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Yield Responses of Maize to Organic and Mineral Fertilizers at Different Inclinations in Tropical Smallholder Farming Systems

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Abstract

A field study was conducted on the potential of Gliricidia (*Gliricidia sepium* (Jacq.) Kunth ex Walp.) to enhance productivity of degraded soils. Maize was cropped in a hilly region of Sri Lanka with and without the recommended mineral fertilization, in two major seasons, October-January in 2007/8 (Year 1) and in 2008/9 (Year 2) on 92 farms at two inclinations: Flat (0-10%) and Moderate (10-30%). On half the farms, green manure (Gliricidia leaves) was added (3 tonnes per hectare per season). NPK boosted production to a very respectable mean grain yield of 4.2 t/ha on Flat farms. At ZERO, the yield was lower by 60%, irrespective of the inclination. Gliricidia failed to replace the required nitrogen, even with an adequate supply of phosphorous and potassium (PK). In contrast, together with NPK, Gliricidia increased yields by 15-20% compared to NPK alone, while the gain was 35% at ZERO. Fields in the Moderate category were more responsive to green manure and mineral fertilizers. The high response to mineral fertilizers indicated that the degradation of the soils resulted to a greater extent in chemical rather than in physical deficits. But intensive cropping reduced the soil organic matter within two years, to some extent slowed down by Gliricidia green manure. Therefore an intense cropping for the sake of food security must be accompanied by soil conserving cropping systems.

Keywords: degraded soils, tree legumes, green manure, inclinations, mineral fertilizers

1. Introduction

Due to continuous cultivation and soil erosion soil fertility often declines in tropical regions, jeopardizing food production on smallholder farms (Kwesiga et al., 2003; Akinnifesi et al., 2006). Agroforestry is a valuable alternative in such systems for regenerating soil fertility, and thus enhancing food security and household income, especially where mineral fertilizers are too expensive for smallholder farmers (Mafongoya et al., 2006; Kimaro et al., 2008). Trees in agroforestry offer diverse advantages like biological nitrogen fixation, nutrient recycling from deeper soil layers and minimization of leaching and soil erosion (Nyadzi et al., 2003). A number of studies revealed the benefits of Gliricidia for soil fertility (Ikerra et al., 1999; Chiwara et al., 2003; Makumba et al., 2005; Akinnifesi et al., 2009). Its green manure can contribute N (and other recycled nutrients) by 20-65 kg/ha in smallholder farming systems (Zingore et al., 2003; Baggie et al., 2004; De Costa et al., 2005).

Repeated green manure applications can provide more long-term (Sileshi & Mafongoya, 2006; Kimaro et al., 2007; Makumba et al., 2007) or more short-term (Sangakkara et al., 2004; Reddy et al., 2008; Silva et al., 2008) benefits. However, there are not always positive effects (Pandey & Rai, 2007; Marin et al., 2007). A meta-analysis by Sileshi et al. (2008) showed a lack of quantitative synthesis in terms of the nature and magnitude of green manuring and also the linkages among location, soil type and climate. In a recent study, 30 twinned focal points, i.e. a homegarden with long-term intensive application of green manure and a field, were compared with regard to the content of soil organic matter and maize yield (Egodawatta et al., 2012). Both parameters were much higher in homegardens than in fields, revealing that the annual application of Gliricidia green manure together with mineral fertilizer increased yields mostly in homegardens.

An agroforestry system based on Gliricidia was introduced into a mountainous rural region of Sri Lanka in 2001/2002 with the objective of replenishing the degraded landscape and simultaneously providing direct and indirect economic benefits. Farmers were encouraged to use green manure as part of their agricultural practices and to integrate nutrient management by synchronizing the application of mineral fertilizers and organic constituents.

The hypothesis was that Gliricidia green manure can increase the production potential of the model crop maize, irrespective of the terrain. The specific objectives were: 1) to assess the impact of Gliricidia manure on soil productivity, taking into account inclination and 2) to compare the impact of Gliricidia green manure and a recommended supply of mineral NPK fertilizer on the growth and yield of maize.

2. Method

2.1 Study Area and Experimental Sites

This on-farm study was conducted from 2007 to 2009 (Year 1 and Year 2) on 92 fields in the Meegahakiula region at 7°07.485'N, 81°02.740'E and at elevations between 270-400 MSL covering a total area of 25 km^2. The pattern of rainfall in the region is bi-modal, with an annual 1300 mm; about 60% is available for maize cultivation in the major season from October to January. The actual annual rainfall was 1325 mm (Year 1) and 919 mm (Year 2).

The absolute inclination of the 92 farms was measured (Bandara et al., 2011) and categorized as "Flat" (0-10%) and "Moderate" (10-30%). Initially, 27 farms at steeper inclinations were measured as well, but the cultivation practises often differed from those in the Flat and Moderate categories. Anyhow, sustainable arable cropping cannot be recommended for those steep areas (Egodawatta et al., 2012). Based on the use of Gliricidia, a tree legume crop, farms were further categorized as "G YES" and "G NO", depending on whether or not Gliricidia green manure was applied during cropping. Before the experiment started and after two years of cropping, with the same amount of Gliricidia manure being applied twice a year to the maize crop and to the subsequent crop of mungbean (*Vigna radiata*) in the minor rainy season (data not recorded here), a soil analysis was carried out for an easy determination of chemical and physical properties (*i.e.* pH, total nitrogen, available phosphorus, extractable potassium, organic matter, texture and bulk density) prior to crop establishment.

2.2 Experimental Set Up and Plot Management

With the onset of monsoonal rains, the existing vegetation was slashed to the ground, and all the debris was removed. The selected lands were ploughed with a conventional plough at an effective depth of 20 cm. Maize seeds of the local variety Ruwan (OPV, open pollinated variety) were planted into mounds, spaced at 30 cm x 45 cm, one seed per point to obtain a planting density of 7.4 plants/m^2. Plots were kept weed-free until four weeks after planting. All the cultivation practices followed local recommendations (Department of Agriculture, Sri Lanka, 1995). The three mineral fertilizer treatments were established in plots of 10 m x 10 m, randomly established within in each field: 1) total recommended fertilizer dosage (NPK), 69 kg N (Urea), P 20 kg (Triple Super Phosphate) and K 50 kg (Muriate of Potash) per hectare, 2) recommended fertilizer dosage without N (PK), and 3) no fertilizer (ZERO). On G YES farms, 3 t/ha (dry weight basis), half the Gliricidia leaves were incorporated during preparation of the land for planting and half as surface mulch four weeks after planting, amounting to 24 kg N, 3 kg P and 18 kg K per hectare and season.

2.3 Observed Parameters

A number of parameters (plant height, leaf number and SPAD values) were assessed during the vegetative period of maize at two-week intervals. The final analysis of the data proved that none of these parameters reflected the impact of factorial combinations better than the maize yield itself, and therefore the data are not shown. At full maturity, 10 m^2 were harvested to determine the grain yield. After harvesting the ears, the plants (without roots) from 1 m^2 were taken from each plot and separated into stover and cobs. The shoots were oven-dried at 60°C for 48 hours to determine the dry weight and leaf nitrogen. Total biomass, grain yield and harvest index were determined based on the collected data. The yield components (cobs per plant, rows per cob, number of kernels per row, and 100 kernel weight) were determined using the harvested sub samples. Since grain yield best explained the impact of the treatments, the data of all related parameters are not shown.

2.4 Data Analysis

Prior to the detailed analysis, the maize yield data was tested for normality, autocorrelation and homoscedasticity. A general linear Model (GLM) and ANOVA were carried out to assess the effects of inclination, year and Gliricidia on the model crop maize. By means of ANOVA, significant means were separated by the least significant difference (LSD) test. Pearson correlation coefficients were used to identify the relationships between soil and yield parameters. All analyses were conducted at the 5% level of significance. Appropriate statistical tools from SAS version 9.2 (SAS Institute, 2008) were used to perform the analysis.

3. Results

At the upper 30cm soil level available phosphorous (P) ranged between 24-26 mg/kg, and extractable potassium (K) between 15-18 mg/kg; detailed data is exemplarily shown in Table 1 for soil organic matter (SOM) total nitrogen (TN). Their values ranged between 12.8-16.5 g/kg, between 10.6-12.9 mg/kg, respectively. All ranges were generally narrow and differed little when comparing Flat and Moderate inclinations. SOM values significantly declined after two years of cultivation, irrespective of inclination and of Gliricidia green manure (G YES) addition. However, in the latter case the decline was slowed down. Opposite to SOM, TN values had increased over the two years of cropping (Table 1); a partly significant positive impact of green manure addition existed but it was less pronounced than for SOM values.

Table 1. Soil chemical and physical properties of top soil (0-30cm) in the inclination classes with use of Gliricidia as green manure (G YES and G NO) in 2007 and 2009

Soil Property	G use	Flat (*n=52*)		Moderate (*n*=40)	
		2007	2009	2007	2009
SOM (g/ kg)	G YES	16.5^{ax}	15.0^{ay}	16.4^{ax}	15.0^{ay}
		$0.8^{\dagger}$	0.6	1.1	0.9
	G NO	16.6^{ax}	13.3^{ay}	15.6^{ax}	12.8^{ay}
		0.8	0.6	1.0	0.7
Total Nitrogen (mg/ kg)	G YES	12.2^{ax}	12.9^{ax}	10.6^{bx}	12.7^{ay}
		0.4	0.4	0.1	0.5
	G NO	10.7^{ax}	11.5^{ay}	10.6^{ax}	12.3^{by}
		0.4	0.4	0.3	0.3

n = number of replicates in each inclination;

† standard deviation with corresponding mean;

Means followed by the same letters in a row are not significantly different at $p < 0.05$;

a, b: denote the difference between inclination categories, x,y : denote the difference between two years.

The statistical model for grain yield represented 57% of the total associated variability. Grain yield was only marginally ($P = 0.051$) influenced by year and, thus, it was not considered in the model. The differences between the years were mainly due to the small amount of rainfall in Year 2. The relative differences in yield due to fertilizer treatments were within a similar range at each inclination in both years. The two-way interactions (inclination and season, inclination and fertilizer combination, season and fertilizer combinations) or the three-way interaction (inclination and season and fertilizer combination) were not significant ($P < 0.05$). NPK, PK and ZERO fertilizer treatments significantly ($P < 0.001$) influenced grain yield at both inclinations (Table 2). At ZERO yields ranged around a subsistence level of about 0.9 to 1.7 t/ha and were mostly lower at Moderate than at Flat. PK raised the yield generally by more than 1 t/ha. Adding N, i.e. NPK, increased yields by a further 33 to 36%, and the combination NPK, Flat and G YES resulted in a respectable yield of 4.4 t/ha for an OPV. In general, yields were somewhat higher at Flat than at Moderate. G YES improved yields compared to G NO by about 15 to 20% at both NPK and PK and by about 35% at ZERO. Correlations between maize grain yields and soil properties were calculated on the basis of the single combinations of inclination category, use of Gliricidia, and fertilizer application. The respective values were mostly low but positive for SOM, TN and K. Some significant correlations existed in the combination Flat and G NO, with positive R-values of about 0.5 for P and negative ones of about 0.6 for bulk density for all three mineral fertilizer combinations.

Table 2. Mean grain yield (t/ha) of maize at two ranges of inclination with the use and non-use, or not, of Gliricidia (G YES or G NO) as green manure

Inclination category			Flat (0-10%) (*n=52*)			Moderate (10-30%) (*n=40*)		
Use of Gliricidia			G YES (*n=30*)	G NO (*n=22*)	% diff	G YES (*n=19*)	G NO (*n=21*)	% diff
Fertilizer combination	NPK		4.37* 1.06†	3.67 1.53	19	3.57* 1.57	3.10 1.38	15
	PK		2.84* 1.03	2.36 1.17	20	2.40* 1.18	2.07 1.17	16
	ZERO		1.65* 0.67	1.20 0.84	37	1.25* 0.67	0.93 0.71	34
	% diff	NPK-PK	35	36		33	33	
		NPK-ZERO	62	67		65	70	

n= number of replicates in each range of inclination;

† standard deviation associated with corresponding mean;

* significant difference at $P < 0.05$ (G YES and G NO) at the corresponding inclination and fertilizer combinations following the mean separation by least significant difference (LSD).

4. Discussion

The soil fertility status of the farms was heterogeneous, which led to a highly variable crop response and final grain yields of maize, even at the same inclination range, partly due to the diversity of management practices by individual farmers. This strongly highlights the advantage of multi-locational on-farm studies to avoid generalisations that are not justified in regions of varied topography. Generally, intensive cropping with a long and a short season crop per year reduced the SOM values within two years, a process that could be just slowed down by Gliricidia green manure. This indicated that an intense cropping must be accompanied by soil conserving cropping systems in the long term. In addition to soil parameters, different social status and income may have caused deviations in the correlations between soil quality and yield and requires further study, although the heterogeneity of crop yields can usually be linked directly to the fertility of the field (Mairura et al., 2007). Despite relatively small differences in the chemical soil parameters, yields were considerably higher at Flat than at Moderate. In Thailand and Australia the relative yield reduction at greater inclinations was lower (Sipaseuth et al., 2007; Cotching et al., 2002), but the annual rainfall was higher (2,000 mm) in Thailand, whereas the soil was more fertile in Australia. Therefore, attention must be paid to other factors that influence growth, not only to inclination.

Flat farms showed higher mean yields, especially at recommended levels of NPK. However, seasonal application of Gliricidia green manure still caused a significant increase in grain yields. It had been assumed that much of the impact of green manure on yield was due to nitrogen release. However, this assumption was largely negated by an identical response to green manure at PK, where available nitrogen is lower. Neither P and K nor N were sufficiently increased with the application of Gliricidia during the vegetative growth of these crops, even though the addition of Gliricidia should have resulted in the release of more than one third of the mineral N. Only at Zero was the relative response to G Yes higher, but since the absolute yield increase in comparison to NPK and PK was lower, the direct utilization of the nutrient contents in the green manure was clearly insufficient. In a parallel study, the maize yield of fields at selected farms was compared to the yields achieved in home gardens, which had received large amounts of organic manure, including Gliricidia, over long periods of time (Egodawatta et al., 2012). The higher yield potential of homegardens was probably due, not only to mineral fertilizers and the seasonal application of Gliricidia manure, but also to a generally greater fertility of the soil. These findings indicate that the long-term improvement of soil fertility was more important than short-term impacts of nutrients in our study (cf. literature review in the Introduction). Despite comparatively high P availability in the studied soils, the variability on the individual farms was still important for the exploitation of the yield potential, as indicated by the positive correlations for different combinations of fertilization and inclinations. Across farms for each range of inclination and mineral nutrient fertilization, the high impact of NPK and PK indicates that the chemical soil fertility was not exploited at ZERO, so that there is considerable room for increasing yield when and if it becomes economically feasible in the future. Confirming a report by FAO (2006), nitrogen was a key factor in achieving higher yields; this was corroborated too for more fertile home gardens at much greater inclinations (Wijesinghe et al., 2009; Egodawatta et al., 2012). However, even a high rate of N was not enough to elevate yields on farms at Moderate compared to yield at Flat, which was especially pronounced in the rather dry second season. Without addition of green manure, physical restrictions (Bulk density) and chemical restriction (P) were indicated in the former case by significant correlations to grain yield.

5. Conclusions

The production potential of maize was limited by a low content of soil nitrogen, as indicated by the strong response to the application of mineral N. The combined application of both fertilizer and green manure usually had a mutual effect on crop yields. Though the direct contribution of N by green manure was low, there seemed to be an indirect influence on chemical and physical soil parameters like SOM, bulk density and P, an important contribution to yield consistency in regions where "self-supply and food security " is of great importance.

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