

Inoculation Responses of Soybean and Liquid Inoculants as an Alternative to Peat-Based Inoculants

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Abstract

Field experiments were conducted in acrisol, ferrasol and fluvisol soils in the Eastern region and Mekong delta of the south of Vietnam to evaluate nodulation and yield of 'promiscuous' soybean lines from Africa in the presence and absence of inoculation, and the efficacy of liquid formulations as an alternative to peat-based inoculants. Both the 'promiscuous' lines and the liquid inoculants represented technologies that might have relevance for the farmer of Vietnam. Notwithstanding individual treatment effects, responses to rhizobial inoculation were observed in each of the six experiments of this study. Responses on the acrisol and alluvial soils were large, up to 40-fold increases in nodulation and 87% and 51% increases in shoot DM and grain yield, respectively. All four sites were new to soybean. Inoculation responses were even recorded at the ferrasol sites, both of which were on old soybean land. In the two experiments for which we had N fixation data, inoculation increased total N fixed by as much as 400%. Although successful in Africa, the 'promiscuous' lines did not nodulate well in the absence of inoculation and showed substantial increases in nodulation and yield when inoculated. Responses were similar to the responses of the local cultivars. The second technology related to media formulation used to produce the inoculant rhizobia and to deliver them to the legume seed. The different growth formulations (G5, G6 and YEM) were similarly effective as were the two methods of delivery, peat and liquid. Future utilisation of liquid inoculants in Vietnam will depend to a large extent on demonstrated benefits in the manufacturing process and in inoculant distribution. Farmer acceptance will most likely be the ultimate determinant of their future.

TECHNOLOGY that has been developed in the technically-advanced countries may not be immediately appropriate to the smallholder farmers in the less-developed countries. Rhizobial inoculation of legumes is one such technology. It is not the price of the product that is the problem; rather the problems relate to quality and availability in the market place.

In Vietnam, the current production and distribution of inoculants may only be sufficient for about 1000 ha, far less than the quantity required to inoculate the 700,000 ha of legumes currently grown each year in the country. Vietnamese farmers fertilise their legume crops with N instead of inoculating, a practice that adds US\$25–30 million annually to

their cost of production and to Vietnam's import account. Inoculation, on the other hand, would cost the farmers only about US\$1 million annually and they would be supporting a local industry.

Responses to inoculation in research experiments in the country show clearly that inoculation is justified, at least in soil that has never grown the legume before or has not grown the legume for many years (Tran Phuoc Duong et al. 1984; Cao Ngoc Diep et al. 1996; Pham Thi Phuong Lan et al. 1999; Tran Yen Thao 1997, 2001). It is also beneficial in soils that are marginal for survival of the rhizobia, e.g. very acid soils. What is needed is research to develop inoculant-production technology that is relevant to the needs of the country and to extend the message to farmers that inoculating rather than fertilising legumes with N should lead to greater profitability. In addition to enhancing the country's inoculant technology, other strategies should be explored that might reduce legume cropping dependence on either fertiliser N or inoculants.

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In this paper, we present results from research that has started to examine both of these options. We compared 'promiscuous' nodulating soybean (*Glycine max*) from the International Institute for Tropical Agriculture (IITA) with local cultivars in a single field experiment Tay Ninh province in the south of the country. We evaluated all cultivars for ability to nodulate without inoculation and nodulation and yield responses to inoculation. In addition, in a series of experiments on three major soil types in the south, we examined both liquid and traditional peat-based inoculants of *Bradyrhizobium japonicum* produced using different culture medium formulations. The liquid inoculants may have particular relevance to Vietnam because of their relative ease of production and distribution.

Materials and Methods

Evaluation of 'promiscuous' cultivars of soybean

Field site

The experiment was conducted at Trang Bang, Tay Ninh Province, in the Eastern Region of the south (ERS) of Vietnam on an Acrisol. The most common cropping system there is groundnut-groundnut-rice. The land has never before grown soybean.

Experimental treatments, cultural practices and sowing

Treatments were 7 cultivars as main plots and +/- inoculation as subplots. The cultivars were HL2 and MTD-176, 2 commercial soybean cultivars in Vietnam, Nam Vang, a local cultivar, and 4 soybean lines from IITA, Nigeria, supplied by Dr Andrew James (CSIRO, Australia). They were considered as 'promiscuous' soybean that nodulate abundantly and effectively with naturalised rhizobia in most soils of Nigeria. Days to maturity were as follows: 80-85 days (HL2), 85-90 days for MTD-176 and Nam Vang, 90-100 days for TGX1437-1D and TGX1447-3D, and 100-110 days for TGX1440 and TGX1448-2E.

The 14 treatments were arranged in randomised complete blocks, replicated 4 times, with the main factor (7 cultivars), split for inoculation treatment (2). Each plot measured 9 m x 5 rows wide. Rows were spaced 40 cm apart.

Phosphate (60 kg P₂O₅/ha), potash (90 kg K₂O₅/ha), and lime (500 kg/ha) were incorporated into the soil to 10-15 cm depth on the day before sowing. Fertiliser N was not applied to any of the plots. The soybean seed was sown in April 2001. Three seeds were placed in holes 30 cm apart along the rows. Seeds in the plus inoculation treatments

were inoculated, using a liquid formulation at a rate of 10 mL/kg seed, with *B. japonicum* strain SEMIA 5019, supplied by the University of Hawaii NifTAL Project. The plants were thinned to two/planting hole after 10 days of growth. During the experiment period, plots were kept weed-free, and pesticides were applied when necessary.

Sampling

Plants were assessed for nodulation 55 days after sowing (DAS) in the case of MTD-176, HL2, Nam Vang, TGX1437-1D and TGX1447-3D, and at 75 DAS for TGX1440 and TGX1448-2E. Nodules were counted, oven dried at 65°C, weighed.

Shoot samples were collected 10 days before final grain harvest. Plants were cut at the soil surface, oven dried at 65°C, weighed, ground and sent to CSIRO Plant Industry, Canberra, Australia, for ¹⁵N analysis. At crop maturity, the grain was harvested, oven dried at 65°C, weighed, analysed for total N by Kjeldahl analysis.

Statistical analysis

All measured and calculated variables were subjected to analysis of variance using MSTATC. Comparisons between treatment means were made by the Duncan Multiple Range Test.

Evaluation of inoculant formulations

Field sites

The experiments were conducted in the ERS of Vietnam, one in Cu Chi, Ho Chi Minh City, on an Acrisol (Phuoc Thanh site) and two in Dong Nai province (Vinh Cuu and Tan Phu sites) on Ferrasols. The fourth site was in the Mekong Delta on a fluvial soil (Vinh Long site). At Phuoc Thanh and Vinh Long, the land was new to soybean. At both sites, the soybean experiment followed rice. At Vinh Cuu, soybean was grown every year after rice. At Tan Phu, soybean had been intercropped with maize in the past; in the year before the experiment, only maize was grown by the farmer.

An experiment to examine rates of liquid inoculation was conducted at Tan An Hoi (Cu Chi) on an Acrisol. Soybean has never been grown there before. Unfortunately, plants were damaged by the bad weather at pod filling. Only nodule data were collected.

Other experiments, damaged by bad weather to the point that data could not be collected, were on Ferrasols at Hung Loc (>5 years without soybean) and at Dinh Quan (farmers routinely intercrop soybean and maize).

Bradyrhizobium culture and inoculant preparation

The rhizobial strain used was *B. japonicum* SEMIA 5019, supplied by the University of Hawaii, NifTAL Project. The culture was maintained on yeast-extract mannitol agar (YEM) and stored at 4°C. The inoculant cultures were prepared in yeast mannitol broth or liquid inoculant formulations, G5 and G6. The G5 formulation contained per litre: 1 g mannitol, 0.5 g K₂HPO₄, 0.2 g MgSO₄·7H₂O, 0.1 g NaCl, 1 g yeast extract, 1 g glucose, 0.5 g arabinose, 20 g PVP K30, 0.073 g FeEDTA, and 4.0 ml glycerol. G6 consisted of 0.8 g K₂HPO₄, 0.49 g MgSO₄, 0.1 g NaCl, 0.14 g CaCl₂, 8.4 mL of a FeCl₃ solution (1g/L), 12 mL glycerol, 0.6 g NH₄Cl, 2 g yeast extract, 4 mL of 1.0 M NaOH solution, and 20 g PVP. When the broths in the 3 different media were sufficiently grown (4–5 days), they were injected aseptically into autoclaved, sterile polythene bags of peat (peat-based inoculants) or into sterile polythene bags (liquid inoculants). For peat inoculants made using G5 or G6 media, PVP was not included.

Two other inoculants, one liquid and one peat-based, were also used. They were from the QUIMICA Company, Argentina. The peat inoculant was a commercial product but the liquid one was for experimental purposes only. All inoculants were applied direct onto the seed at a rate of 10 mL/kg seed for liquid inoculants and 10 g/kg seed for peat-based inoculants.

Experimental treatments, cultural practices and sowing

In all experiments, a randomised complete block design with 4 replications was used. The soybean cultivar was MTD-176, supplied by University of Can Tho (growth duration 85–90 days). Inoculated treatments consisted of liquid formulations G5 and G6, peat inoculants based on YEM and peat inoculants made from G5 and G6 media without PVP. There were two control treatments, uninoculated without N and uninoculated with 40 or 60 kg N/ha.

In the experiment at the Tan An Hoi site, the treatments were different rates of liquid inoculant – 5, 10, 15, 20 and 40 mL/kg seed, the 2 uninoculated controls and commercially-prepared peat inoculant and experimentally prepared liquid inoculant from Argentina.

Sampling

Nodulation was assessed 55–60 days after sowing, except at the Vinh Cuu site where nodules were sampled 35 days after sowing. Nodules were counted, oven dried at 65°C and weighed. Biomass and grain yields were assessed at 80 and 90 DAS, respectively.

Plants were cut at the soil surface, oven dried and weighed, ground and sent to CSIRO Plant Industry, Australia, for ¹⁵N analysis. After grain was oven dried to constant weight, samples were sent to the University of Hawaii NifTAL for total N analysis.

Statistical analysis

All measured and calculated variables were subjected to analysis of variance using MSTAT. Comparisons between treatment means were made by the Duncan Multiple Range Test.

Economic analysis

Economic analysis of inoculation/uninoculation (with and without N fertiliser application) treatments at 4 sites was done. The calculation was based on output and input and data of inoculation treatment was on average of 5 inoculant formulations. The total input was consisted of fertiliser input including P, K, Mg, microfertilisers, lime for all treatments, urea for uninoculation plus N fertiliser treatment, inoculant cost for inoculation treatments (50,000 VND/ha), and other managements such as pesticides, weed control, irrigation for all treatments. Extra labour for harvest due to yield increase of inoculation treatments was also included.

Results and Discussion

Evaluation of ‘promiscuous’ cultivars of soybean

Nodulation of both local and ‘promiscuous’ IITA cultivars showed large responses to inoculation (Table 1). Plants were poorly nodulated without inoculation; nodule number was in the range 1–6/plant and nodule weight 16–69 mg/plant. There were no differences between the local cultivars and the ‘promiscuous’ cultivars. When inoculated, soybean nodule number was increased to 8–54/plant and nodule weight to 91–946 mg/plant. With such a large range, it is not surprising that the interaction of cultivar and inoculation was highly significant ($P < 0.01$). Cultivars that performed best were the ‘promiscuous’ TGX1440 and TGX1448-2E. Next best were local cultivars MTD-176 and Nam Vang. The least responsive of the cultivars was ‘promiscuous’ line TGX1447-1D.

Inoculation effects on shoot and grain yields of the 7 cultivars are shown in Table 2. Shoot DM yields were 2.4–5.1 t/ha without inoculation, increasing to 2.6–7.3 t/ha with inoculation. Grain yields followed similar trends, i.e. 0.45–1.38 without inoculation and 0.48–1.81 with inoculation. Grain yields were particularly low for the non-adapted IITA lines, averaging just 0.64 t/ha (uninoculated)

and 0.77 t/ha (inoculated). By comparison, yields of the local cultivars were 1.11 t/ha (uninoculated) and 1.38 t/ha (inoculated). The most responsive cultivars (i.e. 29–43% for shoot DM and 25–37% for grain yield) were the ‘promiscuous’ TGX1440 and TGX1448-2E and local cultivar MTD-176. The ‘promiscuous’ TGX1447-1D was again the least responsive; increases due to inoculation were just 9% for shoot DM and 7% for grain yield

There was a moderately high and significant ($P < 0.01$) correlation between nodulation and shoot DM, suggesting that nodulation played a key role in plant growth. On the other hand, variation in nodulation amongst the cultivars may reflect their different capacities for growth under the environmental and edaphic conditions of this experiment.

The TGX lines express high levels of nodulation without inoculation in West Africa and in other parts of Africa. The fact that none of the four lines in this

experiment nodulated well in the absence of inoculation suggests that compatible, effective cowpea-type rhizobia, present in the soils of Africa, are absent from this part of Vietnam. In the field in which the experiment was conducted, there would have been abundant cowpea rhizobia in the soil because the farmer grows well-nodulated groundnut every year without inoculation. However, MNP counts using soybean or related species were not done to determine the number of rhizobia infective and effective for soybean. Such counts would most likely have confirmed an absence of compatible soybean rhizobia. ‘Promiscuous’ cultivars still represent a highly attractive and appropriate technology for the small-holder farmers of Vietnam, as they do in Africa. However, it seems that such cultivars, adapted to the soils of Vietnam, will need to be identified from other germplasm sources, if indeed they exist.

Table 1. Nodulation of local and ‘promiscuous’ cultivars of soybean in the field in Tay Ninh province in the south of Vietnam during spring-autumn 2001.

| Cultivar | Nodule no/plant | | Nodule wt/plant (mg) | |
|--------------------------------|-----------------|------------|----------------------|------------|
| | Uninoculated | Inoculated | Uninoculated | Inoculated |
| Local cultivars | | | | |
| MTD-176 | 2 | 38 | 25 | 671 |
| HL92 | 2 | 15 | 16 | 249 |
| Nam Vang | 2 | 30 | 22 | 503 |
| ‘Promiscuous’ cultivars | | | | |
| TGX1447-1D | 1 | 8 | 22 | 91 |
| TGX1437-3D | 1 | 16 | 29 | 118 |
| TGX1440 | 5 | 52 | 59 | 852 |
| TGX1448-2E | 6 | 54 | 69 | 946 |
| LSD ($P = 0.05$) | | 5 | | 67 |

Table 2. Yields of shoot DM and grain of local and ‘promiscuous’ cultivars of soybean in the field in Tay Ninh province in the south of Vietnam during spring-autumn 2001.

| Cultivar | Shoot DM (t/ha) | | | Grain yield (t/ha) | | |
|----------------------|-----------------|------------|------------|--------------------|------------|------------|
| | Uninoculated | Inoculated | % response | Uninoculated | Inoculated | % response |
| Local | | | | | | |
| MTD-176 | 4.08 | 5.67 | +39 | 1.38 | 1.81 | +31 |
| HL92 | 3.32 | 4.09 | +23 | 0.72 | 0.93 | +29 |
| Nam Vang | 4.23 | 5.05 | +19 | 1.24 | 1.41 | +14 |
| ‘Promiscuous’ | | | | | | |
| TGX1447-1D | 2.39 | 2.60 | +9 | 0.45 | 0.48 | +7 |
| TGX1437-3D | 3.53 | 4.21 | +19 | 0.70 | 0.78 | +11 |
| TGX1440 | 4.55 | 5.86 | +29 | 0.67 | 0.92 | +37 |
| TGX1448-2E | 5.09 | 7.26 | +43 | 0.72 | 0.90 | +25 |
| LSD ($P = 0.05$) | | 0.40 | | | 0.10 | |

Evaluation of inoculant formulations

Experiments on acrisols

There were large, i.e. about 10-fold, nodulation responses to both peat-based and liquid inoculants as shown in Table 3. Shoot dry matters also responded strongly to inoculation, with increases of 42–68%. Grain yield were improved by 17–34%. The G6 formulation was slightly superior to the G5 formulation, producing 30–50% more nodule mass and numbers and 7–9% more shoot biomass and grain. The liquid and peat-based formulations were essentially identical in their efficacy.

The %Ndfa values were 18% for uninoculated plants and in 35–51% for the inoculated plants (Table 4). Again, the G6-formulated inoculants performed better than the G5 inoculants and there were no differences between liquid and peat inoculants. The differences in shoot N contents and %Ndfa values between inoculated and uninoculated plots compounded to generate even larger differences in crop N fixed. It was 33 kg N/ha for uninoculated and 110–217 kg N/ha (average of 177 kg N/ha) for the

inoculated. In the case of the latter, the net N balances (fixed N – grain N harvested) were very positive, ranging from just 7 kg N/ha for G5-liquid inoculant to 96 kg N/ha for G6-peat inoculant.

Strong responses to inoculation were recorded in an experiment to examine the efficacy of the liquid inoculants used at different rates (Table 5). The results showed that there was no effect of rate in the range 5–40 mL liquid inoculant/kg seed and there were no differences between the local products and the commercial products from Argentina. As stated previously, yield data was not obtained from this experiment because of extensive storm damage. It is likely though, that the very large nodulation responses to inoculation would have meant large responses in DM and grain yields.

Experiment on alluvial soil

Although this land has not been planted soybean before, root nodules were abundant in the uninoculated plots (Table 6). Even so, there were strong responses to inoculation – 3–4 fold increase for nodulation, 55–87% increase for shoot DM and 36–51%

Table 3. Effects of inoculant formulations on nodulation, shoot biomass and grain yield of soybean, grown on an acrisol at Phuoc Thanh (Cu Chi) in the south of Vietnam. The land had never grown soybean.

| Treatment | Nodule no./ plant | Nodule wt/ plant (mg) | Shoot DM (t/ha) | Grain yield (t/ha) |
|-----------------------------|----------------------|--------------------------|--------------------|-----------------------|
| 1. Uninoculated, 0N | 1 | 25 | 5.0 | 1.67 |
| 2. Uninoculated, 40N | 1 | 6 | 6.1 | 1.81 |
| 3. Liquid inoculant G5 | 12 | 280 | 7.1 | 1.96 |
| 4. Liquid inoculant G6 | 20 | 401 | 8.4 | 2.12 |
| 5. Peat inoculant using G5 | 16 | 351 | 7.9 | 2.00 |
| 6. Peat inoculant using G6 | 21 | 414 | 7.5 | 2.18 |
| 7. Peat inoculant using YMB | 21 | 353 | 8.1 | 2.24 |
| LSD ($P = 0.05$) | 3 | 36 | 0.8 | 0.20 |

Table 4. Effects of inoculant formulations on shoot and grain N and N₂ fixation of soybean, grown on an acrisol at Phuoc Thanh (Cu Chi) in the south of Vietnam. The land had never grown soybean.

| Treatment | Shoot N (kg/ha) | Grain N (kg/ha) | %Ndfa | Crop N fixed ^A (kg/ha) |
|-----------------------------|-----------------|-----------------|-------|--------------------------------------|
| 1. Uninoculated, 0N | 124 | 71 | 18 | 33 |
| 2. Uninoculated, 40N | 126 | 87 | * | * |
| 3. Liquid inoculant G5 | 209 | 103 | 35 | 110 |
| 4. Liquid inoculant G6 | 283 | 114 | 48 | 204 |
| 5. Peat inoculant using G5 | 276 | 111 | 41 | 170 |
| 6. Peat inoculant using G6 | 284 | 122 | 51 | 217 |
| 7. Peat inoculant using YMB | 262 | 110 | 47 | 184 |
| LSD ($P = 0.05$) | 54 | 13 | 9 | 60 |

^ACrop N = shoot N × 1.5, to account for below-ground N

Table 5. Effects of different rates of liquid inoculants on nodulation of soybean, grown on an acrisol at Tan An Hoi (Cu Chi) in the south of Vietnam. The land had never grown soybean.

| Treatment | Nodule no./plant | Nodule wt (mg/plant) |
|--|------------------|----------------------|
| Uninoculated, 0N | 3 | 18 |
| Uninoculated, 40N | 1 | 9 |
| G6 liquid inoculant, 5 ml/kg seed | 44 | 902 |
| G6 liquid inoculant, 10 ml/kg seed | 42 | 864 |
| G6 liquid inoculant, 15 ml/kg seed | 41 | 858 |
| G6 liquid inoculant, 20 ml/kg seed | 40 | 872 |
| G6 liquid inoculant, 40 ml/kg seed | 42 | 967 |
| Experimental liquid inoculant from Argentina, 5 ml/kg seed | 48 | 1003 |
| Commercial peat inoculant from Argentina, 5 g/kg seed | 40 | 870 |
| LSD ($P = 0.05$) | 10 | 162 |

Table 6. Effects of inoculant formulations on nodulation, shoot biomass and grain yield of soybean, grown on a fluvisol soil at Vinh Long in the Mekong Delta in the south of Vietnam. The land had never grown soybean.

| Treatment | Nodule No./plant | Nodule wt (mg/plant) | Shoot DM (t/ha) | Grain yield (t/ha) |
|-----------------------------|------------------|----------------------|-----------------|--------------------|
| 1. Uninoculated, 0N | 31 | 391 | 3.22 | 1.06 |
| 2. Uninoculated, 60N | 15 | 250 | 4.71 | 1.39 |
| 3. Liquid inoculant G5 | 122 | 1119 | 5.53 | 1.44 |
| 4. Liquid inoculant G6 | 141 | 1039 | 4.99 | 1.49 |
| 5. Peat inoculant using G5 | 118 | 1047 | 5.80 | 1.48 |
| 6. Peat inoculant using G6 | 93 | 1046 | 6.03 | 1.60 |
| 7. Peat inoculant using YMB | 115 | 1094 | 4.95 | 1.43 |
| LSD ($P = 0.05$) | 28 | 256 | 1.23 | 0.37 |

increase for grain yield. There were no differences between the G5 and G6 formulations and no differences between liquid and peat-based inoculants.

The %Ndfa values were similar for the uninoculated-ON control (71%) and the five inoculation treatments (average of 74%) (Table 7). The uninoculated-60N control %Ndfa value was substantially less at 29%. Estimated crop N fixed was 118 kg N/ha for the uninoculated-ON control and 51 kg N/ha for the uninoculated-60N control. It would seem that the fertiliser N effectively replaced fixed N in the crop, but did little to add to total crop N (estimated at 167 and 176 kg N/ha, for the two control plots). The inoculated plants fixed 192–228 kg N/ha (average of 212 kg N/ha) compared with the 118 kg N/ha fixed by the uninoculated (ON) control.

Experiments on ferrasols

Inoculation effects at the two ferrasol sites were consistent with the other sites, even though soybean had been grown on this land previously (Table 8). Nodulation responses were about 3-fold at tan Phu and

only marginal, about 50%, at Vinh Cuu. This was not surprising and would have reflected the more intensive soybean cultivation at Vinh Cuu. Responses in shoot DM were 64–75% (Tan Phu). There was no shoot biomass data for Vinh Cuu. Grain yield responses were 0–16% at Tan Phu and 12% at Vinh Cuu. There were no differences between inoculant formulations or inoculant types.

Economic analysis

There were differences in profitability for the inoculation and uninoculation treatments (Table 9). It was 91% more profitable in inoculation treatment than the uninoculation one because of grain yield increase. The benefit that farmers gained from the inoculation was 19% higher when they applied urea. This benefit came from the lower costs of fertiliser input (no urea was used) and grain yield increase. The benefit from the inoculation was 1.454.000 VND per ha.

The economic value of inoculation would be more considerable if we see it in term of benefits for soil N

Table 7. Effects of inoculant formulations on N₂ fixation of soybean, grown on a fluvisol soil at Vinh Long in the Mekong Delta in the south of Vietnam. The land had never grown soybean.

| Treatment | Shoot N (kg/ha) | %Ndfa | Crop N fixed (kg/ha) ^A |
|-----------------------------|-----------------|-------|-----------------------------------|
| 1. Uninoculated, 0N | 111 | 71 | 118 |
| 2. Uninoculated, 60N | 117 | 29 | 51 |
| 3. Liquid inoculant G5 | 170 | 75 | 192 |
| 4. Liquid inoculant G6 | 184 | 78 | 215 |
| 5. Peat inoculant using G5 | 204 | 72 | 220 |
| 6. Peat inoculant using G6 | 227 | 67 | 228 |
| 7. Peat inoculant using YMB | 175 | 78 | 205 |
| LSD (<i>P</i> = 0.05) | 68 | 25 | 88 |

^ACrop N = shoot N × 1.5, to account for below-ground N

Table 8. Effects of inoculant formulations on nodulation, shoot biomass and grain yield of soybean, grown on ferrasols at two sites in Dong Nai province in the south of Vietnam. Soybean had been grown at both sites previously.

| Treatment | Tan Phu | | | | Vinh Cuu | | |
|-----------------------------|---------------|-----------------------|-----------------|--------------------|---------------|-----------------------|--------------------|
| | Nod.no /plant | Nodule wt. (mg/plant) | Shoot DM (t/ha) | Grain yield (t/ha) | Nod.no /plant | Nodule wt. (mg/plant) | Grain yield (t/ha) |
| 1. Uninoculated, 0N | 8 | 91 | 4.31 | 1.83 | 27 | 184 | 1.73 |
| 2. Uninoculated, 60N | 5 | 63 | 7.41 | 1.90 | 14 | 135 | 2.21 |
| 3. Liquid inoculant G5 | 21 | 245 | 7.41 | 2.06 | 34 | 262 | 1.95 |
| 4. Liquid inoculant G6 | 18 | 214 | 7.44 | 2.12 | * | * | * |
| 5. Peat inoculant using G5 | 18 | 234 | 7.07 | 2.12 | * | * | * |
| 6. Peat inoculant using G6 | 20 | 258 | 7.22 | 1.82 | * | * | * |
| 7. Peat inoculant using YMB | 23 | 252 | 7.54 | 1.96 | 36 | 260 | 1.96 |
| LSD (<i>P</i> = 0.05) | 5 | 53 | 1.4 | 0.34 | 8 | 27 | 0.28 |

Table 9. Economic analysis of effects of inoculation and uninoculation applications on grain yield of soybean (mean values were from 4 sites).

| Treatment | Grain yield (t/ha) | Fertiliser input (VND) | Total input (VND) | Output (VND) | Benefit (Gross margin) (VND) | Benefit from N fertiliser or inoculation |
|---|--------------------|------------------------|-------------------|--------------|------------------------------|--|
| 1. Uninoculation without urea application | 1,57 | 2,134,000 | 6,252,000 | 7,850,000 | 1,598,000 | |
| 2. Inoculation with urea application | 1,83 | 2,396,250 | 6,592,000 | 9,150,000 | 2,558,000 | 960,000 |
| 3. Inoculation | 1,89 | 2,184,000 | 6,398,000 | 9,450,000 | 3,052,000 | 1,454,000 |

Price of 1kg soybean grain (March 2001): 5000 VND (1US\$ = 14,600 VND)

VND: Vietnamese dong

fertility and resultant increased productivity of subsequent crops as we discussed previously in the part of results and discussions.

Conclusions

Responses to rhizobial inoculation were observed in each of the six experiments of this study. Responses on the Acrisol and alluvial soils were large, up to 40-fold increases in nodulation and 87% and 51% increases in shoot DM and grain yield, respectively. All four sites were new to soybean. Inoculation responses were even recorded at the Ferrasol sites, both of which were on old soybean land. In the two experiments for which we had N fixation data, inoculation increased total N fixed by as much as 400%.

The purpose of this study was not to examine effects of inoculation *per se*, rather to examine two different technologies that might have relevance for the farmer of Vietnam.

The first technology was the 'promiscuous' nodulation trait that has been effectively exploited in soybean cultivation in parts of Africa. Thus, we evaluated four lines from the IITA breeding program, together with three local cultivars. Although successful in Africa, the IITA lines did not nodulate well in the absence of inoculation and showed substantial increases in nodulation and yield when inoculated. Responses were similar to the responses of the local cultivars.

The second technology related to media formulation used to produce the inoculant rhizobia and to deliver them to the legume seed. The different growth formulations (G5, G6 and YEM) were similarly effective as were the two methods of delivery, peat and liquid. Future utilisation of liquid inoculants in Vietnam will depend largely on demonstrated benefits in the manufacturing process and in inoculant

distribution. Farmer acceptance will most likely be the ultimate determinant of their future.

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