., 1: 11-19.
23. Lannauce, C., 1996. Nitrogen cycling in Portuguese soils and its assessment by ^{15}N tracer techniques. Ph.D. Thesis (Agronomy), University of Lisbon, pp: 150
24. Hornetz, B., 1997. Resourcenschutz und Ernahrungssicherung in den semiariden Gebieten Kenyas. Reimer Verlag, Berlin, pp: 301.
25. Menge, J.A., 1983. Utilization of vesicular-arbuscular mycorrhizal fungi in agriculture. Canad. J. Bot., 61: 1015-1024.