3. Role of Legumes in Improving Soil Fertility and Increasing Crop Productivity in Northeast Thailand

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Introduction

Northeast Thailand constitutes one-third of total area of the whole country and one-third of the total population live in this region. The income of the majority of the people living here is below half of the national average mainly due to low agricultural production and productivity. The low agricultural productivity of the northeast region compared to other regions of Thailand is attributed mainly to erratic rainfall, water shortage during the dry season, undulating terrain and poor and marginal soils. The soils in the region are mostly sandy in texture with low soil moisture holding capacity. The soils are also very low in organic matter and low in general fertility.

Major crops grown in the northeast region of Thailand in this region are rice, cassava, sugarcane and maize. However, the yields are very low compared to those in other regions of the country. Crop productivity can be improved through addition of chemical fertilizers. However, chemical fertilizers are expensive and generally out of reach for many poor farmers. Moreover, in some areas of Thailand, there is evidence to show that non-judicious, long-term use of chemical fertilizers, especially on light-textured soils, can lead to the contamination of surface and groundwater.

Improved crop productivity can also be achieved through the use of organic fertilizers such as compost or farmyard manure and recycling of crop and organic residues in production systems can improve crop productivity. However, lack of availability of organic fertilizers in sufficient quantities in the region and the high cost of transporting the bulky materials are major constraints. Therefore, in this agricultural scenario, the introduction of legumes into the existing cropping systems seems to be a logical approach. Legumes are known to biologically fix atmospheric nitrogen (N) in symbiosis with *Rhizobium* bacteria. The fixed N can at least partly reduce the N fertilizer requirement of the main field crop in rotation. Thus it becomes an affordable source of N for resource-poor farmers in the region (McDonagh et al. 1995a).

This paper summarizes the work done by the researchers in Khon Kaen University in collaboration with the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and other partners in identifying crop, soil and water management practices that improve fertility and increase crop productivity. A special emphasis was placed on the use of legumes in sequence with major crops namely, rice, maize and sugarcane in northeast Thailand.

Rice-based System

Rice is one of the major crops that are economically important in Thailand and at present the country is among the top exporters of rice. Rice is grown both for domestic consumption and for export. Thailand is considered to be one of the top exporters of rice. In 2004, Thailand exported 10 million t of rice worth 108,393 million bahts (US$ 2970 million) (Centre for Agricultural Information 2006). The total area under rice production in Thailand is approximately 10 million ha, with an average yield of 2.65 t ha^{-1}, which is lower compared to the average yields of rice in Japan, China, Vietnam, Indonesia, and Myanmar.

Rice production area in the northeast is about 5 million ha with average yield of 1.9 t ha^{-1}, which is lower than the average yield in other regions of the country. Rice is grown during rainy or wet and dry seasons. Rice grown in the rainy season is mainly rainfed, while that grown in the dry season is irrigated. The total area under rice cultivation in the country during the rainy season is about 9.22 million ha while the area under rice in the dry season is only 1 million ha. However, rice yields are higher in the dry season than in the rainy season. Upland rice is also grown in Thailand, especially in the mountainous areas of the North, Northeast and the central regions of the country. The area under upland rice is smaller than that under lowland rice. However, upland rice provides a staple food for the people living in the mountainous areas of the country.

Researchers at Khon Kaen University have studied in detail the effects of legumes in improving the yield of rice. Even though, there are studies on the use of legumes as green manure in improving rice yields, most of the research works are focused on the use of groundnut stover as a source of N (McDonagh et al. 1995a, 1995b, Toomsan et al. 2000). However, green manure legumes do not provide cash or economic returns to the farmers. Besides, there are also problems such as the availability of legume seeds, requirement of P fertilizer and incorporation of green manure legumes in rice production systems. Hence, green manure legumes are not widely accepted by small farmers who have limited resources. On the other hand, as the grain legumes that provide grain appear to be more attractive, groundnut seems to fit well in the production systems (McDonagh et al. 1995a, Whitmore et al. 2000).

Groundnut can be grown after the harvest of rice (December to early January). Our previous studies indicated that groundnut crop can fix substantial amount of N (McDonagh et al. 1993, Toomsan et al. 1995). Our studies revealed that nitrogen harvest index (% NHI) of groundnut in economic yield (pod) was lower than the proportion of N fixed from air (% N derived from air) and thus makes it a suitable crop to improve soil fertility and increase yields of succeeding crops through the residual effects via N (McDonagh et al. 1995a, Toomsan et al. 2000).

Our studies also showed that groundnut can be grown after the harvest of rice and the crop could give good pod and stover yields. Pod yield as high as 3 t ha^{-1} and stover yield of 10 t ha^{-1} can be obtained, depending on the location and the groundnut cultivar used. The N in the stover could be as high as 166 kg N ha^{-1} (Toomsan et al. 1995). In order to get the full benefit of N in groundnut, it is important to return the stover to the soil. At the time of harvest many farmers burn or remove the stover from the field and never return it to the soil. This has a negative effect on growth and yield of succeeding rice crop and on organic matter content. Our studies indicated that growth and yield of rice could be significantly increased by returning the stover to the soil (Table 1).

Table 1. Grain and total biomass yield of rice grown after groundnut with stover removed (– stover) or returned (+ stover) at two locations in farmers' fields in Khon Kaen, Thailand[1].

Groundnut cultivar	Grain yield ($kg\ ha^{-1}$)			Total biomass yield ($kg\ ha^{-1}$)		
	– Stover	+ Stover	% Difference	– Stover	+ Stover	% Difference
Location 1 (Kranuan, Khon Kaen)						
KK 60-1	3290	3870	17.7	6565	8500	29.5
KK 60-3	2910	3660	25.9	5890	7685	30.5
Non-nod	2895	3190	10.3	5390	6495	20.5
Location 2 (Ban Thon, Khon Kaen)						
KK 60-1	3250	3710	14.2	7390	9550	29.3
KK 60-2	3275	3675	12.2	7430	9365	26.0
Non-nod	3210	3435	6.9	7115	8220	15.6

1. Source: Toomsan et al. (1995).

Contrary to the results obtained with groundnut, the effect of soybean had lower proportion of N fixed from the air (% Ndfa) than the nitrogen harvest index (% NHI). Although soybean stover when returned to the soil increased total biomass, it did not increase the rice grain yields (Table 2). This could be attributed to low N content in soybean stover. Nitrogen returned to the soil via soybean stover was about 21–27 kg N ha^{-1} while that returned via groundnut haulms was in the range of 74–166 kg N ha^{-1}. The effects of groundnut stover application on growth and yield of lowland rice was also studied (Toomsan et al. 2003). Application of groundnut stover at 3.75 t ha^{-1} along with PK (25 kg P_2O_5 + 12.5 kg K_2O ha^{-1}) and N fertilizer (14.4 kg N ha^{-1}) at the panicle initiation stage gave significantly higher rice yields than the no-chemical fertilizer application (control) treatment and N control treatment (NPK fertilizer application at the recommended rates) (Table 3).

Table 2. Grain and total biomass yields of rice grown after soybean with stover removed (- stover) or returned (+ stover) in a farmer's field at Ban Thon, Khon Kaen[1].

Soybean cultivar	Rice grain yield (kg ha^{-1})			Rice total biomass yield (kg ha^{-1})		
	– Stover	+ Stover	% Difference	– Stover	+ Stover	% Difference
SJ 4	3675	3700	0.7	9020	10850	20.3
KKU 35	3770	3530	-6.3	9510	10690	12.4

1. Source: Toomsan et al. (1995).

Table 3. Grain and total biomass yield of rice as affected by different rates of groundnut stover and chemical fertilizers at Kalasin, Northeast Thailand, 1999[1].

Treatment[2]	Yield[3] (kg ha^{-1})		Harvest index (%)
	Grain yield	Total biomass	
Stover, no chemical fertilizer (control)	2600[f]	5050[e]	51
+ Stover 1.875 t ha^{-1} + PK	3060[def]	6400[cd]	48
+ Stover 1.875 t ha^{-1} + PK + N (PI)	3320[bcd]	6470[cd]	51
+ Stover 3.75 t ha^{-1} + PK	3430[bcd]	6990[bc]	49
+ Stover 3.75 t ha^{-1} + PK + N (PI)	3770[ab]	7860[ab]	48
+ Stover 5.625 t ha^{-1} + PK	3670[abc]	7860[ab]	47
+ Stover 5.625 t ha^{-1} + PK + N (PI)	3830[ab]	8000[ab]	48
+ Stover 7.50 t ha^{-1} + PK	3770[ab]	8120[ab]	46
+ Stover 7.50 t ha^{-1} + PK + N (PI)	4070[a]	8460[a]	48
– Stover + N_0PK	2680[f]	5210[e]	51
– Stover + N_0PK + N (PI)	3230[cde]	6370[cd]	51
– Stover + N_1 PK	2780[ef]	5430[de]	51
– Stover + N_1PK + N (PI)	3260[de]	6390[cd]	51
F-test	**	**	NS
CV (%)	9.61	10.99	6.03

1. Source: Toomsan et al. (2003).
2. – Stover = Stover removed; + Stover = Stover returned; PI = At panicle initiation stage.
3. NS = Not significant; ** = Significant at P <0.01. Figures followed by the same letter(s) in a column are not significantly different.

Although the best response was obtained in the treatment with groundnut stover at 7.5 t ha^{-1} + PK (25 kg P_2O_5 + 12.5 kg K_2O ha^{-1}) + N (14.4 kg N ha^{-1}), it is often difficult for most of the farmers to get such large quantities of groundnut stover to incorporate in the field. It is therefore recommended that groundnut stover at 3.75 t ha^{-1} + PK + N (at panicle initiation stage) should be used for increasing rice growth and yields. Generally, most farmers can get the recommended quantity of groundnut biomass yield in their fields. Groundnut stover decomposes quickly as it has a high percentage of N and low C: N ratio. The released N is prone to losses through leaching and denitrification. To study this, we conducted an experiment to determine the methods and time of stover application on growth and yield of rice. The results are shown in Table 4.

Storing groundnut stover after harvest for a short period before incorporating in the field shortly before rice transplanting helps in improving better growth and yield of rice than the recommended chemical fertilizer application. Stover application prior to planting (ie, 45 days before transplanting) of rice showed slower growth and lower yield than when applied just before planting. Early stover application (45 days before transplanting) may need N fertilizer application at panicle initiation stage of rice. But storing groundnut stover and applying it shortly before rice transplanting requires storage and extra labor to store and return the stover to the field. If this is not feasible, then it is recommended that the groundnut stover can be returned to the field immediately after harvest and plowed under.

Table 4. Biomass and harvest index of rice as affected by groundnut stover removal (–S) or addition (+S) either applied on surface or incorporated at different days before rice transplanting (DBT), with and without chemical fertilizers at Kalasin, Northeast Thailand, 2000[1].

	Yield[3] (kg ha^{-1})		Harvest
Treatment[2]	Grain	Total biomass	index[3] (%)
– S – NPK (control)	2380[d]	4310[f]	56[a]
+ S 45 DBT (surface) + PK	2910[abc]	5790[de]	51[abcd]
+ S 45 DBT (surface) + N_pPK	2850[bc]	6480[abcd]	44[d]
+ S 45 DBT (incorporated) + PK	3050[abc]	6120[cd]	50[abcd]
+ S 45 DBT (incorporated) + N_pPK	3340[a]	6460[abcd]	52[abcd]
+ S 27 DBT (incorporated) + PK	3230[ab]	6940[abc]	47[bcd]
+ S 27 DBT (incorporated) + N_pPK	3340[a]	7470[ab]	45[cd]
+ S 13 DBT (incorporated) + PK	3160[abc]	6580[abcd]	49[abcd]
+ S 13 DBT (incorporated) + N_pPK	3260[ab]	6710[abcd]	49[abcd]
+ S 6 DBT (incorporated) + PK	3250[ab]	7260[ab]	45[cd]
+ S 6 DBT (incorporated) – PK	3160[abc]	6520[abcd]	48[abcd]
+ S 6 DBT (incorporated) + N_tPK	3150[abc]	6420[abcd]	49[abcd]
+ S 6 DBT (incorporated) + N_pPK	3320[a]	7550[a]	44[d]
– S + PK	2740[cd]	5050[ef]	54[ab]
– S + (N_t + N_pPK)	2940[abc]	5660[de]	52[abc]
F-test	**	**	**
CV (%)	9.0	10.5	9.4

1. Source: Srichantawong et al. (2005).
2. Nt = 25 kg N ha^{-1} at transplanting; Np = 14.4 kg N ha^{-1} at panicle initiation as urea; PK = 10.9 P and 10.4 K kg ha^{-1} at transplanting.
3. ** = Significant at P <0.01. Figures followed by the same letter(s) in a column are not significantly different.

If rice cannot be transplanted within 45 days after incorporation, N fertilizer application at panicle initiation stage is recommended. It is therefore recommended that depending upon local constraints and labor cost involved, farmers should return the groundnut stover shortly before transplanting of the rice crop (6–18 days before transplanting) to get the best results.

We also studied the effect of groundnut stover application in improving growth and yield of rice cultivar KDML 105 in 11 farmers' fields for three years (2002–04). The results revealed that growth and yield of rice grown in the plot, which was kept fallow, was poorer than those in the plot where groundnut was grown in the preceding season. Stover removal also gave lower grain yield but increased total biomass yield (Table 5). When groundnut stover was returned to the field, rice yield was high. The highest rice yield was obtained when stover was returned immediately and incorporated into soils and nitrogen fertilizer was applied at the panicle initiation stage. However, the yield obtained with this particular treatment was not significantly different from the treatment in which stover was stored for short period and returned to the field at 15 days before transplanting. However, when labor cost is taken into account, storing stover requires extra space, time and money and may not be suitable in many situations.

Table 5. Biomass and harvest index (HI) of rice as affected by different groundnut stover application methods with or without chemical fertilizer during 2002–04[1].

Treatment[2]	Yield[3] (kg ha^{-1})		Harvest index (%)
	Grain	Total biomass	
No GN crop (fallow)	3160[b]	9150[b]	35
+ GN crop, – Stover	3230[b]	9520[ab]	34
+ GN crop, + Stover (farmer practice)	3130[b]	9960[ab]	34
+ GN crop, + Stover (incorporated) + N (PI)	3970[a]	11450[a]	35
+ GN crop, + Stover (15 DBT) + N (PI)	3620[ab]	11040[ab]	35
F-test	*	*	NS[4]
CV (%)	9.20	11.0	9.14

1. Source: Groundnut Improvement Project (2006).
2. GN = Groundnut; PI = Panicle initiation stage; DBT = Days before transplanting.
3. * = Significant at P <0.05; figures followed by the same letter(s) in a column are not significantly different at P <0.05.
4. NS = Not significant.

At Wang Chai watershed, we also examined the effect of groundnut stover on growth and yield of rice in three farmers' fields during 2005. The effect of groundnut stover application on rice grain yield was not statistically different (Table 6). This could be attributed to the occurrence of blast disease in two farmers' fields (farmer 1 and farmer 2). It was also noted that the N content in the stover applied to the fields of these two farmers was higher (113 and 131 kg N ha^{-1}) than that of the third farmer (85 kg N ha^{-1}).

In Tad Fa watershed, we studied the effect of groundnut stover on growth and yield of upland rice. The growth and yield of upland rice was reduced when groundnut stover was removed from the field. Stover application increased growth and yield of the succeeding rice crop (Table 7). Stover removal of non-nod groundnut also showed reduction of rice yield. Stover application gave higher growth and yield of rice and in some cases the rice crop did not require N fertilizer application at the panicle initiation stage. Perhaps N fertilizer application at panicle initiation stage might have resulted in the occurrence of blast disease in rice.

A farmer participatory experiment to study the effect of growing groundnut on succeeding rice was initiated at Tad Fa watershed. Only one out of three farmers was able to plant upland rice after groundnut as the farmers were busy in harvesting their first maize crop and they did not have enough time to harvest groundnut and plant upland rice. Additionally, it was also a severe drought year when the experiment was conducted. During the grain-filling stage of the rice crop, there was severe shortage of water.

Table 6. Growth and yield of rice grown after groundnut with different groundnut stover management practices at Wang Chai watershed in 2005.

Treatment[1]	Yield (kg ha^{-1}) Grain	Stover	Total biomass	Harvest index[2] (%)
+ GN stover + N_0PK + N (PI)	2750	3580[a]	6330	43
+ GN stover + N_1PK	2525	2840[ab]	5690	44
+ GN stover + N_1PK + N (PI)	2594	3390[a]	5980	43
– GN stover (fallow) + N_0PK	1835	2480[b]	4240	43
F-test	NS	*	NS	NS
CV (%)	24.56	14.89	23.02	2.93

1. N_1 = 25 kg N ha^{-1} at 2 weeks after transplanting; N (PI) = 14.4 kg N ha^{-1} applied at panicle initiation stage; PK = 25 kg ha^{-1} of P_2O_5 and 12.5 kg ha^{-1} of K_2O and applied at 2 weeks after transplanting.
2. NS = Not significant; * = Significant at *P* <0.05; figures followed by the same letter in a column are not significantly different.

Table 7. Grain and biomass yield and harvest index of upland rice as affected by different groundnut stover application methods with or without chemical fertilizer at Ban Koke Mon in 2003.

Treatment[1]	Yield[2] (kg ha^{-1})		Harvest index[2] (%)
	Grain	Total biomass	
– Stover + $N_0P_0K_0$ (control)	2560^{bc}	5980^{bc}	43^{ab}
+ Stover (incorporated) + PK	3620^{ab}	8620^{ab}	42^{abc}
+ Stover (mulch) + PK	3940^{a}	9250^{a}	43^{ab}
+ Stover (incorporated) + PK + N (PI)	3750^{ab}	9840^{a}	38^{cd}
+ Stover (mulch) + PK + N (PI)	4210^{a}	9990^{a}	42^{abc}
– Stover (non-nod) + PK	2020^{c}	5600^{c}	36^{a}
– Stover + (½ N) PK	3560^{ab}	7890^{abc}	46^{a}
– Stover + NPK	3020^{abc}	7200^{abc}	42^{abc}
– Stover + (2N) PK	3480^{ab}	8570^{ab}	41^{bcd}
F-test	**	*	*
CV (%)	22.64	22.31	8.13

1. N = 25 kg N ha^{-1} applied at 15 days after planting; N (PI) =14.4 kg N ha^{-1} applied as urea at panicle initiation stage; PK = 25 kg ha^{-1} of P_2O_5 and 12.5 kg ha^{-1} K_2O applied at 2 weeks after planting.
2. * = Significant at P <0.05; ** = Significant at P <0.01; means followed by the same letter(s) in a column are not significantly different at P <0.05 by DMRT.

The growth and productivity of rice was very poor. Groundnut stover application did not increase rice growth, especially when NPK fertilizers were applied to the crop. Rice yields were very low and there were no significant differences among the various treatments (Table 8).

A good yield of upland rice after groundnut can be obtained when groundnut is planted early (end of March to early April). Also, the cultivar should mature, preferably by the end of June. Therefore, an early-maturing groundnut cultivar or boiling type groundnut should be used in the production systems. After groundnut harvest, a rice crop should be sown as soon as possible (first week of July) so that it will have enough moisture up to the grain-filling stage. This will also avoid labor conflict with maize harvesting.

Table 8. Grain and biomass yield of rice grown after groundnut with different groundnut stover management practices in a farmer's field at Ban Koke Mon in rainy season 2004.

	Yield[1] (kg ha^{-1})		
Farmer	Grain	Stover	Total biomass
– Stover, – NPK	420	1320[b]	1750[b]
– Stover, + NPK	390	1520[b]	1910[b]
+ Stover, – NPK	550	1730[b]	2280[b]
+ Stover, + NPK	550	2400[a]	2950[a]
F-test	NS	**	**
CV (%)	32.9	13.63	11.57

1. ** = Significant at *P* <0.01; NS = Not significant; means followed by the same letter in a column are not significantly different.

Maize-based System

Maize is another crop that is economically important to Thailand. In Thailand the total area under maize is about 1.09 million ha with an average yield of 3.87 t ha^{-1}, which is lower than that reported from Vietnam and China. Major maize production areas in Thailand are in the North, Northeast and central regions of the country (Center for Agricultural Information 2006). Maize production area in the Northeast is about 325,000 ha with average yield of 3.42 t ha^{-1}, which is slightly lower compared to those obtained in the North and the central parts of Thailand.

The role of legumes in improving the yield of maize has been studied by several researchers (McDonagh et al. 1993, Phoomthaisong et al. 2003). Under the ADB-ICRISAT-KKU watershed project, research was conducted on the use of groundnut stover at Tad Fa watershed, where maize is the major crop. We did not focus our effort on the use of green manure legumes in maize system because of the reasons discussed earlier. Legume crops that provide cash or economic income will fit better in the production systems practiced by small farmers with limited resources. These small farmers invest their limited resources only when they are sure of getting good returns on their investment of time and labor. Grain or edible legumes seem better alternatives. However, different legumes are known to fix different amounts of N from the air. They also have different nitrogen harvest index (NHI). Some of the legumes store most of the N in their grain and are soil exhaustive crops, while the fertility (%) NHI is lower than the proportion of N derived from air (% Ndfa). However, this is not the case with groundnut.

Our research at Khon Kaen University indicated that the amount of N fixed from the air by groundnut was higher than the amount of N removed through pods. Groundnut crop can improve the soil fertility, provided the stover is returned to the field. We compared the effect of growing mung bean and groundnut cultivars on growth and yield of maize. The crops were grown and harvested for grain and the stover was returned to the fields before maize planting. The results are summarized in Table 9.

The results showed that the total biomass and grain yield of maize grown after mung bean were lower than that grown after groundnut cultivar Tainan 9. The amount of N fixed using ^{15}N isotope dilution technique revealed that the NHI (%) of mung bean is higher than % Ndfa. Thus mung bean is a soil fertility exhaustive crop and the succeeding maize crop yield was not significantly different from that following the non-nod groundnut.

Table 9. Grain and biomass yield and harvest index of maize cultivar NS1 grown after mung bean (MB), groundnut (GN) and fallow treatments at Khon Kaen in 1999–2000[1].

Preceding crops[2]	Yield[3] (kg ha^{-1})		Harvest index[4] (%)
	Grain	Total biomass	
MB cv KPS 1	1770de	4480^{ef}	39
MB cv KPS 2	2260^{bcde}	5960^{bcdef}	38
MB cv CN 36	2650^{bcd}	6910^{bcd}	38
MB cv CN 72	1670^{e}	4280^{f}	39
MB cv UT 1	2040^{cde}	5420^{def}	38
MB cv PSU 1	2090^{cde}	5310^{def}	39
GN cv Tainan 9	3840^{a}	10980^{a}	35
GN cv Non-nod	2200^{bcde}	6510^{bcde}	34
Fallow + N_0	1570^{e}	4300^{f}	36
Fallow + N_1	1830de	5650^{cdef}	32
Fallow + N_2	3040^{ab}	7900^{b}	39
Fallow + N_3	2930^{abc}	7630^{bc}	38
F-test	**	**	NS
CV (%)	24.5	20.1	11.7

1. Source: Phoomthaisong et al. (2003).
2. N_0, N_1, N_2, N_3 = 0, 30, 60 and 90 kg N ha^{-1}.
3. ** = Significant at P <0.01; figures followed by the same letter(s) in a column are not significantly different.
4. NS = Not significant.

The groundnut cultivar Tainan 9 had higher % Ndfa than NHI (%) and thus improves the soil fertility when its stover is returned to the field. The yield of maize grown after groundnut cultivar Tainan 9 was equivalent to maize grown after fallow with the application of 60–90 kg N ha^{-1}.

A legume crop, which has higher % Ndfa than NHI (%), will be a soil fertility exhaustive crop if the stover is not returned to the field (Table 10). Thus the groundnut stover removal from the field could reduce growth and yield of maize, which is comparable to the yields obtained in fallow plot that received no N fertilizer. In treatments where the stover biomass was returned to the field, maize yields were higher even following non-nod groundnut cultivar.

Table 10. Grain and total biomass yield of maize grown after groundnut or after fallow with stover removed (– S) or returned (+ S) to the soil at Khon Kaen in 1990–91[1].

Groundnut cultivar	Grain yield (kg ha^{-1})			Total biomass (kg ha^{-1})		
	– S	+ S	Difference (%)	– S	+ S	Difference (%)
Tainan 9	1650	2730	65	3940	6420	63
KK 60-1	1980	2960	50	4700	6690	42
LK 60-2	1970	2620	33	4610	6060	32
KK 60-3	2130	3010	41	5240	7300	39
Non-nod	1740	2220	27	4070	5320	31
	–N	+N[2]	-	–N	+N	-
Fallow	1912	2723	42	4546	6394	41

1. Source: McDonagh et al. (1993).

2. N = 75 kg N ha^{-1} applied as urea.

How much groundnut stover should a farmer return to the field to get the best benefit? To answer this question, we conducted an experiment near Tad Fa watershed using different rates of groundnut stover in combination with chemical fertilizers (Table 11). Application of 7.5 t ha^{-1} of groundnut stover with P and K fertilizer at planting and top dressing of N fertilizer at tasseling stage gave the highest biomass and grain yield. However, this treatment was not significantly different from the treatment that received groundnut stover at 3.75 t ha^{-1}. This quantity of stover (3.75 t ha^{-1}) should be available for application by farmers and therefore is recommended for sustaining maize yields.

A farmer participatory experiment on the effect of groundnut on the succeeding maize crop was initiated at Tad Fa watershed in 2004. Due to drought year, only one farmer was able to plant maize after groundnut. Most of the farmers got very poor yields (Table 12).

Table 11. Grain and biomass yield and harvest index of maize grown after groundnut with various rates of stover returned with or without chemical fertilizer at Ban Koke Mon in 2005.

Treatment[1]	Yield (kg ha^{-1}) Grain	Yield (kg ha^{-1}) Total biomass	Harvest index[2] (%)
– Stover + $N_0P_0K_0$	2230[e]	6720[e]	34[bc]
+ 1.88 t ha^{-1} Stover + PK	2750[de]	7020[e]	38[a]
+ 1.88 t ha^{-1} Stover + PK + N top dress	3980[ab]	9740[bcd]	40[a]
+ 3.75 t ha^{-1} Stover + PK	3210[cd]	8300[cde]	39[a]
+ 3.75 t ha^{-1} Stover + PK + N top dress	4050[ab]	10120[ab]	41[a]
+ 5.63 t ha^{-1} Stover + PK	3870[abc]	9820[bc]	40[a]
+ 5.65 t ha^{-1} Stover + PK + N top dress	3970[ab]	9880[bc]	40[a]
+ 7.5 t ha^{-1} Stover + PK	3570[bc]	9310[bcd]	38[ab]
+ 7.5 t ha^{-1} Stover + PK + N top dress	4410[a]	11790[a]	38[ab]
– Stover + N_0PK	2370[e]	7980[de]	30[c]
– Stover + N_1PK	3770[abe]	10000[abc]	38[a]
– Stover + N_1PK + N top dress	4110[ab]	10780[ab]	38[a]
F-test	**	**	**
CV (%)	14.91	13.56	8.56

1. N_1 = 25 kg N ha^{-1} at 2 weeks after transplanting; N top dress = 31.3 kg N ha^{-1} as urea; PK = 47 kg ha^{-1} each of P_2O_5 and K_2O applied at 2 weeks after planting.
2. ** = Significant at *P* <0.01; figures followed by the same letter(s) in a column are not significantly different.

Table 12. Performance of maize grown after groundnut in a farmer's field at Ban Koke Mon in the rainy season 2004.

Treatment	Yield[1] (kg ha^{-1}) Grain	Cob	Stover	Total
+ Stover, + NPK	1520	290[a]	1840[a]	3660[a]
– Stover, + NPK	990	165[b]	1340[b]	2500[b]
F-test	NS	**	*	*
CV (%)	19.37	13.04	11.30	10.77[b]

1. NS = Not significant; * = Significant at *P* <0.05; ** = Significant at *P* <0.01; figures followed by the same letter(s) in a column are not significantly different.

At Tad Fa watershed, we also studied the effects of some green manure and grain legumes, which were grown during August to December 1999, on the growth and yield of maize crop in the 2000 wet season. In this experiment green manure legumes were grown up to maturity and the grain legumes were harvested for grain. The crops were harvested and their residues were kept and applied to the field before planting of the maize crop. The results are shown in Tables 13 and 14.

Table 13. Performance of maize grown after five leguminous crops at Ban Koke Mon in the rainy season 2000.

	Yield[1] ($kg\ ha^{-1}$)			
Treatment	Grain	Cob	Stover	Total
Ricebean	820	4540[a]	7070	12420
Sunnhemp	790	4720[a]	6630	12140
Sword bean	660	3640[b]	6670	10990
Black gram	870	4490[a]	6790	12150
Maize	700	3520[b]	5560	9780
F-test	NS	*	NS	NS
CV (%)	14.41	13.36	14.57	13.13

1. NS = Not significant; * = Significant at P <0.05; figures followed by the same letter in a column are not significantly different.

Table 14. Nitrogen fixed and benefit realized from legumes in maize-based system at Ban Koke Mon, Tad Fa watershed in 2000.

Preceding crop	N_2 fixed ($kg\ ha^{-1}$)	Expected net N benefit[1] ($kg\ ha^{-1}$)	Total N uptake by succeeding maize ($kg\ ha^{-1}$)	N benefit realized from legume over maize[2] ($kg\ ha^{-1}$)	Expected benefit from BNF + N saving benefit ($kg\ ha^{-1}$)
Ricebean	20	2	75.9	19.1	15
Sunnhemp	90	31	76.1	19.3	44
Sword bean	104	51	62.1	5.3	64
Black gram	27	8	68.9	12.1	21
Maize	-	–13	56.8	-	-

1. N_2 fixed – Grain N.

2. Total uptake by succeeding maize – Total N uptake by maize grown after maize.

We evaluated the amount of N_2 fixed by preceding crops using the N difference method; the amount of N fixed varied from 20 to 104 kg N ha^{-1} and the net N benefit to the succeeding crop was estimated at 2 to 51 kg N ha^{-1} (Table 14). Maize crop was grown after legumes with 40 kg N ha^{-1} along with the organic matter from legume residues. Grain yield of the succeeding maize crop was significantly ($P \leq 0.05$) higher by 27 to 34% in treatments following black gram, ricebean and sunnhemp over the yield of maize in control treatment (Table 13). Although N_2 fixation was highest in sword bean (104 kg N ha^{-1}), N benefit expected (51 kg N ha^{-1}) was not realized in increased maize yield. These results demonstrated that it is not only the quantity of N_2 fixed that determines the benefit to the succeeding crop but also the quality of organic matter and N release pattern from the legume residue. However, in the long-term sword bean could play an important role for improving the soil fertility.

Growing black gram, ricebean and sunnhemp in the system would help in reducing N requirement for the succeeding maize crop. In addition, in the long-term it is expected to improve soil physical properties such as structure. The actual realized benefit from legumes in terms of increased N uptake by the succeeding maize crop varied from 5.3 to 19.3 kg N ha^{-1} whereas the expected benefit from legume through biological nitrogen fixation (BNF) and soil N sparing effect on the maize crop varied from 15 to 64 kg N ha^{-1} (Table 14). In conclusion, growing legumes such as ricebean, sunnhemp and black gram benefits the succeeding maize crop substantially. In the long-term it is expected to also improve the soil structure.

Sugarcane-based System

Sugarcane is also one of the important economic field crops in Thailand and the country is one of the major sugar exporters of the world. In 2005, it exported 3.04 million t sugar, which was worth 28,362 million bahts (US$ 777.04 million) (Center for Agricultural Information 2006). In Thailand the total area under sugarcane is about 1.17 million ha with average yield of 57.94 t ha^{-1}. Sugarcane is grown mainly in the Northeast, Central and Northern parts of Thailand. Sugar factories are shifting from the central to northeast parts of the country due to availability of good quality sugarcane and cheap labor. Consequently the area under sugarcane cultivation in Northeast region is increasing fast.

Sugarcane area in the Northeast is about 0.443 million ha with average yield of 57.24 t ha^{-1}, which is only slightly lower than the national average. In the northeast, sugarcane is grown either at the beginning of rainy season (starting in March) or at the end of the rainy season (October–November).

Only one or two ratoon crops can be grown after the harvest. Low soil fertility and erratic rainfall are the main reasons for low sugarcane yield and also for fewer ratoon crops.

Sugarcane yield can be substantially increased with the application of chemical fertilizers. However, chemical fertilizers are expensive and not affordable for many poor farmers. Alternate ways to reduce the use of chemical fertilizers needs to be worked out. Incorporating legumes in the cropping system seems to be one of the alternatives.

Sugarcane crushing season in the Northeast starts in December and continues until April in the succeeding year. Sugarcane sown in March is harvested when it is 8–10 months old while that sown in October is harvested after 14 months. Maximum of two ratoon crops could be obtained in the region. In most cases only one ratoon crop can be harvested. If the next sugarcane crop has to be grown in early rainy season (starting in March) there will be a fallow period of 2–4 months. During this fallow period, hardly any crop can be grown due to the lack of soil moisture. However, if the next sugarcane crop is to be grown next October, then there should be a gap of 6–8 months so that the soil has good moisture availability. Introducing legumes during this gap period in the sugarcane-based system seems to be logical. The legumes could be green manure or grain legumes. Many green manure legumes have been recommended by the Department of Agriculture, particularly sunnhemp (*Crotalaria juncea*) and sword bean (*Canavalia gladiata*). Recently, local leguminous weeds such as hairy indigo (*Indigofera hirsuta*) and *Crotalaria striata* were also evaluated for their potential as a green manure crop.

It is observed that during the gap period between the previous sugarcane harvest and the next sugarcane planting in October, some farmers grow or allow other farmers to grow groundnut in their fields free of charge on the condition that groundnut stover is left in the field. In view of this practice, a study was undertaken to examine the effects of cultivating pigeonpea, sunnhemp, groundnut, soybean, hairy indigo and maize on the succeeding sugarcane crop.

Two experiments were conducted at Wang Chai watershed to evaluate growth and yield of these six crops and their residual N benefits to the succeeding sugarcane grown in October. The first experiment was initiated in July 2003 while the second experiment started in June 2004. The biomass yield of different preceding crops and nutrient content in the stover are shown in Table 15. Maize, which received NPK fertilizers, gave the highest yield of grain, stover and total biomass. Only maize, soybean and groundnut gave economic yields. Soybean had the lowest grain yield because of poor nodulation (due to failure of *Rhizobium* inoculation). The N, P, K and Ca contents of the stover was highest in hairy indigo. Nitrogen content in different plant residues varied, with the highest in hairy indigo (122 kg N ha^{-1}) and the lowest in maize (18 kg N ha^{-1}) while P content ranged between 7 and 32 kg ha^{-1}, K ranged between 28 and 102 kg ha^{-1} and Ca ranged between 15 and 79 kg ha^{-1}.

Sugarcane cultivar Khon Kaen 1 was grown after the stover incorporation into the soil. All treatments received P and K fertilizers at 47 kg ha^{-1} each of P_2O_5 and K_2O, respectively at the time of sugarcane planting with the exception of treatment 7, which received N fertilizer at 47 kg N ha^{-1} in addition to the N applied at the time of planting (N_1). NPK fertilizers at 47 kg ha^{-1} each of N, P_2O_5 and K_2O were applied uniformly to all treatments at seven months after planting except in treatment 7, which received only P and K fertilizers at 47 kg ha^{-1} each of P_2O_5 and K_2O. There was no significant difference between treatments in all parameters measured. Millable cane weight was 43.19–50.81 t ha^{-1} and commercial cane sugar (CCS) was 13.75–14.00. This indicated that the N in the stover can supplement N requirement of sugarcane during the first six months of crop growth (Table 16).

Table 15. Total biomass yields and nutrient contents in the stover of different preceding crops grown before sugarcane at Ban Wang Chai in 2003 (experiment 1)[1].

Treatment	Yield (kg ha^{-1}) Pod/grain	Yield (kg ha^{-1}) Stover	Total biomass	Nutrient content (kg ha^{-1}) N	P	K	Ca
Groundnut	1780	4390^{c}	6170^{a}	71^{bc}	10^{b}	52^{b}	79^{a}
Soybean	420	1990^{e}	2410^{c}	33^{d}	9^{b}	28^{c}	22^{b}
Pigeonpea	-	4020^{bcd}	4020^{b}	86^{b}	11^{b}	30^{c}	39^{b}
Sunnhemp	-	3400^{bc}	3400^{bc}	43^{cd}	8^{b}	42^{bc}	26^{b}
Maize + NPK[2]	1880	6390^{a}	8270^{a}	18^{d}	7^{b}	33^{c}	15^{b}
Hairy indigo	-	6030^{a}	6030^{a}	122^{a}	32^{a}	102^{a}	77^{a}
Fallow	-	2620^{bc}	2620^{bc}	48^{cd}	7^{b}	32^{c}	30^{b}
Fallow	-	2950^{bc}	2950^{bc}	43^{cd}	8^{b}	42^{bc}	25^{b}
F-test	-	**	**	**	**	**	**
CV (%)	-	25.93	28.72	33.14	25.91	22.91	38.87

1. ** = Significant at $P < 0.01$; figures followed by the same letter(s) in a column are not significantly different.

2. Fertilizer at 47 kg ha^{-1} each of N, P_2O_5 and K_2O.

Table 16. Number of millable canes, cane height, cane diameter, millable cane weight and commercial cane sugar (CCS) of sugarcane cultivar Khon Kaen 1 grown after different preceding crops at final harvest in January 2005 (experiment 1).

Treatment[1]	Millable cane (no. ha^{-1})	Cane height (cm)	Cane diameter (cm)	Millable cane weight (t ha^{-1})	CCS	Sugar yield (kg ha^{-1})
(1) Groundnut + N_2	48,000	275	2.40	49.93	13.87	6,930
(2) Soybean + N_2	43,500	288	2.50	50.46	13.86	6,960
(3) Pigeonpea + N_2	44,833	270	2.40	43.80	13.88	6,040
(4) Sunnhemp + N_2	46,833	287	2.50	50.81	14.00	7,140
(5) Maize + N_2	51,667	243	2.40	54.44	13.88	7,570
(6) Hairy indigo + N_2	46,333	277	2.50	48.06	13.75	6,560
(7) Fallow + N_1	43,000	286	2.60	44.49	13.79	5,980
(8) Fallow + N_2	42,167	270	2.60	43.19	13.78	6,120
F-test	NS[2]	NS	NS	NS	NS	NS
CV (%)	16.06	4.52	5.36	24.40	2.85	24.88

1. N_1 = 47 kg N ha^{-1} applied at planting of sugarcane; N_2 = 47 kg N ha^{-1} applied when sugarcane was 7 months old.

2. NS = Not significant.

After sugarcane harvest, the ratoon cane was allowed to grow. Since it was a dry year, ratoon cane was not fertilized until 6 months after sugarcane harvest. The N, P and K fertilizers were applied to all treatments at 47 kg ha^{-1} each of N, P_2O_5 and K_2O, respectively. The last treatment received the same amount of NPK again one month later (ie, 7 months after sugarcane cutting). The growth and yield of the ratoon cane are shown in Table 17. The results indicate that there are significant differences in cane diameter and number of millable canes per hectare. However, cane height, millable cane weight, CCS and sugar yields were not statistically different. This indicates that the beneficial effect of plant stover did not carry through to the ratoon cane.

A second experiment was conducted in 2004 at Wang Chai watershed. The preceding crop treatments were the same as in the first experiment. Growth and yields of preceding crops are shown in Table 18. It was found that groundnut is suitable at this site; its growth and yield was similar to that in 2003. However in the 2004 season, soybean gave better yield (2.3 t ha^{-1}) than in 2003. This was partially due to good nodulation after proper *Rhizobium* inoculation. Sunnhemp did not perform well in 2004 due to severe waterlogged conditions. Nutrient contents in the stover varied with crops. Sunnhemp and maize had low nutrient contents due to low biomass yield. It should be noted that maize did not receive any N fertilizer in the 2004 experiment.

Table 17. Height, diameter, number and fresh weight of millable cane, commercial cane sugar (CCS) and sugar yield of the first ratoon cane (cultivar Khon Kaen 1) grown after different preceding crops (ratoon cane)[1].

Treatment	Height (m)	Diameter (cm)	Millable cane (no. ha^{-1})	Fresh weight (t ha^{-1})	CCS	Sugar yield (kg ha^{-1})
Groundnut (KK 1)	2.17	2.53^{ab}	52056^{ab}	37.2	14.69	5470
Soybean (SJ 5)	2.31	2.64^{a}	48944^{ab}	40.5	14.41	5860
Pigeonpea	2.33	2.58^{ab}	56664^{a}	43.0	14.61	6270
Sunnhemp	2.24	2.55^{ab}	42726^{b}	31.6	13.96	4450
Maize (NS 72)	2.24	2.51^{ab}	49444^{ab}	38.9	14.62	4940
Hairy indigo	2.19	2.57^{ab}	48836^{ab}	37.0	14.66	5360
Fallow	2.17	2.46^{b}	53388^{ab}	34.5	15.00	5170
Fallow + N	2.33	2.48^{b}	52889^{ab}	41.1	15.08	6180
F-test	NS	*	*	NS	NS	NS
CV (%)	6.88	3.42	13.96	21.20	4.97	20.75

1. NS = Not significant; ** = Significant at P <0.01; figures followed by the same letter(s) in a column are not significantly different.

Sugarcane cultivar Khon Kaen 1 was grown after stover incorporation in late October. P and K fertilizers were applied to all treatments at the rate of 47 kg ha^{-1} each of P_2O_5 and K_2O, at the time of sugarcane planting except treatment 7, which received 47 kg N ha^{-1} in addition to P and K fertilizers. At six months after planting, N, P and K fertilizers were applied to all treatments at the rate of 47 kg ha^{-1} of N, P_2O_5 and K_2O, with the exception of treatment 8 which received only P and K fertilizers. The crops were harvested in the beginning of January 2006.

Significant differences between the various treatments in all measured parameters for sugarcane were recorded (Table 19). Sugarcane grown in fallow plot, which did not receive N fertilizer, gave the lowest growth and yield than other treatments. Amongst the treatments, where biomass from the preceding crops was returned to the field, highest sugarcane fresh weight (56.69 t ha^{-1}) was obtained in groundnut treatment, which was significantly higher than soybean treatment. Results clearly show the beneficial effect of legumes in increasing sugarcane yield. Although sunnhemp produced low biomass and had low nutrient contents in the stover, it positively influenced sugarcane yield. This could be due to the fact that sunnhemp suffered from the high water content during late rainy season, which resulted in leaf fall and decay of plants much before the final harvest. This might have released mineral N for use by the sugarcane crop.

Table 18. Pod/grain/pod yield, biomass and nutrient contents in the stover of different preceding crops grown before sugarcane at Ban Wang Chai in 2004 (experiment 2).

	Yield[1] (kg ha^{-1})			Nutrient content (kg ha^{-1})			
Treatment	Pod/grain	Stover	Total biomass	N	P	K	Ca
Groundnut	1750	2500[c]	4250[bc]	48	8	46	51
Soybean	2280	2180[c]	4460[b]	48	16	111	67
Pigeonpea	–	5100[b]	5100[b]	83	14	56	26
Sunnhemp	330	440[d]	770[e]	3	1	7	2
Maize	480	1660[cd]	2130[d]	3	4	19	4
Hairy indigo	–	2910[c]	2910[cd]	58	9	44	43
Fallow	–	8740[a]	8740[a]	29	15	90	22
F-test	–	**	**	–	–	–	–
CV (%)	–	21.18	19.75	–	–	–	–

1. ** = Significant at *P* <0.01; figures followed by the same letter(s) in a column are not significantly different.

Table 19. Height, diameter, number and fresh weight of millable cane, commercial cane sugar (CCS) and sugar yield of sugar cane (cultivar Khon Kaen 1) grown after different preceding crops (experiment 2)[1].

Treatment	Height (m)	Diameter (cm)	Millable cane (no. ha^{-1})	Fresh weight (t ha^{-1})	CCS	Sugar yield (kg ha^{-1})
(1) Groundnut (KK 1)	2.65[bc]	2.70[a]	51350[ab]	56.7[a]	14.60	8280[a]
(2) Soybean (SJ 5)	2.64[bc]	2.58[ab]	51250[ab]	46.9[bc]	13.43	6290[ab]
(3) Pigeonpea	2.57[c]	2.56[ab]	53020[a]	52.6[ab]	14.82	7800[ab]
(4) Sunnhemp	2.91[a]	2.67[a]	47710[abc]	56.1[ab]	15.34	8610[a]
(5) Maize (NS 72)	2.65[bc]	2.55[ab]	49480[abc]	48.6[abc]	13.31	6470[ab]
(6) Hairy indigo	2.66[bc]	2.64[ab]	49580[abc]	54.7[ab]	14.50	7930[ab]
(7) Fallow + NPK	2.83[ab]	2.40[b]	45100[abc]	48.6[abc]	13.83	6730[ab]
(8) Fallow + PK	2.50[c]	2.51[ab]	43440[c]	39.2[c]	14.05	5520[b]
F-test	**	*	*	*	**	*
CV (%)	4.89	6.85	6.85	9.43	4.89	22.39

1. * = Significant at *P* <0.05; * = Significant at *P* <0.01. Figures followed by the same letter(s) are not significantly different.

Economic analysis was made for different treatments in both experiments 1 and 2 and the results are summarized in Tables 20 and 21. The analysis in experiment 1 involves three crops, ie, preceding crops, first sugarcane crop and ratoon sugarcane crop, while in experiment 2 there were only preceding crops and the first harvest of sugarcane crop.

Table 20. Net profit from growing different preceding crops and followed by sugarcane cultivar Khon Kaen 1 (plant cane and ratoon cane) in experiment 1 (2003–06).

	Net profit (US$ ha^{-1})			
Treatment	Preceding crops	First sugarcane	Ratoon sugarcane	Total
Groundnut	61.6 (142.8)	299	370	732.3
Soybean	–338.5	330	460	450.1
Pigeonpea	–452.9	148	520	211.8
Sunnhemp	–448.6	339	210	100.0
Maize	–440.5	416	420	399.9
Hairy indigo	–437.5	250	370	185.7
Fallow 1	-	166	307	473.1
Fallow 2	-	132	460	590.5

Table 21. Net income from growing different preceding crops and followed by sugarcane cultivar Khon Kaen 1 (plant cane) in experiment 2 (2004–06).

	Net income (US$ ha^{-1})		
Treatment	Preceding crop	First sugarcane harvest	Total
Groundnut	50.1	531.7	581.8
Soybean	220.8	185.0	405.8
Pigeonpea	–452.9	429.4	–23.5
Sunnhemp	–249.1	552.4	303.3
Maize	–481.1	228.9	–252.2
Hairy indigo	–437.5	473.7	36.2
Fallow 1	-	235.3	235.3
Fallow 2	-	76.8	76.8

Economic analysis of preceding crops in experiment 1 shows that only groundnut gave positive net profit while other preceding crops gave negative net profit. Groundnut gave net profit of US$ 61.6 ha^{-1} when sold as dry pod at US$ 0.4 kg^{-1} and net profit of US$ 142.8 ha^{-1} when sold as boiled groundnut pod at US$ 2.7 kg^{-1} (Table 20). Soybean and maize had economic yield but gave negative profit because of low yield in the case of soybean and low selling price in the case of maize. Pigeonpea, sunnhemp and hairy indigo did not give economic yield and therefore the net profits were negative ranging from US$ –437.5 to US$ –452.9 ha^{-1}. The reason for the negative net profit of green manure legumes was that they received the same crop management as groundnut, soybean and maize but they did not produce any grain.

Economic analysis of first harvest of sugarcane shows that all treatments gave positive net income ranging from US$ 132.7 to US$ 416.4 ha^{-1}. The highest net profit was obtained with maize treatment (US$ 416.4 ha^{-1}) and the lowest in fallow 2 treatment (US$ 132.7 ha^{-1}). Treatment with groundnut gave net income of US$ 299.3 ha^{-1}, which was lower than that from sunnhemp and soybean, but greater than that from pigeonpea and hairy indigo.

In ratoon sugarcane, the highest net profit was observed in pigeonpea treatment (US$ 517.1 ha^{-1}) and lowest in the case of sunnhemp (US$ 209.0 ha^{-1}). Groundnut gave net income of US$ 371.3 ha^{-1}, which was similar to hairy indigo, but lower than pigeonpea, soybean, fallow 2 and maize, and greater than those in sunnhemp and fallow 1.

When the net profit from all the three crops were added, groundnut gave the highest net profit (US$ 732.3 ha^{-1} when sold as dry pod and US$ 813.5 ha^{-1} as fresh pod for boiling) followed by fallow 2 (US$ 90.5 ha^{-1}), fallow 1 (US$ 473.1 ha^{-1}), soybean (US$ 450.1 ha^{-1}), maize (US$ 399.9 ha^{-1}), pigeonpea (US$ 211.8 ha^{-1}), hairy indigo (US$ 185.7 ha^{-1}) and sunnhemp (US$ 100 ha^{-1}). Results show that groundnut can provide economic return to the farmers in addition to providing residues rich in nutrients for soil application. The green manure legumes did not give economic yield and this was the main reason for negative net profit, which resulted in lower total net profit where these crops were involved.

Economic analysis of the preceding crops and the first harvest of sugarcane in experiment 2 showed that among the preceding crops, only groundnut and soybean gave positive net income (Table 21). The net income involving groundnut in the system was US$ 50.1 ha^{-1} when sold as dry pod and US$ 130 ha^{-1} when sold as boiling type groundnut. Soybean in this experiment gave very high yield of 2.3 t ha^{-1} and therefore had a positive net income of US$ 220.8 ha^{-1}, which was contradictory to the results obtained in experiment 1. Good nodulation by proper *Rhizobium* inoculation was the main reason for high grain yield. The rest of the preceding crops gave negative net income ranging from US$ –249.1 to US$ –481.1 ha^{-1}. Economic analysis of first sugarcane harvest shows that all treatments gave positive net profit. Maximum net income was obtained in sunnhemp (US$ 552.4 ha^{-1}) followed by groundnut, hairy indigo, pigeonpea, fallow 1, maize, soybean and fallow 2. Total system net profit was the highest in groundnut treatment (US$ 581.8 ha^{-1}) when sold as dry pod (US$ 661.8

ha^{-1}) and when sold as boiling groundnut, followed by soybean (US$ 405.8 ha^{-1}), sunnhemp (US$ 303.3 ha^{-1}), fallow 1, (US$ 235.3 ha^{-1}), fallow 2 (US$ 76.8 ha^{-1}) and hairy indigo (US$ 36.2 ha^{-1}). Maize and pigeonpea gave negative net profit of US$ –252.2 ha^{-1} and US$ –23.5 ha^{-1}.

The results from the second experiment further strengthened the view that the crops grown before sugarcane should be legumes. The legumes should be able to produce grain or economic return to compensate the cost of production. Groundnut seems to be the best crop for the sugarcane system; and if properly inoculated with *Rhizobium,* soybean can also be considered. But it should be noted that soybean stover did not have high nutrients content. Contrary to this, groundnut did not have a lot of leaf fall at maturity and therefore its stover was rich in nutrient contents. This makes it suitable for both soil improvement and increasing the sugarcane yield. The other green manure legumes had high biomass yield but were not economical. Such problems can be solved by lowering their production cost and making them attractive to the small farmers.

Conclusion

Our studies clearly showed that legumes can help to improve the soil fertility and increase the yield of succeeding crops. The effects of legumes were investigated on three main crops, ie, rice, maize and sugarcane. Some of the conclusions from these studies are given below.

Rice-based system

1. Both green manure and grain legume crops have been investigated and were found to increase the rice yield. However, our research work focused mainly on the use of grain legumes to improve crop yield because they can provide economic returns to the small farmers.
2. Among the grain legumes, groundnut seems to be best suited for the rice-based cropping system. The crop not only provides economic returns to the farmers, but also helps in improving the soil fertility. The amount of N_2 fixed by groundnut exceeded the amount of N contained in economic yield. Therefore, it should be able to help improve soil fertility when its stover is returned to the field after final harvest.
3. Groundnut stover removal resulted in a reduction in rice yield while returning the stover to the soil increased the yield.

4. Groundnut stover should be returned to the field immediately after groundnut harvest and plowed. Rice should be transplanted within 45 days after incorporation. If it is not possible, N fertilizer application (14.4 kg N ha^{-1}) during panicle initiation stage is recommended.

5. Groundnut stover application can also increase the yield of upland rice. However, blast disease may be a problem in mountainous areas where the soils are more fertile. Growing upland rice after groundnut may be difficult, because it needs to be done in shorter span of time and would face competition for labor with other crops. Rice also faces moisture stress at the grain-filling stage.

Maize-based system

1. Groundnut performed better in increasing maize yield than mung bean. This was mainly due to the higher amount of N_2 fixed by groundnut than the amount of N removed through its pods. In the case of mung bean, it was vice-versa.

2. Returning groundnut stover to the field could increase maize yield equivalent to the application of 75 kg N ha^{-1}.

3. Groundnut stover application at 3.75 t ha^{-1} plus application of N fertilizer (31.3 kg N ha^{-1}) at tasseling stage can give maize yield equivalent to the application of N fertilizers at the recommended rates (56.3 kg N ha^{-1}).

4. The quality of green manure legumes was found to be quite different, especially when they were harvested at maturity. The quality and quantity both needs to be taken into consideration when we want to use them as green manure to improve maize yield. A good quality stover should release the nutrient to match with the plant N requirement.

Sugarcane-based system

1. Groundnut has been found to be a profitable crop in sugarcane system.

2. Groundnut gave higher profit than other legumes or crops because it can produce economic yield, which can compensate for its production cost.

3. Green manure crops can compete with groundnut only when their production costs are low.

4. Groundnut should be planted early, so that there is enough moisture at the time of sugarcane planting.

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