Nitrogen Fixation of Soybean and Groundnut in the Mekong Delta, Vietnam

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Abstract

Rice is the major crop of the Mekong Delta (MD) of Vietnam with legumes, groundnut (*Arachis hypogaea*) and soybean (*Glycine max*) cultivated in sequence with the rice in some areas. As part of a country-wide study to determine the current use and potential benefits of rhizobial inoculation in Vietnam, we conducted surveys of commercial groundnut and soybean crops and six inoculation experiments in the MD. The surveys were conducted in winter-spring 1999–2000 and summer-autumn 2000 (groundnut in Long An province) and spring-summer 2000 and 2001 (soybean in Dong Thap, Vinh Long and Can Tho provinces). All farmer crops in the surveys were nodulated and fixed N (means of 50% Ndfa for groundnut and 70% for soybean), even though none of the crops were inoculated. All crops were fertilised with N at high rates (range 35–165 kg/ha, with averages of 70 kg/ha (groundnut) and 108 kg/ha (soybean)). The six inoculation/fertiliser experiments showed that both legumes responded to inoculation by producing more abundant nodulation and higher pod or grain yields. Pod yield benefits were as much as 1.5 t/ha for groundnut and 0.5–0.6 t/ha for soybean. For both species, the optimum fertiliser mixture plus inoculation produced the greatest economic returns. Farmers could clearly improve profitability by reducing fertiliser N inputs from the current rates of 50–150 kg/ha to 'starter' rates of <20 kg/ha and inoculating with high-quality rhizobial inoculants.

THE MEKONG DELTA (MD) occupies 2.9 million ha (12% of the Vietnam's total land area) and is one of the two principal areas of rice production of Vietnam. The weather in the MD is determined by two seasons—the rainy season from May to October followed by the dry season from November to April. Annual rainfall is 1200–2400 mm and mean temperatures are high (25–29°C). About 35% of the MD is alluvial soil, covering 1.1 million ha along the rivers with most of the remainder acid sulfate clay soil (1.6 million ha). Both the acid and alluvial soils are deficient in phosphorus (P) since P generally reacts with aluminium and iron under low pH conditions and forms insoluble compounds (Thanh et al. 1997).

Paddy rice dominates the MD with an average yield of 4.1 t/ha. Soybean is grown on 9100 ha with an average yield of 2.2 t/ha and groundnut is similarly cultivated on 9900 ha with an average yield of 1.5 t/ha (General Statistical Office 2000). Paddy rice is either monocultured or rotated with legumes (soy-bean, groundnut, mungbean), vegetables, or other cereals (sweet potato, corn). To obtain the high rice and other crop yields, large amounts of fertiliser N are applied, e.g. 100–150 kg N/ha for rice, 100–120 kg N/ha for soybean and 80–100 kg N/ha for groundnut. Soybean and groundnut have been cultivated in the MD in rice rotations in order to improve soil N fertility and soil structure. Several cultural techniques have been developed to produce high soybean yields in MD (Duong et al. 1984a,b, 1992; Hiep and Huy 1999).

We report in this paper results of surveys of farmers' crops of soybean in the Dong Thap, Can Tho and Vinh Long provinces of the MD and groundnut in the Long An province. The aims of the surveys were to quantify N_2 fixation activity of the commercial crops and to identify factors either contributing to (e.g. rhizobial inoculation, optimum fertiliser management) or depressing N_2 fixation and yield (e.g. poor agronomy). Of particular importance was data on farmer use of and atitudes to rhizobial inoculants. The second part of this paper reports

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results of four field experiments involving soybean and two experiments with groundnut, all in the MD, to assess the effects of inoculation and fertiliser N on nodulation, N_2 fixation and yield of the two species.

Materials and Methods

Surveys

The groundnut surveys were conducted during winter-spring 1999–2000 (W-S) and summer-autumn 2000 (S-A) in the Duc Hoa district, Long An province, about 85 km from Ho Chi Minh City. Ten farmers' fields were involved in each survey. The soybean surveys were in spring-summer 2000 (20 fields) and spring-summer 2001 in the Dong Thap, Vinh Long and Can Tho provinces.

Data were collected on cultural practices (fertiliser applications, plant cultivars, cropping sequences), soil (pH, organic C, soil type (% sand, % silt, % clay) and plant traits (nodulation scores, shoot dry matter (DM), grain and pod yield, shoot N and $\delta^{15}N$). Non N_2-fixing reference plants (weeds) were collected for $\delta^{15}N$ analysis. Procedures for soil and plant sampling and analysis and for %Ndfa estimations can be found in Lien Hoa et al. (these Proceedings). The B values for groundnut and soybean were –1.87‰ and –2.50‰, respectively (Peoples et al. 1989).

On-farm experiments

Two on-farm inoculation experiments involving groundnut were conducted in Long An province during winter-spring 2000–2001. These were followed by four soybean inoculation experiments during spring-summer 2001 in Dong thap and Vinh Long provinces. Treatments, common to all experiments, were as follows:

1. Farmers' practice without fertiliser N (FP0N);
2. Farmers' practice with fertiliser N (FP+N);
3. Farmers' practice without N + inoculation with foreign strain (NC92 for groundnut and CB1809 for soybean) (FP+NC92, FP+CB1809);
4. Farmers' practice without N + inoculation with local strain (FP+local strain);
5. Optimum fertiliser formula + inoculation with foreign strain (OP+NC92, OP+CB1809).

Peat-based inoculants were applied at sowing as seed coatings for both soybean and groundnut. The experimental design was a randomised complete block with 4 replications. Plot size was 4 m × 5 m; plants were spaced at 10 cm intervals in 40 cm rows (soybean) or at 20 cm intervals in 20 cm rows (groundnut).

Measurements were made of soil parameters, pH, %C, total N, total P_2O_5, available P, and exchangeable K. Crop parameters measured were nodulation score, nodule dry weight, shoot (soybean) DM, N and $\delta^{15}N$, pod yield (groundnut) and grain yield (soybean).

Results and Discussion

Farmers' field surveys

Soil, agronomic and plant data

Data from the farmer crop surveys of groundnut and soybean are summarised in Tables 2 and 3. The groundnut fields were acidic (means of 4.68 and 4.76 for the W-S and S-A surveys, respectively) (Table 2). Organic C levels were low, although variable. The soils were sandy loams, with very little clay (<12%) and were characterised as having poor nutrient retention and being prone to leaching. As a consequence of these traits, the farmers routinely apply large quantities of coconut ash, which also acts as an effective source of K (Duong et al. 1992). Average rates of application were 3.9 and 4.4 t/ha for the two seasons, with individual fields receiving as much as 6 t/ha.

Inorganic fertiliser applications involved N, P and K with farmers applying 30–70% more to the W-S crops than to those grown in S-A. Winter-spring is the main groundnut season and higher yields are expected. Thus, higher inputs of nutrients are required. Additionally, farmers consider that the residues of the W-S groundnut would supply some of the nutrients of the following S-A crop. Rates of N, P and K applied to individual fields varied substantially, i.e. >10-fold. For example, N rates varied between 35 and 165 kg/ha with averages of 82 kg N/ha for the W-S season and 58 kg N/ha for S-A.

Table 1. Fertilisers applied in groundnut and soybean inoculation experiments (kg/ha).

Treatments	Groundnut	Soybean
1	2000 coconut ash	$0N + 40P_2O_5 + 30K_2O$
2	2000 coconut ash + 100N	$100N + 40P_2O_5 + 30K_2O$
3	2000 coconut ash	$0N + 40P_2O_5 + 30K_2O$
4	2000 coconut ash	$0N + 40P_2O_5 + 30K_2O$
5	$20N + 40P_2O_5 + 60K_2O + 200CaCO_3$	$20N + 40P_2O_5 + 30K_2O$

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Table 2. A summary of data from the farmer' field surveys of winter-spring 1999–2000 and summer-autumn 2000 groundnut in Long An province of the Mekong Delta, Vietnam.

Data	Factor	Winter-spring 1999/2000		Summer-autumn 2000	
		Mean	Range	Mean	Range
Soil	pH (soil:water, 1:2.5)	4.68	4.29–5.23	4.76	4.47–5.42
	Organic C (%)	0.88	0.56–1.20	0.76	0.46–1.16
	Sand (%)	58	36–68	67	53–80
	Silt (%)	36	26–54	29	20–43
	Clay (%)	6	2–11	4	0.6–12
Agronomy	Crop area (m^2)	5000	1500–10,000	2830	1000–7000
	N applied (kg/ha)	82	40–165	58	35–80
	P_2O_5 applied (kg/ha)	118	20–200	90	50–130
	K_2O applied (kg/ha)	73	15–200	43	0–80
	Coconut ash (kg/ha)	3900	0–6000	4350	3250–5000
	Cropping system	R-R-G/R-G		R-G-G	
Plant	Shoot DM (t/ha)	5.54	4.38–6.30	5.65	4.26–8.42
	Nodules score (0-3)	2.3	1.9–2.6	2.0	1.2–2.4
	Potential pod yield (t/ha)	2.72	2.50–3.30	1.74	1.20–3.00
N budget	Crop N (kg/ha)	218	177–260	168	119–258
	%Ndfa	53	40–71	47	12–71
	Crop N fixed (kg/ha)	116	88–155	77	21–153
Economic analysis	Input (VND)	12,051,805		11787945	
	Output (VND)	15,719,600		10753600	
	Benefit (VND)	3,667,795		–1034345	

R = Rice, G = Groundnut
Price 1 kg groundnut = 5200 VND (April 2000); ($US1 = 14,500 VND); VND : Vietnamese dong

Table 3. A summary of data from the farmers' field surveys of spring-summer 2000 (20 fields) and spring-summer 2001 (10 fields) in Dong Thap, Can Tho and Vinh Long provinces of the Mekong Delta, Vietnam.

Data	Factor	Spring-summer 2000		Spring-summer 2001	
		Mean	Range	Mean	Range
Soil	pH (soil:water, 1:2.5)	4.45	4.14–4.84		
	Organic C (%)	1.68	1.08–2.19		
	Sand (%)	2	0.4–5		
	Silt (%)	56	42–69		
	Clay (%)	42	26–57		
Agronomy	Crop area (m^2)	3620	1500–10,000		
	N applied (kg/ha)	108	80–150		
	P_2O_5 applied (kg/ha)	51	30–80		
	K_2O applied (kg/ha)	28	0–40		
	Coconut ash (kg/ha)	0	0		
	Cropping system	R-S-R			
Plant	Shoot DM (t/ha)	6.50	5.15–8.13		
	Nodules score (0-3)	1.4	0.8–2.4		
	Potential grain yield (t/ha)	2.38	1.50–3.00		
N budget	Crop N (kg/ha)	326	266–413		
	%Ndfa	70	50–92	70	51–92
	Crop N fixed (kg/ha)	232	152–377		
Economic analysis	Input (VND)	7,002,747			
	Output (VND)	7,538,240			
	Benefit (VND)	535,493			

R = Rice, S = Soybean
Price 1 kg soybean = 3200 VND (May 2000)

Shoot DM yields were similar for the two seasons, with individual crops varying about 2-fold (4.3–8.4 t/ha). Pod yields were about 60% higher for the W-S crops than for those in S-A. Even though none of the crops were inoculated, all were nodulated.

The soybean fields were also acidic, but were quite different from the groundnut fields in physical composition (Table 3). They had much higher clay levels (average of 42%) and very little sand (<5%). Consequently, organic matter levels were about double those of the groundnut soils. Coconut ash was not used on soybean. With the chemical fertilisers, N rates were higher than used on groundnut (average 108 kg N/ha), but P and K rates were lower. Shoot DM and grain yield were, on average, 6.5 and 2.4 t/ha, respectively.

None of the soybean crops were inoculated either. Nodulation scores ranged about 3-fold and were slightly inferior overall to the groundnut nodulation. It appears that the rhizobia for both species survives the flooding and associated anaerobic conditions, even though there may be some loss of numbers (e.g. Rupela et al. 1987; Wood and Myers 1987). Generally, the nodules on the roots of both species were small and white and, rather than being clustered near to the crown, were scattered throughout the root system. This suggests that they were not highly effective.

Nitrogen fixation and N balance

Nitrogen fixation was quantified using the natural ^{15}N abundance method. The $\delta^{15}N$ values of the groundnut and soybean crops, together with their non N_2-fixing reference plant values, are presented in Figure 1. The $\delta^{15}N$ values of the reference plants were similar for both surveys, with ranges 2.51–9.36‰ for the groundnut fields and 0.88–11.08‰ for soybean. Mean values were 4.79‰ (groundnut reference) and 3.60‰ (soybean reference). For the legumes themselves, mean values were 1.41‰ (groundnut) and –0.80‰ (soybean). Differences between the $\delta^{15}N$ values of the legumes and reference plants were, for the most part, 3.0–4.0‰.

Average %Ndfa values were 50% for groundnut and 70% for soybean, although there was substantial variation in the values for each species (Tables 2 and 3). With groundnut, most crops fixed 40–60% of their N requirements and none fixed >80% (Figure 2A). Soybean %Ndfa values, on the other hand, were mainly in the 60–80% range with 20% of the crops fixing 80–100% of N requirements (Figure 3A). Crop N fixed reflected the %Ndfa distributions. With groundnut, the majority of crops fixed 50–150 kg N/ha (Figure 2B), while the majority of soybean crops fixed 200–300 kg N/ha (Figure 3B). Average values for crop N fixed were 116 kh/ha (groundnut) and 232 kg/ha (soybean).

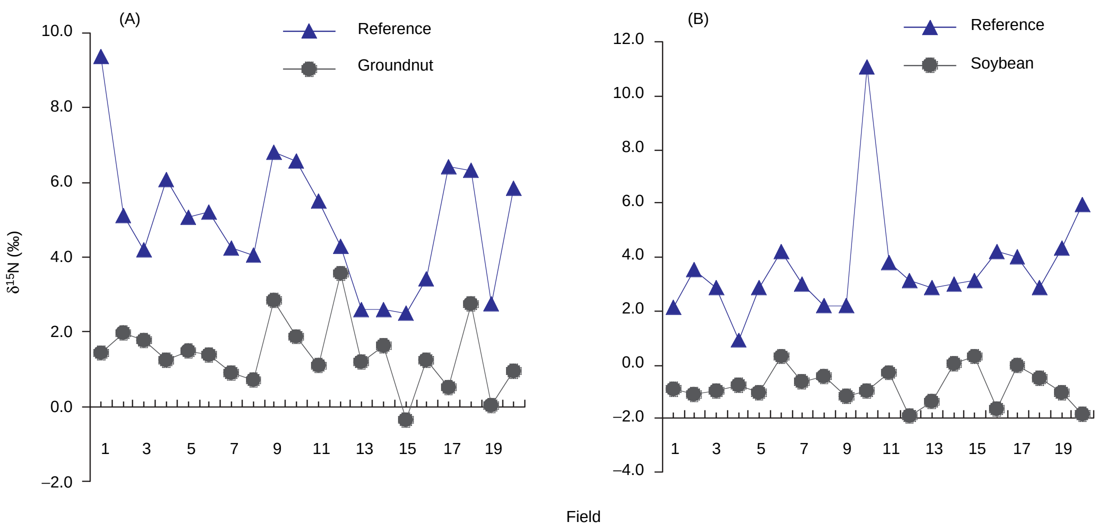

Figure 1. $\delta^{15}N$ values of (A) groundnut and reference weeds and (B) soybean and reference weeds from farmers' fields in the surveys of legume N_2 fixation in the Mekong Delta of Vietnam. The groundnut surveys were conducted in winter-spring 1999–2000 and summer-autumn 2000 groundnut in Long An province; the soybean surveys in spring-summer 2000 in Dong Thap, Can Tho and Vinh Long provinces.

Factors affecting N_2 fixation

Correlation analysis of the various soil and plant parameters in Tables 2 and 3 indicated, for both species, crop N fixed was highly correlated with %Ndfa (data not shown) and shoot N (Figure 4). Unlike other surveys of legume N_2 fixation in Vietnam (see Lien Hoa et al., Tien et al., and Hong and Herridge, these Proceedings), there were no soil or plant parameters that were correlated with N_2 fixation.

Economic analysis

The economic analyses of the two seasons' groundnut crops provided an interesting contrast. For the winter-spring crops, the benefit was, on average, 3,667,800 VND/ha (about $US250), compared to a net loss of 1,034,350 VND/ha (USD71) for the summer-autumn crops. The largest contributing factor to the differences in profitability was pod yield (see Table 2). For soybean, both input costs and grain prices were less than for groundnut. The average benefit was 535,500 VND, equivalent to $US37.

Inoculation experiments

Soil, agronomic and plant data

The two groundnut inoculation experiments were conducted in low organic matter, acidic (pH 5.49–5.71) sandy loam soils. Major nutrients

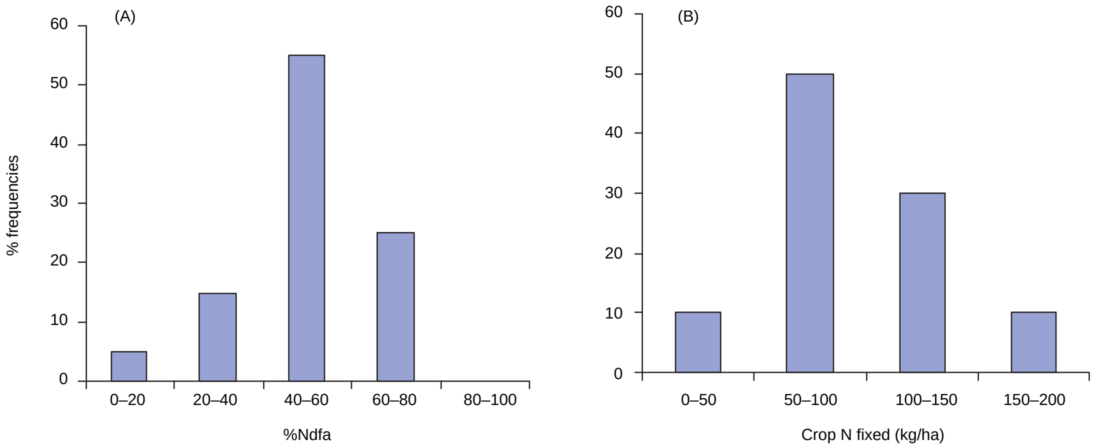

Figure 2. Frequency histograms of %Ndfa and crop N fixed of farmers' fields of winter-spring 1999–2000 and summer-autumn 2000 groundnut in Long An province of the Mekong Delta. There were 20 fields in the surveys.

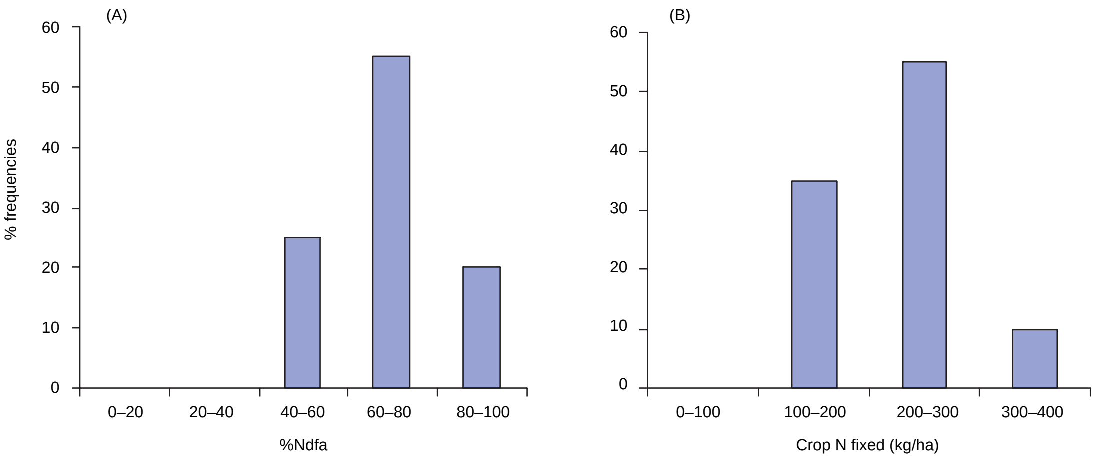

Figure 3. Frequency histograms of %Ndfa and crop N fixed of farmers' fields of soybean surveyed in spring-summer 2000 in Dong Thap, Can Tho and Vinh Long provinces of the Mekong Delta. There were 20 fields in the surveys.

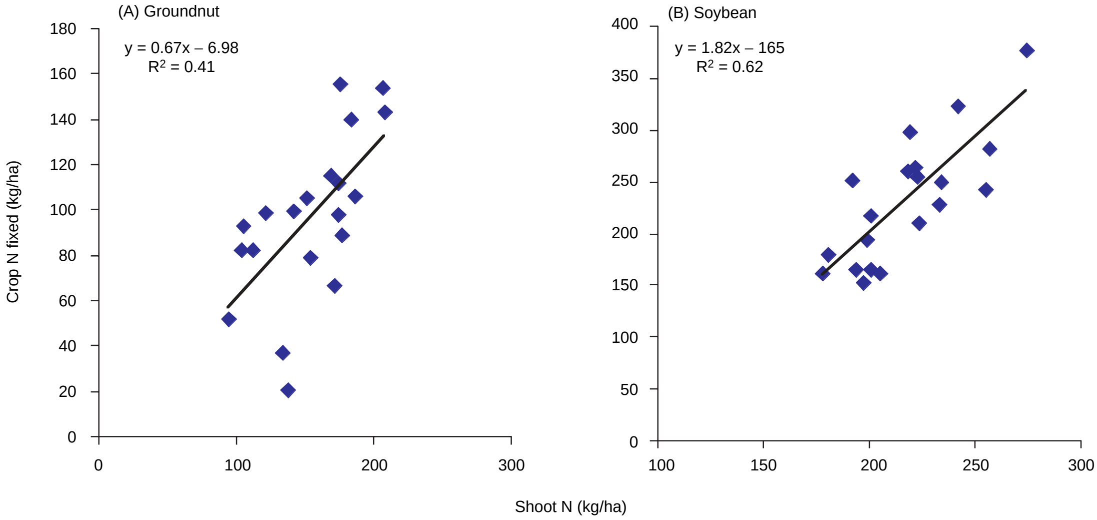

Figure 4. Relationships between crop growth (shoot N) and N_2 fixation (crop N fixed) of (A) groundnut and (B) soybean in surveyed farmers' fields in the Mekong Delta of Vietnam. The groundnut surveys were conducted in winter-spring 1999–2000 and summer-autumn 2000 groundnut in Long An province; the soybean surveys in spring-summer 2000 in Dong Thap, Can Tho and Vinh Long provinces

(N, P and K) were low as was CEC (data not shown). The four soybean inoculation experiments, on the other hand, were conducted in acidic clay loams (pH 4.58–5.76). Total N and P were average but exchangeable K was low. CEC was higher than in the groundnut soils.

Data on plant nodulation from all 6 experiments are presented in Tables 4 and 5. Groundnut responded to inoculation at both sites with no apparent difference between the local strain and the imported strain, NC92.

Results were similar for soybean, except that nodules were entirely absent from the uninoculated treatments (1 and 2) at two of the four sites. Again, there was no difference in nodulating ability between the local strain and the imported strain, CB1809. The groundnut and soybean plants in Treatments 1 and 2 that were nodulated (sites Long An 1 and 2, Dong Thap 1 and 3) did not have large nodules near to the crown region as with Treatments 3–5; rather the nodules were small and white and scattered along the entire root.

Nodule mass, assessed for soybean only, reflected the difference in size of the nodules formed by the indigenous rhizobia in the uninoculated plots (Treatments 1 and 2) and those formed by the inoculant rhizobia (Treatments 3–5) (Table 5). At Dong Thap 3, for example, the inoculated plants in

Table 4. Effects of rhizobial inoculation and fertiliser application on nodulation scores of groundnut at two field sites in Long An province and soybean at 4 sites in Vinh Long and Dong Thap provinces of the Mekong Delta of Vietnam. The experiments were conducted during winter-spring 2000–2001 and spring-summer 2001.

Treatments	Long An 1 (GN)[A]	Long An 2 (GN)	Vinh Long (SB)[B]	Dong Thap 1 (SB)	Dong Thap 2 (SB)	Dong Thap 3 (SB)
1. FP0N-inoc	2.0 a	1.6 a	0.0 a	1.0 a	0.0 a	1.0 a
2. FP+N-inoc	1.9 a	1.9 a	0.0 a	1.0 a	0.0 a	0.8 a
3. FP+NC92/CB1809	2.9 b	2.6 b	2.0 b	2.0 b	2.8 b	2.0 b
4. FP+local strain	2.9 b	2.5 b	1.8 b	2.0 b	2.8 b	2.0 b
5. OP+NC92/CB1809	2.9 b	2.9 b	2.0 b	2.0 b	3.0 b	2.0 b
CV (%)	5.5	14	37	13.5	16	14.4

[A]GN = groundnut; [B]SB = soybean
Means followed by the same letter in the same column were not significantly different (P>0.05)

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Treatments 3–5 had 20–40 times the nodule mass as the uninoculated Treatment 1 and 2 plants.

The enhanced nodulation of inoculated groundnut was reflected in higher pod yields (Table 6). Overall, Treatment 5 (optimum fertiliser + inoculation) produced the highest yield (average of 5 t/ha). The yield was 1.5 t/ha (42%) greater than that of Treatment 1 (0N, no inoculation) and 1.1 t/ha (28%) greater than Treatment 2 (100N, no inoculation). Treatments 3 and 4 were intermediate between Treatment 5 and the two uninoculated treatments.

Soybean grain yields also responded to inoculation. However, Treatment 2 (+fertiliser N) performed relatively better than it had with groundnut. The responses to inoculation (Treatments 3–5 *versus* Treatment 1) and fertiliser N (Treatment 2 *versus* Treatment 1) were consistent for the four experiments. Yield benefits were 0.51–0.64 t/ha (26–33%).

Economic analysis

Economic analysis of the data indicated very large differences between groundnut and soybean in returns to the farmers (Tables 7 and 8). Even though costs of production for groundnut were about 50% higher than for soybean, this was more than offset by the 75% higher yields and 67% higher prices for groundnut.

Table 5. Effects of rhizobial inoculation and fertiliser application on nodule weights (mg/plant) of soybean at 4 sites in Vinh Long and Dong Thap provinces of the Mekong Delta of Vietnam. The experiments were conducted during spring-summer 2001.

Treatments	Vinh Long (SB)[A]	Dong Thap 1 (SB)	Dong Thap 2 (SB)	Dong Thap 3 (SB)
1. FP0N-inoc	0 a	29 a	0 a	5 a
2. FP+N-inoc	0 a	25 a	0 a	8 a
3. FP+CB1809	174 b	221 c	23 b	192 b
4. FP+local strain	140 b	183 bc	21 b	133 b
5. OP+CB1809	215 b	158 b	27 b	158 b
CV (%)	58	30	31	45

[A]SB = soybean
Means followed by the same letter in the same column were not significantly different (P>0.05)

Table 6. Effects of rhizobial inoculation and fertiliser application on pod/grain yields (t/ha) of groundnut at two field sites in Long An province and soybean at 4 sites in Vinh Long and Dong Thap provinces of the Mekong Delta of Vietnam. The experiments were conducted during winter-spring 2000–2001 and spring-summer 2001.

Treatments	Long An 1 (GN)[A]	Long An 2 (GN)	Vinh Long (SB)[B]	Dong Thap 1 (SB)	Dong Thap 2 (SB)	Dong Thap 3 (SB)
1. FP0N-inoc	3.90 a	3.13 a	3.32 a	2.37 a	0.81 a	1.34 a
2. FP+N-inoc	4.31 a	3.48 bc	4.35 b	3.12 b	1.18 b	1.73 b
3. FP+NC92/CB1809	4.55 b	3.83 cd	4.20 b	3.04 b	1.29 b	1.62 b
4. FP+local strain	5.56 b	3.83 cd	4.16 b	2.75 ab	1.26 b	1.70 b
5. OP+NC92/CB1809	5.76 b	4.23 d	4.33 b	3.07 b	1.30 b	1.70 b
CV (%)	11	3	5	9	7	8

[A]GN = groundnut; [B]SB = soybean
Means followed by the same letter in the same column were not significantly different (P>0.05)

Table 7. Economic analysis of inoculation and fertiliser treatments in two field experiments in Long An province, Mekong Delta, involving groundnut. The experiments were conducted during winter-spring 2000–2001.

Treatments	Pod yield (t/ha)	Fertiliser input (VND)	Total input (VND)	Output (VND)	Benefit (VND)
1. FP0N-inoc	3.52	975,000	9,475,000	15,840,000	6,365,000
2. FP+N-inoc	3.90	1,520,000	10,020,000	17,550,000	7,530,000
3. FP+NC92	4.20	1,005,000	9,475,000	18,900,000	9,425,000
4. FP+local strain	4.70	1,005,000	9,475,000	21,150,000	11,675,000
5. OP+NC92	5.00	739,000	9,209,000	22,500,000	13,291,000

Price of 1kg of groundnut (May 2001) = 4500 VND ($US1 = 14,800 VND)

Table 8. Economic analysis of inoculation and fertiliser treatments in four soybean field experiments in Vinh Long and Dong Thap provinces, Mekong Delta. The experiments were conducted during spring-summer 2001.

Treatments	Grain yield (t/ha)	Fertiliser input (VND)	Total input (VND)	Output (VND)	Benefit (VND)
1. FP0N-inoc	1.96	450,000	6,365,000	5,292,000	–1,073,000
2. FP+N-inoc	2.60	949,000	6,864,000	7,020,000	156,000
3. FP+CB1809	2.54	480,000	6,395,000	6,858,000	463,000
4. FP+local strain	2.47	480,000	6,395,000	6,669,000	274,000
5. OP+CB1809	2.60	589,000	6,504,000	7,020,000	516,000

Price of 1kg of soybean (May 2001) = 2700 VND ($US1 = 14,800 VND)

For groundnut, best returns were from Treatment 5. It was almost double that of Treatment 1 and 75% higher than Treatment 2. Results were much the same for soybean with Treatment 5>Treatments 3 and 4>Treatment 2>Treatment 1. Although Treatment 2 yielded well, the high cost of fertiliser N substantially reduced profitability.

Attitude to the use of inoculants

Farmer interviews in both the groundnut and soybean-growing areas revealed that they knew a little about inoculants, but encountered difficulty in purchasing them. They were eager to use inoculants on groundnut and saw the economic benefits (through reduced fertiliser and labour costs) of replacing coconut ash with the optimum fertiliser mixture. With soybean, farmers preferred to used N fertiliser because it was cheap, easy to buy and apply and the effects were quick and clearly evident within a few days of application.

With the six inoculation/fertiliser experiments, many of the nearby farmers came to study the plots and discuss the optimum fertiliser formulae. In particular, they picked up on the fact that P and K were just as important to apply as N. Farmers were surprised when shown the large nodules of the inoculated plants of both groundnut and soybean compared to the small nodules formed by indigenous rhizobia.

At the four soybean sites, we also discussed with farmers about the positive effects of the nodules for subsequent crops, through improved soil structure and soil fertility.

Conclusion

The surveys of farmers' crops of groundnut and soybean indicated that they were not inoculated with rhizobia. Nonetheless, all 40 crops were nodulated and all fixed N. Inputs were high, particularly fertiliser N inputs and economic analysis of the 20 soybean fields and 10 summer-autumn groundnut fields indicated either low or negative returns. Only the winter-spring groundnut showed good levels of profitability.

The six inoculation/fertiliser experiments showed that both groundnut and soybean responded to inoculation by producing more abundant nodulation and higher pod or grain yields. For both species, the optimum fertiliser mixture plus inoculation produced the greatest economic returns. Farmers could clearly improve profitability by reducing fertiliser N inputs from the current rates of 50–150 kg/ha to 'starter' rates of <20 kg/ha and inoculating with high-quality rhizobial inoculants.

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