Journal of Agriculture and Rural Development in the Tropics and Subtropics
Volume 109, No. 2, 2008, pages 123–137

Green Gram Rotation Effects on Maize Growth Parameters and Soil Quality in Myanmar

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Abstract

At present maize–green gram crop rotations are not widely practiced among farmers in Myanmar. However, this cropping system might become more popular in the future given raising prices for green gram and maize grain and scarcity of mineral nitrogen (N) fertilizers in this Asian country. The results of a cropping systems experiment with continuous maize versus a green gram-maize rotation, manure application (0 and 2 t ha^{-1}) and phosphorus (P) fertilization (0 and 15 kg P ha^{-1}) in each of five consecutive seasons revealed a strong decline in total dry matter and grains yields for both crops irrespective of the treatment. Treatment effects on yield components, nutrient concentrations, mycorrhizal infection and nematode infestation were small or negligible. The data show that in addition to manure used at 2 t ha^{-1}, application of mineral N fertilizers is essential to maintain particularly maize yields. A comparison of different green gram cultivars did not indicate genotype specific effects on maize growth. The incorporation of legume residues, unless they are used as animal feed, is recommended to increase the recycling of N and to balance N fluxes when green gram is cultivated for seed.

Keywords: Maize, Green gram, Rotation, Manure, Nitrogen, Phosphorus, Myanmar

1 Introduction

Among the 60 different crop species grown in Myanmar, maize (*Zea mays* L.), grown for domestic use and export, is the second most important cereal after rice (*Oryza sativa* L.). In 2003, the total maize area in Myanmar was 300,000 ha with an average grain yield of 2,500 kg ha^{-1} (FAO, 2004). Given favourable terms of trade on export markets, maize cultivation is becoming increasingly popular and farmers are using more and more hybrid varieties. However, soil fertility in continuously cropped maize fields is deteriorating rapidly leading to declining yields during the rainy (May-September) and dry (October-December) season (MOAI, 2005). To supply nitrogen (N) to the crop, farmers often use mineral fertilizers at rates of up to 100 kg N ha^{-1} rather than legume

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rotations. However, imports of mineral fertilizers are severely hampered by shortages of foreign exchange and therefore their use is low. Similarly, manure application is restricted due to scarcity-induced high prices.

With productive farmland facing increased pressure from a growing population, cereal-legume rotations have been proposed as an effective means to increase the productivity of nutrient-depleted soils in low-external input systems (BUERKERT *et al.*, 2001a,b). On acid sandy soils of semi-arid West Africa where crop yields are strongly limited by P availability (BATIONO *et al.*, 1992), cereal/legume rotations based on maize, sorghum (*Sorghum bicolor* L. Moench), cowpea (Vigna unguiculata L.) and groundnut (*Arachis hypogaea* L.) have been shown to cause large increases in cereal yields (BAGAYOKO *et al.*, 2000a,c).

Similarly, soil productivity in SE Asia including Myanmar is limited by low pH, low CEC, low base saturation and high P-fixation capacity (PUSHPARAJAH and BACHIK, 1987). Highly weathered tropical soils (Oxisols, Ultisols) are typically characterized by low total and available P and an often high P retention capacity (FRIESEN *et al.*, 1997). Moreover, P use efficiency is usually low and rarely exceeds 20% of applied P in the year of application depending on the nature of the soils and crops concerned (SUBBA RAO *et al.*, 1995). However, when manure and fertilizer P are applied together, synergistic effects often lead to available P being higher than expected from the sum of both amendments alone (REDDY *et al.*, 1999). While the addition of animal manure may improve P-availability, it is unlikely to have much impact on other yield limiting factors such as pests and diseases, which are favoured by continuous cropping, but it may slow down the deterioration of soil structure. While yield increases in cereals following rotation with legumes have been reported from Myanmar (HAN *et al.*, 2001), solid experimental data from cropping systems experiments are necessary to substantiate these reports. So far, the few available data refer to rice-based systems and were collected on acid Vertisols (FARIS, 1992).

Given the scarcity of data on legume rotation effects for maize in Myanmar, the objectives of this study were to examine to what degree an expected N-related yield decline in a maize monocropping system under the low external input conditions of local farmers could be slowed down by a rotation with green gram and to explore the causes of possible yield-enhancing effects of green gram on maize. The following research hypotheses were therefore tested in field experiments: (i) rotation with green gram (*Vigna radiata*), farm yard manure and P fertilizer will slow down the expected yield decline in a continuous maize system, (ii) incorporation of green gram shoot residues will further enhance maize growth. Different green gram cultivars were used to determine possible cultivar-system interactions.

2 Methodology

2.1 Experimental details

The experiment was conducted from 2002 to 2004 on a Gleysol soil with $\mathrm{pH}_{\mathrm{water}}$ of 5.6; 50 mg total N kg^{-1} soil and 6.8 mg Bray-1 P kg^{-1} soil at the farm of Yezin

Agricultural University (191°38' N latitude, 96°50' E longitude, 102 m altitude). The layout consisted of a split-split plot design with four replications. Treatment factors were two cropping systems as main plots. The subplot factor was manure application at 0 and 2 t ha^{-1} cattle compost, with N concentrations of 1.15, 0.78, 0.67, 1.01 and 0.89% and P concentrations of 0.51, 0.97, 1.15, 0.91 and 0.78% for the five experimental seasons, respectively. The sub-sub plot factors consisted of 0 and 15 kg P ha^{-1} as basal triple-super phosphate (TSP with 21% P). In the first season, three introduced green gram cultivars (V-3726, VC-5205 and Kanti) and one maize cultivar (Yezin Hybrid-3) were used. In season two and three, the three green gram cultivars V-3726, Kanti and the landrace Pakhoku were grown. Because of its high yield, V-3726 was also chosen for the 4th and 5th season.

Annual rainfall, distributed bimodally between May and November, totalled 1369 mm in 2002, 727 mm in 2003 and 1279 mm in 2004. Land preparation was done once by an animal-drawn plough followed by two harrowing operations. Plant spacing was 0.5 m between and 0.1 m within rows for green gram and 0.5 m between and within rows with one plant per hill for maize. Weed and pest control was done as necessary. To examine the effects of legume residue management, treatments of shoot incorporation and removal were added in the 5th season as a further split of legume plots.

2.2 Plant sampling and analysis

At flowering samples for tissue analysis of both crops were taken, dried at 70°C to weight constancy and analysed for N and P at the Agricultural Chemistry Division Laboratory, Department of Agricultural Research in Yezin and at the Institute of Crop Science Laboratory, University of Kassel, Germany. Total N was determined with a Macro-N-Analyser (Heraeus, Bremen, Germany). For P analysis, shoot and seed samples were ashed for 4 hrs in a muffle furnace at 500°C and the ash was dissolved in 1:30 (v/v) HCl. Phosphorus was determined calorimetrically (Hitachi U-2000 spectrophotometer). At final harvest total dry matter (TDM, kg ha^{-1}) was measured and the Harvest Index (HI) was determined. For root analyses soil samples (0 to 0.2 m) were collected at five locations within each plot in all blocks at flowering. All samples were washed over a 0.5 mm sieve to remove adherent soil and analysed for root length density according to TENNANT (1975) in a 10 mm grid line petri dish with a binocular at 40×. After counting, root samples were dried at 60°C for 12 h. Dry weight, total root length (TRL), specific root length (SRL) and root length density (RLD) were determined using the following equations:

$$SRL = \frac{Z * mesh\,(cm) * 11/14}{X\,(g)} \tag{1}$$

$$TRL = SRL * y\,(g) \tag{2}$$

where:
$Z =$ total numbers of intersects; $X =$ dry weight of counted sample;
$y =$ dry weight of entire root; and

$$RLD = \frac{TRL(cm)}{soil\ volume\,(cm^3)} \tag{3}$$

2.3 Measurements of mycorrhizae and nematodes

Mycorrhiza and nematode incidence were assessed in the 4^{th} and 5^{th} growing season. For measurement of mycorrhizae, 100 g of washed maize roots were cut into segments of 10-20 mm and cleared with 10% KOH at 60°C for 1 h. Subsequently, roots were rinsed three times in deionized water and acidified for 30 minutes in 2 N HCl. Then, roots were stained with 0.05% trypan blue in lactic acid over night followed by destaining in lactic acid. Percent mycorrhiza colonization of roots was determined by the line intersection method (Kormanik and McGraw, 1982). A modified Baerman funnel method as described by Hooper (1984) was used for the extraction of nematodes from 200 g soil and root samples prior to counting.

2.4 Data analysis

Data of TDM, grain yield and nutrient concentrations were analysed for all seasons together whereby treatments were split into seasons and subsequently analysed for each season separately by Analysis of Variance (ANOVA) using the Restricted Maximum Likelihood procedure (REML) and time series analysis of GENSTAT (Lawes Agricultural Trust, 2000). Seasonal data of grain yield and plant nutrient concentrations were also subjected to ANOVA. The data of nematode populations obtained in the final season was transformed as log base 10 and analysed as above.

3 Results

3.1 Green gram

Regardless of the treatment level TDM and grain yield of green gram decreased over the course of the experiment by an average of 41% and 52% (Fig. 1 and 2). Across seasons manure application led to consistently higher TDM whereas P application was only enhancing growth in season 2 and 5 without manure (Fig. 1). Significant effects of manure on grain yield were noted in season 4 and 5 (Fig. 2).

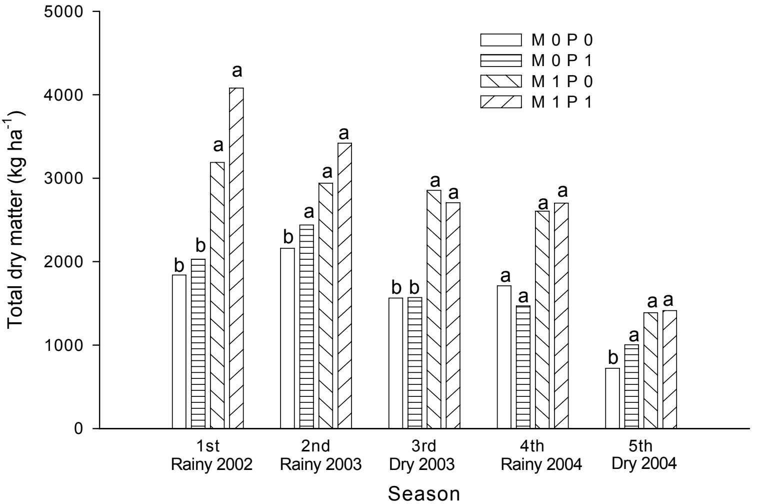
Effects of manure and P on grain yield varied greatly with the season. No effects were observed in season 1, whereas in season 2 P and manure addition resulted in significant yield increases with no synergistic effects being observed between both types of amendments (Table 1).

While mean grain yield declined by about half over the duration of the experiments (from 600 kg ha^{-1} in season 1 to 310 kg ha^{-1} in season 5) during the same period, RLD was reduced by 75% (from 4.5 cm cm^{-3} to 0.9 cm cm^{-3}). The LAI of green gram was also reduced by 59% across seasons (from 3.3 to 1.9), but the HI remained with values of 0.182 and 0.183 unchanged. Pod numbers per plant declined from 12.9 to 12.3 over the course of the experiment. Of the cultivars tested in some, but not all seasons grain yields were highest for cultivar V-3726 which is very popular in Myanmar because of its large grain size and subsequent high market price.

Although not significant, N and P concentrations in green gram shoots of all treatments increased over the duration of the experiment from around 23 to 42 mg g^{-1} and from 2.2 to 3.6 mg g^{-1}, respectively (Table 2). In untreated controls shoot N concentration

was higher than with manure and shoot P increased from 3.9 to 4.6 mg P g^{-1}. No correlations were found between N and P concentrations and green gram grain yield ($r = 0.37$, $r = 0.34$).

Figure 1: Effects of manure and phosphorus (P) application on total dry matter of green gram (cv. V-3726) in a field trial in Myanmar (2002-2004).



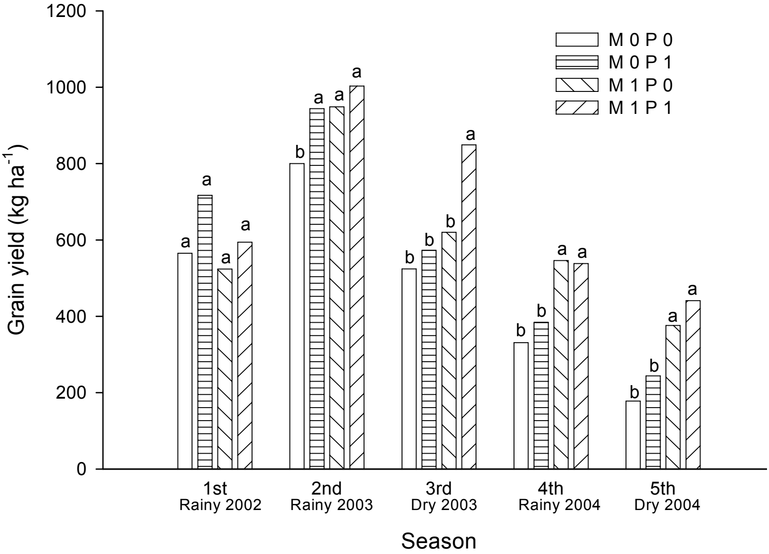
M0P0 = no manure, no mineral P; M0P1 = no manure, 15 kg P ha^{-1}; M1P0 = 2 t ha^{-1} manure, no mineral P; M1P1 = 2 t ha^{-1} manure, 15 kg P ha^{-1}. The lsd0.05 values across treatments are 1650, 1208, 720, 1175 and 480, in season 1-5, respectively. Columns within season marked with different letters are significantly different at $P < 0.05$.

Table 1: Combined analysis of variance (ANOVA) of manure (M) and phosphorus (P) application effects in green gram grown in a cropping systems (CS) experiment with continuous maize and maize in rotation with green gram at Yezin, Myanmar (five seasons from 2002-2004).

Source of variation	*Pr > F* *		
Parameter	*Total dry matter* (kg ha^{-1})	*Grain yield* (kg ha^{-1})	*RLD* † (cm cm^{-1})
Season ‡	0.001	0.001	0.001
Manure	0.001	0.003	0.801
Season × Manure	0.443	0.077	0.825
P	0.274	0.002	0.055
Season × P	0.709	0.652	0.798
Manure × P	0.623	0.837	0.216
Season × Manure × P	0.895	0.435	0.062

* Probability of a treatment effect (significance level), † Root length density,
‡ 2002 rainy, 2003 rainy, 2003 dry, 2004 rainy, 2004 dry

Figure 2: Effects of manure and phosphorus (P) application on grain yield of green gram (cv. V-3726) in a field trial at Yezin, Myanmar (2002-2004).



M0P0 = no manure, no mineral P; M0P1 = no manure, 15 kg P ha^{-1}; M1P0 = 2 t ha^{-1} manure, no mineral P; M1P1 = 2 t ha^{-1} manure, 15 kg P ha^{-1}. The lsd0.05 values are 201, 143, 199, 95 and 80, in season 1-5, respectively. Columns within seasons marked with different letters are significantly different at $P < 0.05$.

Table 2: Nitrogen (N) and phosphorus (P) concentrations in green gram and maize shoots in a cropping system field experiment at Yezin, Myanmar across five seasons (2002-2004). Data show treatments means.

	Concentration (mg g^{-1}) in Season				
	1	*2*	*3*	*4*	*5*
Green gram					
Shoot N	n.a.	23.2	28.4	41.6	41.9
Shoot P	n.a.	2.16	3.52	4.01	3.57
Maize					
Shoot N	n.a.	18.6	16.9	19.2	12.6
Shoot P	n.a.	1.6	3.0	3.5	4.6

n.a. – not available

3.2 Maize

With 93% and 97% the respective decline of maize TDM and grain yield over the duration of the experiment was larger than similar effects in green gram (Fig. 3 and 4). The overall ANOVA showed significant F-value for season, cropping system, manure and P application (Table 3). For individual years, F-values did not show significant rotation effects from season 2 onwards, although yields from rotation plots tended to be higher than those from continuous maize plots. Root length density decreased over time and there were only marginal effects of P fertilizer and no effects of rotation on RLD. Although across years rotation effects on maize growth were inconsistent, crop rotation increased TDM, grain yield, RLD and the number of ears per plant compared to continuous maize in seasons 2, 3 and 4.

Manure application led to increased leaf area, plant height, TDM and grain yield. Phosphorus application also increased LAI and plant height, thereby contributing to increased TDM and grain yield. In season 5, incorporation of legume residues significantly enhanced grain yield relative to residue removal only without P application (Fig. 5). However, compared to maize growth in previous seasons, grain yield and TDM of maize in all treatments sharply declined.

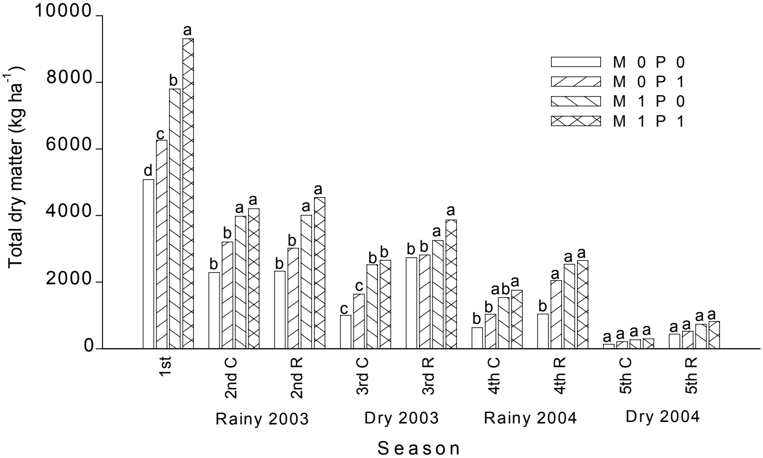
By season 3, legume rotation-induced increases in maize growth were larger than those caused by manure- and P-application (Fig. 4). From season 2 onwards, rotation effects were little affected by manure and P application. In the 4th and 5th cropping season manure application tended to increase mycorrhizal infection but effects on plant-parasitic nematodes were inconsistent across cropping systems (Fig. 6 and 7). The average LAI of maize decreased from 4.0 to 0.3 and there was no significant effect of manure and P application on ear number per plot.

Manure increased ear numbers from 12 to 15. From season 2 to 5 plant height and stem diameter declined from 143 and 5.7 cm to 48 and 3.9 cm. Across seasons, the HI remained almost constant. Recycling / incorporation of legume straw led to substantial yield increases but was not enough to alleviate N constraints.

Over seasons the rapid yield decline overtime was reflected in a strong decrease of N concentrations in maize shoots from 19 to 13 mg g^{-1} and a concomitant increase in P concentrations from 1.6 to 4.6 mg g^{-1} (Table 2). In the 5th season incorporation of legume residues led to a slight increase in maize N concentration. From season one to season five, N removal of the maize field declined from 54 kg N to 30 kg N.

The soil mineral N concentration in the top 15 cm of the profile tended to be higher in rotation plots with residue incorporation up to six weeks after planting compared to rotation plots with legume residue removal or continuous maize cultivation. However, these differences were not statistically significant.

Figure 3: Effects of cropping system, manure and phosphorus (P) application on total dry matter of maize in a field trial at Yezin, Myanmar (2002-2004).



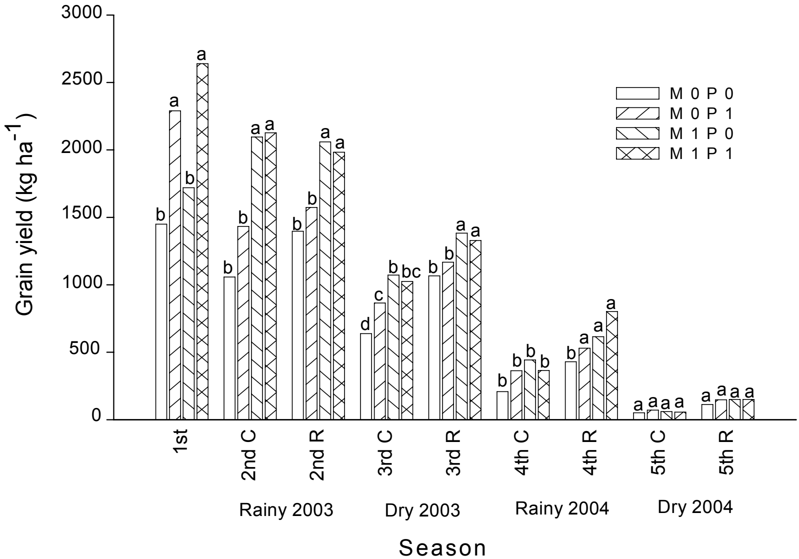
C = continuous maize, R = maize-green gram rotation, M0P0 = no manure, no mineral P; M0P1 = no manure, 15 kg P ha^{-1}; M1P0 = 2 t ha^{-1} manure, no mineral P; M1P1 = 2 t ha^{-1} manure, 15 kg P ha^{-1}. The lsd0.05 values are 1040, 503, 643, 582 and 107, respectively. Columns within seasons marked with different letters are significantly different at $P < 0.05$.

Table 3: Analysis of variance (ANOVA) for the time dependent effects (five seasons from 2002-2004) of cropping system (continuous maize versus green gram-maize rotation), manure application (0 and 2000 kg ha^{-1}) and banded phosphorus (P) fertilization (0 and 15 kg P ha^{-1}) on total dry matter (TDM), grain yield and root length density (RLD) of maize (*Zea mays* L.) at Yezin, Myanmar.

Source of variation	*Pr > F* *		
Parameter	*Total dry matter* (kg ha^{-1})	*Grain yield* (kg ha^{-1})	*RLD* † (cm cm^{-1})
Season ‡	0.001	0.001	0.003
System	0.001	0.007	0.102
Season × System	0.104	0.750	0.838
Manure	0.001	0.001	0.247
Season × Manure	0.001	0.001	0.739
System × Manure	0.305	0.436	0.164
Season × System × Manure	0.971	0.055	0.112
P	0.001	0.015	0.047
Season × P	0.081	0.356	0.913
System × P	0.157	0.122	0.591
Manure × P	0.485	0.434	0.882
Season × System × P	0.697	0.450	0.868
Season × Manure × P	0.390	0.657	0.979
System × Manure × P	0.899	0.535	0.103
Season × System × Manure × P	0.713	0.827	0.634

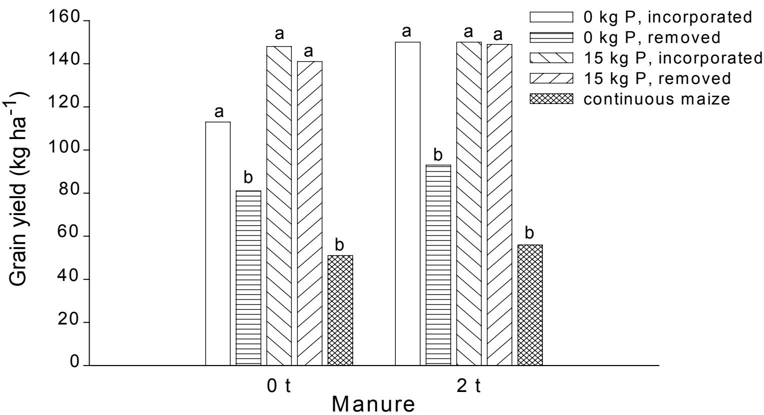
* Probability of a treatment effect (significance level), † Root length density,
‡ 2002 rainy, 2003 rainy, 2003 dry, 2004 rainy, 2004 dry

Figure 4: Effects of cropping system, manure and phosphorus (P) application on grain yield of maize in a field trial at Yezin, Myanmar (2002-2004).



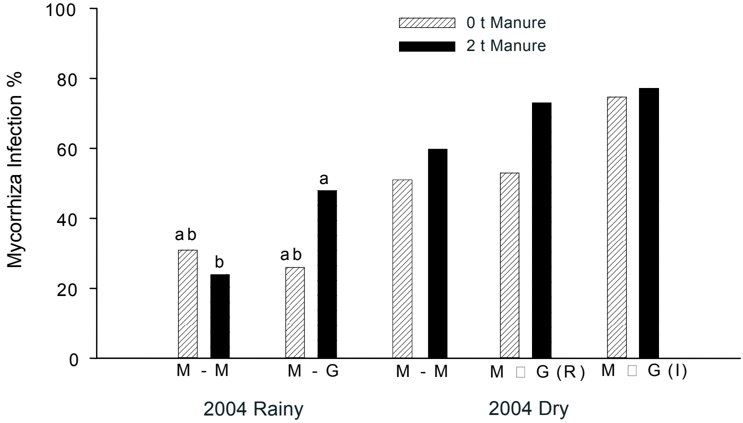
C = continuous maize, R = maize-green gram rotation, M0P0 = no manure, no mineral P; M0P1 = no manure, 15 kg P ha^{-1}; M1P0 = 2 t ha^{-1} manure, no mineral P; M1P1 = 2 t ha^{-1} manure, 15 kg P ha^{-1}. The lsd0.05 values are 450, 568, 743, 477 and 106, respectively. Columns within seasons marked with different letters are significantly different at $P < 0.05$

Figure 5: Effect of phosphorus (P) application (kg ha^{-1}) and legume residue management (removal versus incorporation) on grain yield of maize in the 5$^{\text{th}}$ season at Yezin, Myanmar (2004 dry season).



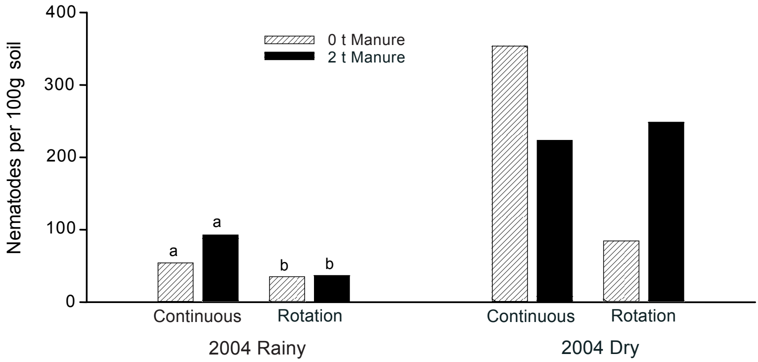
The lsd0.05 value was 42. Columns within seasons marked with different letters are significantly different at $P < 0.05$.

Figure 6: Effects of cropping system and manure application on mycorrhizal infection of maize in the 2004 rainy and dry season at Yezin, Myanmar (2004).



M-M = continuous maize, M-G = maize-green gram rotation; R = legume straw removed; I = legume straw incorporated. The lsd0.05 values 22.6 and 31.0, in season 4 and 5, respectively. Columns within seasons marked with different letters are significantly different at P < 0.05.

Figure 7: Effect of cropping system and manure application on plant-parasitic nematodes in soils of a maize cropping systems experiment in the 4th and 5th season at Yezin, Myanmar (2004).



The data are back transformend after log-transformation for statistical analysis; lsd0.05 values of transformed values are 0.26 and 0.64, respectively. Columns within season marked with different letters are significantly different at P < 0.05.

4 Discussion

4.1 Green gram

Over the five cropping seasons green gram TDM and grain yield steeply declined which likely reflected effects of N deficiency for as evidenced by the decline of N concentrations over time. During the first seasons V-3726 consistently showed highest TDM and grain yield which was also reflected in its high LAI and number of pods per plant.

Although not significant except for the 1st season, P application tended to increase RLD in all seasons, which likely reflected P effects on shoot growth. Ahmad *et al.* (2001) reported total N concentration in green gram ranging from 26 to 36 mg g^{-1}, whereas Lawn and Ahn (1985) showed N concentrations of 6 – 16 mg g^{-1} and P concentrations of 2 – 2.9 g kg^{-1}.

4.2 Maize

The results clearly showed that regardless of the treatment maize growth was strongly limited by N supply which also led to the dramatic decline in yields over time and the decline in shoot N concentrations to 68% of the value measured in the second season. Similar results were found by Cheruiyot *et al.* (2001) who reported that growing continuous maize resulted in a strong growth decline following limited soil N. The data did not show any alleviation of this yield decline or a significant difference in shoot N concentration in plots with green gram rotation. Further studies using acetylene reduction assays or ^{15}N analysis would have been needed to determine the level of N_2 -fixation by green gram in this study. The absence of a difference in the N-status of maize grown in the two cropping systems indicates that under the conditions of this experiment N_2-fixation of green gram may have been severely hampered despite the strong presence of reddish nodules on roots.

At this level of N supply soil P was apparently not limiting despite its low availability (6.8 mg Bray-1 P kg^{-1} in the initial soil). Only this would explain the small response of maize growth to regular P applications in organic form (manure) and as mineral fertilizer. Lacking rotation effects on maize growth in the 2nd season are likely due to the erroneous fallow phase following the first cropping season in 2002. The increase in RLD with P application is in agreement with earlier findings on P-poor sandy soils from West Africa which showed increased root biomass, root to shoot ratio and lateral root length after P addition (Marschner *et al.*, 2004).

Higher TDM yield of maize due to manure were observed in season 2, which may also be linked to the observed increase in pH from 5.6 to 6.8 after five seasons in plots with and without manure application. Similar manure-induced pH increases were observed previously by Harris (2002) and Chettri *et al.* (2003).

Waddington and Karigwindi (2001) reported that on on-farm grain yields from continuous maize (one season per year) without fertilizer ranged from 0.5-0.8 t ha^{-1} over five years. In contrast, in the 5th season of this experiment maize grain yield was $<$ 0.5 t ha^{-1}. McDonagh and Hillyer (2003) also reported that for moderate millet grain yield (1000 kg ha^{-1}) in Africa, 20-30 kg N ha^{-1} and 10-15 kg P ha^{-1} mineral

fertilizer were essential. Kwabiah *et al.* (2003) observed that application of 5 t dry matter ha^{-1} of *Tithonia* and *Croton* was similar to the effects of 120 kg N ha^{-1} and 50 kg P ha^{-1} of inorganic fertilizers in enhancing on maize grain yield. In this experiment only 10-20 kg N was added annually through the application of manure. This was too low to sustain maize yields at average N removals of 70, 74, 43, 32, 4 kg ha^{-1} per season.

Giller and Cadisch (1995) reported that the removal of legume stover at harvest frequently leads to a net removal of N from the soil. Therefore the recycling of residues to the soil is essential for the N-balance in grain legumes. Nevertheless, food legumes such as cowpea, green gram and pigeon pea were found to increase yields of subsequent cereal crops in semi-arid India by an equivalent of 30-40 kg N ha^{-1} (Kumar Rao *et al.*, 1988). Similar results were found by Rego and Rao (2000) in sorghum–pigeon pea intercropping on a Vertisol in India (2000). For maize Herrmann and Taube (2005) reported a critical shoot N concentration of 10.5 g N kg^{-1} TDM.

Chettri *et al.* (2003) reported that the application of 7 t ha^{-1} manure to rice and wheat crops over eight years had no beneficial effect on yields. But Harris (2002) showed manure-induced yield increases due to the improvement of N, P, K and micronutrients and of soil physical properties. In contrast to the latter results, manure effects on crop yield were very small in this experiment. This might have been due to the application rate of only 2 t ha^{-1}.

The slightly (from 19.05 to 19.35 mg N g^{-1}; from 3.24 to 3.73 mg P g^{-1}) increased N and P concentration of rotation maize compared to continuous maize might have been due to a small (though statistical not significant) increase in mycorrhizal infection. Without manure, however, mycorrhizal infection rates were not affected by cropping system. For nematodes, a small, though significant decrease in numbers was observed with green gram rotation in the rainy season of 2004, but differences were insignificant in the following dry season. The compared to the results of Bagayoko *et al.* (2000b) missing consistent rotation-induced decline in nematodes may be due to the fact that in all treatments overall infestation levels were small and unlikely to cause much harm to plant roots.

5 Conclusions

In the absence of mineral N fertilizers and with only moderate amounts of applied cattle manure the green gram rotation failed to increase maize yields compared to the monoculture maize system. The results indicate that under the conditions of this five-season experiment, N_2-fixation of green gram might have been severely hampered and the crop's effects on the N balance negative when seeds and stalks were removed. The absence of significant effects of green gram on mycorrhizal infection and nematodes in subsequent maize may further explain lacking legume-rotation effects on this crop. The results strongly suggest that apart from 2 t ha^{-1} manure, application of mineral N fertilizer is needed to maintain growth and grain yield of maize irrespective of the rotation with different green gram cultivars.

Acknowledgements
The authors are grateful to the German Academic Exchange Service (DAAD) for a scholarship to the first author and to the technical assistance of Claudia Thieme, Eva Wiegard and Burkhard Heiligtag.

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