Development of Inoculant Production and Utilisation in Thailand

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Abstract

The development of the legume inoculant industry in Thailand was started by the public sector in 1976 under a USAID loan. The main objective of the program was to promote the use of inoculant in order to increase important legume products such as soybean, groundnut and mungbean to meet domestic demand. Most of the inoculant production was used in the government-supported programs. With regard to the potential of the inoculant industry, more on-farm research and demonstrations on the use of inoculant should be conducted in order to convince farmers of the benefits of inoculant use, the Government should stop providing free inoculant to farmers and the price of inoculant should be determined by its cost of production. Research on inoculant production technology should be conducted in order to obtain a higher quality product.

INOCULANT research has been conducted in Thailand for a long period. It was reported that the first symposium was held in Bangkok during November 1975, to review rhizobial research in Thailand. Most of the research during that period was conducted by the Bacteriology and Soil Microbiology Branch of the Division of Plant Pathology, Department of Agriculture, Khon Kaen University, and the Applied Scientific Research Corporation of Thailand. Emphasis had been placed on the physiological characterisation of rhizobia, particularly soybean rhizobia, in different environments. Other legumes, such as mungbean and groundnut, were of minor importance.

In December 1975, the Department of Agricultural Extension (DOAE) initiated the Seed Multiplication Project to promote the use of high quality seeds to farmers. In this project, USAID offered a low interest rate loan of 79.8 million baht (US$4 million) for the construction of Seed Centres in Phitsanulok, Chiangmai, Nakhon Ratsima and Chainat. The establishment of the Seed Project generated a huge demand for legume inoculant to go with the foundation seed and commercial seed to be distributed to the farmers. As a result, USAID experts were sent to Thailand in January, 1976, to conduct a feasibility study for the construction of an inoculant production plant at the Department of Agriculture laboratories in Bangkhen, Bangkok. A loan of US$ 0.75 million was guaranteed for the purchase of necessary equipment. The Thai government provided all construction facilities and staff. Production of inoculant in the early stages was behind schedule due to delays in the purchasing of equipment from the U.S. Equipment delivery was completed in 1983.

Training in Rhizobial Inoculant Technology

Training in rhizobial inoculant technology was one of the functions under the Memorandum of Understanding between the Thai DOA and the USAID-funded NifTAL Project, University of Hawaii. The Research Corporation of the University of Hawaii (RCHU) established a model Biological Nitrogen Fixation Resource Centre (BNF Resource Centre) at the DOA inoculant production facility, Bangkok in 1983. The main objective was to provide research support and training in inoculant technology for Southeast Asia and other developing countries.

Following the planning workshop of the leaders of the national BNF programs in the region to formulate future activities of the centre, training workshops in inoculant technology by BNF specialists were implemented frequently. From 1983 to 1993, a total of 165 scientists participated in these training workshop activities (Table 1).

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edited by D. Herridge
ACIAR Proceedings 109e
(printed version published in 2002)

Table 1. International workshop and training in Rhizibial Inoculant Technology during 1983–1993 classified by participated countries.

Participated country	Number of participants
Thailand	46
India	29
Indonesia	24
Nepal	9
Bangladesh	8
China	8
Philippines	8
Sri Lanka	7
Vietnam	6
Malaysia	5
Pakistan	5
Lao PDR	2
Australia	1
Belgium	1
Burundi	1
Kenya	1
Uganda	1
Honduras	1
Korea	1
Singapore	1
Total	165

As well as the international training, the BNF Resource Centre, Bangkok, also provided inoculant training for local extension workers of the DOAE, DAO staff and instructors of agricultural colleges. This group comprised about 40 participants per year since 1984. Finally, the Resource Centre assisted the private sector to produce inoculants for commercial purpose.

Research on Rhizobial Inoculants in Thailand

Research in Thailand on biological nitrogen fixation of the legume-rhizobium symbiosis has been conducted extensively since the world oil crisis of the 1970s. A group of DOA research scientists worked hard to promote the use of rhizobial inoculants as an alternative to the more expensive N-fertiliser. Supporting the rhizobial inoculant production plant was research by the Thai DOA and other institutes concerning inoculant production, application and its improvement.

Rhizobial strain selection

So far, there are many recommended soybean groundnut and mungbean cultivars to meet the needs of the farmers in various environmental situations. Therefore, rhizobial strain selection suitable for each legume cultivar is the first important role for inoculant production because of the specificity of the nodule formation is governed by genes or depends upon genetic inheritance.

To produce inoculant for each recommended cultivar of soybean, groundnut and mungbean, several strains and isolates of rhizobia were firstly screened for their capability in nodulation and N_2-fixation in the glasshouse. After that, each selected strain was produced as inoculum and tested for its capability in nodulation, N_2-fixation and yield response in several fields. Results of most experiments showed that for each legume cultivar there was no extremely significant difference among selected rhizobial strains. Table 2 shows Thai recommended soybean, groundnut and mungbean cultivars and their compat-

Table 2. Recommended soybean, groundnut and mungbean cultivars with their selected rhizobial strains in Thailand.

Legume	Cultivar	Rhizobial strain
Soybean	SJ 1, SJ 2, SJ 4 and SJ 5 Nakorn Sawan 1 (NW 1) Chaing Mai 60 (CM 60)	THA 5, THA 7, THA 1, 2, TAL 102 (USDA 110) USDA 122
Groundnut	Lampang Sukhothai 38 (SK 38) Tainan 9 Khon Kaen 60–1 (KK-1) Khon Kaen 60-2 (KK-2) Khon Kaen 60-3 (KK-3)	THA 201, THA 205, TAL 1000, NC 92
Mungbean	U-Thong 1 (UT 1) Chainat 36 (CN 36) Chainat 60 (CN 60) Kampangsaen 1 (KPS 1) Kampangsaen 1 (KPS 1) PSU 1	THA 301, THA 302, THA 305

Source: Soil Microbiology Research Group, Soil Science Division, DOA

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edited by D. Herridge
ACIAR Proceedings 109e
(printed version published in 2002)

ible rhizobial strains for inoculant production. These rhizobia are distributed on request for private inoculant production also.

Inoculant carrier selection

Selection of the inoculant carrier is the second concern for rhizobial inoculant production. At the very beginning, we produced inoculant using ground and sieved compost and coconut shell dust as carriers. At present, most of the inoculant produced in Thailand uses peat dust as the carrier. But liquid inoculant is being considered to replace the need for solid carriers.

Patiyuth et al. (1985) compared the use of lignite and peat as carriers. They concluded that survival of rhizobia was better in peat carrier. Using peat-lignite mixed enhanced rhizobial survival better than using lignite alone. The number of rhizobia in carriers stored cold (10°C) was higher than when stored at room temperature (Table 3) after long periods of incubation. The results of this experiment were useful for setting time schedules of inoculant production for farmers.

Further study on production and application of liquid inoculant is in progress. A Thai DOA researcher and another from the private sector are now testing its efficiency and feasibility. This kind of inoculant is said to survive longer with 10–100 times higher the number of survival cells than that of the peat-based inoculum, and the cost of production is about 4–5 times less (Susewee 1994). Thananusonth et al. (1994) produced liquid inoculum of *Bradyrhizobium japonicum*, tested it in the field, but found no significantly different response of soybean compared to the use of peat-based inoculant of the same strain.

Inoculant application

Production of highly effective inoculant will be wasteful if application methods and its value cannot be accepted by farmers. There are many diverse situations such as environmental stresses affecting the benefits from inoculant application. Therefore, several experiments were carried out in the field to overcome these problems.

Rate of application

Studies on the rate of inoculant application were carried out to set up standards in Thailand. Boonkerd et al. (1974) tested the effects of five inoculum rates with soybean at three locations (Table 4). They found that increasing inoculum rates up to 100 and 1000 times over normal (10^6 cells of rhizobia per seed) significantly increased nodulation and seed yield of soybean when grown in the field were essentially free of soybean rhizobia, low pH and low fertility (Roi-Et). But when the soil was amended by liming, inoculation at the normal rate was necessary to achieve fair nodulation and increased yield of soybean. In fields where soil fertility was high enough (Hua-Hin and Chainat) an inoculation rate higher than normal was not necessary.

Rungratanakasin et al. (1984) studied a suitable number of rhizobia for inoculating groundnut at three locations. Results of experiments (Table 5) showed that inoculating the groundnut cultivar Tainan with 10^5, 10^6, 10^7 and 10^8 cells per seed (THA 205-peat based inocula) produced no significant difference on nodule fresh weight and pod yield. A slightly significant difference occurred only between inoculated and uninoculated treatments.

From those experiments, standards set up in Thailand were that, under field conditions, an inoculated seed should receive 10^5 to 10^6 cells of rhizobia (Boonkerd 1991). Thus, an acceptable quality inoculant must contain at least 5×10^7 cells of rhizobia per gram (peat-based inoculum).

Table 3. Log_{10} number of viable cells of rhizobia using peat and lignite as carriers stored in room and cold temperature after various of incubation, Patiyuth et al. 1985.

Days after inoculation	Carriers	Room temperature			Cold (10°C) temperature		
		USDA 110	USDA 122	THA 7	USDA 110	USDA 122	THA 7
0	Peat	8.948	9.120	9.208	8.948	9.120	9.208
	Lignite	8.500	8.566	8.650	8.500	8.566	8.650
15	Peat	8.909	9.257	9.024	8.982	9.109	9.150
	Lignite	7.738	8.142	8.240	8.150	8.309	8.560
30	Peat	8.914	9.148	9.002	9.060	9.146	9.135
	Lignite	7.574	7.556	7.478	8.236	8.356	8.548
60	Peat	8.700	9.096	8.990	9.086	9.090	9.112
	Lignite	7.204	7.346	7.327	8.168	8.463	8.654

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ACIAR Proceedings 109e
(printed version published in 2002)

Table 4. Responses of soybean to inoculation rates.

Inoculation rate	Roi-Et			Hua-Hin			Chainat		
	Seed yield (kg/rai)	Nodule number (/pl)	Nodule mass (mg/pl)	Seed yield (kg/rai)	Nodule number (/pl)	Nodule mass (mg/pl)	Seed yield (kg/rai)	Nodule number (/pl)	Nodule mass (mg/pl)
1 x	105	12	310	223	9	230	217	10	230
10 x	150	19	570	229	8	160	223	12	240
100 x	205	23	800	254	9	210	228	18	340
1000 x	113	18	630	215	11	240	235	15	250
0 (Uninoc)	51	<1	20	203	4	245	245	8	160
1 x + Lime	269	44	950	226	6	130	217	8	200
10 x + Lime	301	49	910	235	9	130	202	13	290
100 x + Lime	343	64	1290	239	9	180	217	15	250
1000 x + Lime	369	87	1730	244	8	100	213	16	290
0 + Lime	207	4	250	231	6	80	213	10	210

Table 5. Responses of groundnut to inoculum sizes at three locations.

Inoculum size	Nakornratchasima		Mahasarakarm		Chainat	
	Nodule fr. wt (mh/pl)	Dry pod (kg/rai)	Nodule fr. wt (mh/pl)	Dry pod (kg/rai)	Nodule fr. wt (mh/pl)	Dry pod (kg/rai)
0	30 b	212 b	1000	393	1400 bc	308 b
10^5	550 a	353 a	1100	379	1600 b	332 ab
10^6	390 a	368 a	1400	374	1200 c	354 ab
10^7	570 a	360 a	1200	400	2700 ab	378 a
10^8	510 a	335 a	1500	364	3400 a	378 a
C.V. (%)	31.8	19.6	26.1	9.6	28.6	9.2

Method of inoculant application

Kotepong et al. (1986) studied the number of rhizobia retained on soybean seed after inoculation with peat inoculum using synthetic glue, gum arabic, vegetable oil, tapioca starch 5% boiled, 30% sugar syrup and water as stickers. Results (Table 6) showed that these stickers could retain 1.15×10^6 to 8.4×10^5 cells of rhizobia a seed. Toomsaen et al. (1986) mixed inoculant with soil then inoculated the seeds in shallow furrows or inoculated the seed by pouring peat inoculant solution on to the seeds. This produced better yield than using 40% gum arabic and 40% sugar syrup as stickers. This result supported the finding of Rungratanakasin (1985) who used the same methods to study rhizobial inoculation techniques for peanut.

Rungratanakasin (1986) reported that inoculation with calcium carbonate, gypsum and rock phosphate as seed pelletting increased nodulation and nitrogenase activity over the uninoculated but not seed yield of groundnut. Furthermore, post inoculation can be carried out by pouring inoculum dilution to the rows of soybean as late as two weeks after sowing (Table 7).

Extension Program to Promote Rhizobial Inoculants in Thailand

Most rhizobial legume inoculant extension work in Thailand has been conducted by Department of Agricultural Extension (DOAE) while Department of Agriculture (DOA) is responsible for inoculant production and multi-disciplinary research. The rhizobial promotion includes the training of extension workers at the BNFRC, on-farm trial activities in specific localities to provide information to extension specialists and farmers, and organising field days to demonstrate the results and profitability of the inoculant. (Chanaseni 1991).

Distribution of the rhizobial inoculant during the early stages of production (1977–1981) was

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ACIAR Proceedings 109e
(printed version published in 2002)

performed by DOAE and Market Organisation for Farmers (MFO) as shown in Table 8. In 1982, DOAE started a Seed Exchange Program in order to boost soybean production in Thailand. This 5-year program focused on soybean expansion and improvement of production efficiency. Participating

Table 6. Number of rhizobial cells per seed retained at different time after inoculation (Kotepong et al. 1986).

Adhesive agent	Concentration % (w/v)	Time after inoculation (hr)			
		0	2	4	6
Synthetic glue	100	5.30×10^5	1.45×10^6	8.40×10^5	4.55×10^5
Gum arabic	40	1.55×10^5	3.00×10^5	2.75×10^5	1.45×10^5
Vegetable oil	100	2.45×10^4	2.35×10^4	2.10×10^4	1.40×10^4
Tapioca starch solution	5	7.40×10^4	2.29×10^5	5.80×10^4	4.30×10^4
Sugar syrup	30	8.80×10^4	8.00×10^4	6.10×10^4	6.10×10^4
Water	100	2.40×10^4	1.55×10^4	1.45×10^4	1.15×10^4

Table 7. Effect of post inoculation on nodulation and yield of soybean at two locations (Rungratanakasin et al. 1983).

Inoculation days after sowing	Khon Kaen			Shachoengsao		
	Nodule no. (/pl)	Nodule wt. (g/pl)	Yield (kg/rai)	Nodule no. (/pl)	Nodule wt. (g/pl)	Yield (kg/rai)
0	52 ab	1.8 a	264 a	16 ab	1.9 a	330 ab
5	46 ab	1.3 ab	262 a	12 ab	1.2 ab	357 a
10	35 b	1.2 ab	258 a	11 bc	0.7 b	291 abc
15	49 ab	1.2 ab	235 ab	28 a	0.7 b	275 bc
20	59 a	1.0 b	230 ab	3 bc	0.1 c	226 c
Uninoc.	0	0	111 c	0 c	0 c	249 c

Table 8. Rhizobium production by the Thai Department of Agriculture (DOA), and distribution through three sectors: 1) Thai Department of Agricultural Extension (DOAE), 2) Private Sector (PS), and Marketing of Farmer Organisation (MFO), from 1977–1990.

	Tonnes inoculant		Bag's inoculant distributed			Total quantities of inoculant distributed	
Year	Producted	Used	DOAE	PS	MFO	Bags	Value
1977	5.00	3.36	6,950	—	9,865	16,815	6,467
1978	10.59	11.55	17,523	—	40,430	57,753	22,213
1979	7.42	5.77	22,296	—	6,548	28,844	11,094
1980	4.92	5.64	16,761	—	11,429	28,190	10,842
1981	7.48	7.36	26,649	—	10,164	36,813	14,159
1982	6.58	6.64	23,877	8,584	3,763	33,224	12,778
1983	14.36	13.15	34,557	30,079	1,104	65,740	25,285
1984	36.16	33.79	112,073	56,885	—	168,985	64,994
1985	48.77	46.51	157,323	75,264	—	232,577	89,453
1986	78.00	74.78	285,796	88,115	—	373,911	143,812
1987	81.63	79.79	248,595	150,378	—	398,973	153,451
1988	140.70	136.23	593,941	90,237	—	681,178	261,992
1989	134.27	125.30	557,527	68,996	—	626,523	240,970
1990	126.35	117.67	557,772	30,578	—	588,350	226,288
1991	73.78	72.30	338,006	23,500	—	361,506	129,453
1992	98.44	92.81	445,454	18,621	—	464,075	203,448

[1] One bag contains 200 gm inoculant at a cost of 10 baht ($US 0.40)

farmers were allowed to exchange their local variety seed for selected varieties produced by Government Seed Centres at a 1:1 ratio. Participating farmers were encouraged to buy a 200 g bag of inoculant for every 10 kg of exchanged seed at B10 per bag (B25 = US$1) which enable them to grow 1 rai (6.25 rai = 1 hectare). Production and distribution of inoculant expanded rapidly from 33,200 bags to 373,900 bags or more than ten times because of this program. In order to promote the use of inoculant, DOAE also developed cooperation with the private sector, especially with local dealers close to the cultivated areas to sell inoculant to remote farmers who may need to purchase only small quantities.

A Soybean Marketing and Production Development Project was initiated in 1987 following the Seed Exchange Program. This 5-year project was slightly different from the first program. Farmers were allowed to purchase superior variety seed at B10 per kilogram instead of the normal price of B15, provided they also purchased a bag of inoculant at the normal price of B10. To promote the use of inoculant, DOAE also provided a mobile unit to attract local farmers with training activities, slide presentations on-farm demonstration, field days and inoculant sales.

A similar program was also initiated for groundnut in 1987. Since the use of inoculant on groundnut was not common, farmers were given a bag of inoculant free of charge for a purchase of one kilogram of groundnut seed at B10.

A Soybean Joint Venture Project was conducted between 1989 and 1990. Under this project, the private sector also produced inoculant and distributed approximately 100,000 bags a year to the farmers who received credit from the BAAC to purchase agricultural material such as seed, fertiliser, rhizobial inoculants and pesticide from a certain contracted private company. A major component of the project was an agreement that the contracted company had to purchase farm produce from the farmers at a guaranteed price to ensure a stable market. It was reported that in 1990 the use of rhizobial inoculant produced by DOA were as follows: 477,333 bags for soybean (95.5 t) 72,746 bags for groundnut (14.5 t) and approximately 38,000 bags for mungbean and other leguminous crops.

The Soybean Joint Venture Project was extended from 1990 to 1996 in other to increase soybean production. In 1993, DOAE distributed 3598 tonnes of good quality seed to participating farmers in 33 provinces at B2.0 per kg plus free rhizobial inoculant.

In conclusion, the use of rhizobial inoculants in Thailand increased gradually because of several government programs. A monitoring and evaluation report on the use of inoculant by DOAE showed that in the major growing area the number of inoculant users increased from 30% in 1986–87 to 51% in 1989–90 for soybean and from 9.8% to 22% for groundnut during the same period, as shown in Table 9. However, the percentage of inoculant users will increase further as the government promotion programs continue.

Emergence of the Private Sector

Unlike other farm inputs, rhizobial inoculant required a certain level of production technology. Furthermore, market demand was uncertain. Therefore, it took 10 years before the first private firm entered the market in 1988. Since rhizobial inoculant was rather new to the farmers, marketing of the product was the major problem of the producers. Besides, storage of rhizobium at room temperature for a long period reduced the quality of the product. It was reported that there were four private firms producing rhizobial inoculant in 1989. At present, there are only two firms remaining. The estimated production of rhizobial inoculant by the private sector from 1988–1993 is shown in Table 10.

It can be observed that production of rhizobial inoculant by the private sector fluctuated from 200,000 to 300,000 bags depending upon the demand from the public sector in the government supported programs as mentioned earlier. At present, both firms are producing much below their capacities.

The sale of rhizobial inoculant to government supported programs was based on a bidding process. The wholesale price was around B7 per bag and the government program sold to the participating farmers at the normal market price of B10 per bag at the beginning of the Seed Exchange Program. However, at present, it is given free of charge.

Table 9. Monitoring and evaluation report (MER) on use of rhizobia inoculants (DOAE 1990).

	Percentage of crops inoculated with rhizobia			
Crops	1986–87	1987–88	1988–89	1989–90
Soybean	30.3	44.8	52.4	50.9
Groundnut	9.8	12.3	17.4	22.0

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Another marketing channel for privately produced rhizobial inoculants was through the provincial wholesalers located in the important legume producing province. The wholesalers then distributed inoculants to retailers in their own provinces. The wholesale price was around B6–7 per bag and the retail price was normally fixed at B10 per bag. The difference between privately produced inoculant and the DOA product was that the private firm used sterile peat at 100 grams per bag instead of 200 grams of non-sterile as produced by DOA. However, both sizes were recommended for use with 10 kg of seed to plant 1 rai of land (0.16 hectare).

Growth of Rhizobial Inoculant Production and Price

As mentioned earlier, soybean rhizobial inoculant has played an important role in the development of the inoculant in Thailand. At present, about 90% of the inoculant produced in Thailand is aimed at increasing soybean production. Table 11 shows that production of soybean inoculant increased from 7400 bags in 1980 to 1.0 million bags in 1993, a growth rate of 199%. For groundnut and mungbean, even though the rates of growth are high, the share of production was small, especially in 1993.

Nonetheless, the use of rhizobial inoculant in Thailand depends heavily on the promotion of the public sector. At present, where government policies have been geared towards an increase in soybean production for domestic requirements and groundnut and mungbean as substitute crops of paddy in the dry season, it is expected that there will be a strong demand of rhizobial inoculant, especially through the government-supported programs. With regard to inoculant price, there is no evidence that the retail price will change from B10 per bag. However, private producers complained that it was unfair that the participating farmers in the government-supported program received free inoculant for the purchase of quality seed while other farmers had to pay for the inoculant.

Table 10. Production of rhizobial producted by the private sector classified by type of legume. Unit: bag (100 gram).

Year	Soybean	Groundnut	Mungbean	Total
1988	200,000	—	—	200,000
1989	221,924	25,592	7,764	255,280
1990	310,521	43,329	13,676	367,526
1991	192,180	21,215	10,705	224,100
1992	118,512	213,746	9,382	341,640
1993	248,700	13,013	7,038	268,750

Table 11. Growth of rhizobial inoculant produced by DOA and the private sector classified by types of legumes. Unit: bag (200 g).

Year	Soybean	Groundnut	Mungbean	Others	Total
1980	7,400	12,920	7,318	552	28,190
1981	5,950	20,020	10,756	87	36,813
1982	5,184	13,380	5,907	8,456	32,927
1983	39,162	13,979	7,932	4,667	65,740
1984	97,469	30,482	48,893	2,114	178,958
1985	108,586	21,251	97,115	5,635	232,587
1986	217,988	66,699	83,763	5,461	373,911
1987	347,961	21,849	16,251	12,876	398,937
1988	778,502	46,850	51,626	4,200	881,178
1989	709,110	96,082	72,366	4,245	881,803
1990	787,853	116,074	49,137	2,810	955,876
1991	476,666	66,817	41,169	945	585,597
1992	396,790	275,762	132,675	488	805,715
1993	1,032,899	59,053	34,049	432	1,126,433
Total	5,011,520	861,218	658,957	52,968	6,584,665
Growth rate (%)	199	280	270	−7.8	287

Benefit of Legume Inoculants

Physical impact of rhizobial inoculant in Thailand

As in the other countries, rhizobial inoculant has shown a great potential for increasing legume crop yield. However, research on rhizobial inoculant used has been conducted repeatedly in several legume-growing areas in Thailand to confirm the result of the experiments in various soil types of both growing seasons. The main objective of the research on rhizobial inoculant has been on the effect on legume crop yield, return on investment and the nitrogen replacement by rhizobial inoculant.

Table 12 shows the physical impact of soybean rhizobial inoculant in both wet and dry seasons. The average yield revealed a difference of about 40 kg/ha of soybean grain with the use of rhizobial inoculant over the control plot in both seasons. The experiment on the use of rhizobial with P_2O_5 and K_2O at 56.25 and 37.5 kg/ha also showed a favorable result over N:P:K of 75-56-37 at a difference of 130 kg/ha in both seasons.

Table 12. Physical impact of rhizobial inoculant in wet and dry season.

Treatment	Yield (kg/ha)	
	Wet season	Dry season
Control	803	982
Rhizobium	1228	1377
R + (P − K) (56.25 + 37.5)	1352	1559
N:P:K (75:56:37)	1224	1426

N replaced by R (6.25 bags)

Wet season 1224 kg = 75 kg N

1352 kg = $\frac{75 \times 1352}{1224}$ = 82.8 kg N = 180 kg of Urea

Dry season = $\frac{75 \times 1559}{1426}$ = 89.0 kg N = 178.3 kg of Urea

Average both seasons = 179.2 kg of urea

Nitrogen replacement was calculated in term of urea fertiliser. It was found that 1250 g of inoculant can replace about 179.2 kg of urea fertiliser in both growing seasons or one bag of inoculant for 28.6 kg of urea.

The use of rhizobial inoculant on groundnut and mungbean also showed a positive response. Groundnut yield response to cowpea rhizobium of Tainan 9, the most common cultivar, showed an additional increase of 396.9 kg/ha and 126.9 kg/ha for mungbean rhizobial inoculant, as shown in Table 13.

Table 13. Physical impact of rhizobial inoculant used on groundnut and mungbean yield. Unit: kg/ha.

Treatment	Groundnut	Mungbean
Control	1412.5	1055.0
Rhizobium	1809.4	1181.9
Difference	396.9	126.9

Economic Impact of Rhizobial Inoculant in Thailand

The economic impact of rhizobial inoculant was derived from the physical impact by estimating costs and returns from the use of rhizobial inoculant. Table 14 shows the economic impact on soybean in wet and dry seasons. The use of rhizobial inoculant alone without adding chemical fertiliser on soybean in wet and dry seasons showed the highest net benefit over the control plot at $126.7 and $144.2 per ha respectively. This was mainly due to the high cost of chemical fertiliser.

The economic impacts of rhizobial inoculant used on groundnut and mungbean are also shown in Table 13. Net benefit of using rhizobial inoculants on groundnut and mungbean over the control plots were $91.5 and $36.2 per rai respectively. The use of rhizobial inoculant with additional chemical fertiliser did not reveal higher physical and economic return and was therefore negligible.

Estimated Cumulative Impact of Inoculant at National Level

The cumulative impact of inoculant, calculated from the additional benefit of inoculant in soybean, groundnut and mungbean from 1980–93, is:

Abt = Rit dYi Pit;

Where Abt = Accumulative benefit in year t;

Rit = Quantity of inoculant used on legume I in year t;

DYi = Yield increase from inoculant use on legume I;

Pit = Prince of legume I in year t;

Vit = Value of inoculant use on legume I in year t.

The estimated benefit from inoculants classified by types of legumes during 1980–93 was shown in Table 14. The total benefit of soybean inoculant from 1980–93 was US$100.2 million or more than 80% of the total benefit.

For the economic benefit of inoculant in substitution of nitrogen fertiliser, only soybean inoculant was used in the calculation. Price of urea fertiliser (Table 16) was used to estimate the value of N-fertiliser as shown in Table 16. The total value of N-fertiliser replaced by rhizobial inoculant was US$25.9 million.

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Table 14. Economic impact of soybean rhizobial inoculant in wet and dry seasons. Unit: US$/ha.

Treatment	Wet season			Dry season		
	Revenue	Additional cost	Net benefit over control	Revenue	Additional cost	Net benefit over control
Control	244.1	0	0	364.9	0	0
Rhizobial	373.3	2.5	126.7	511.7	2.5	144.3
R + (P – K) (56 – 37)	411.0	57.2	109.7	579.3	71.5	142.9
N:P:K (75:56:37)	372.1	101.5	26.5	529.9	100.0	65.0

For dry season:
Soybean price at $ 0.37/kg
Urea (46-0-0) at $ 0.19 kg. T.S.P at $0.35 kg, KCl at $ 0.18/kg
Fertiliser application at $15/ha, rhizobium at 2.5/ha
For wet season :
Soybean price at 7.60 B./kg
Urea (46-0-0) at 4.90 B./kg, T.S.P at 9.65 B./kg, KCl at 4.90 B./kg

Table 15. Economic impact of rhizobium inoculant used on groundnut and mungbean. Unit: f baht/ha.

Treatment	Groundnut			Mungbean		
	Revenue[1]	Additional cost	Net benefit over control	Revenue[2]	Additional cost	Net benefit over control
Control	351	0	0	322.5	0	0
Rhizobium	445	2.5	91.5	361.2	2.5	36.2

[1] Farm gate price of groundnut = $ 0.25 per kg
[2] Farm gate price of mungbean = $ 0.31 per kg

Table 16. Cumulative impact of rhizobial inoculant classified by types of legume during 1980–93. Unit: million US$.

Year	Soybean	Groundnut	Mungbean	Total
1980	0.1	0.3	0.04	0.44
1981	0.1	0.3	0.06	0.46
1982	0.1	0.2	0.03	0.33
1983	0.6	0.3	0.04	0.94
1984	1.5	0.4	0.26	2.16
1985	1.7	0.4	0.50	2.60
1986	3.5	0.8	0.40	4.70
1987	7.3	0.4	0.10	7.80
1988	17.3	0.9	0.36	18.56
1989	13.6	2.0	0.37	15.97
1990	15.2	2.4	0.25	17.85
1991	9.8	1.5	0.34	11.64
1992	8.1	5.9	1.20	15.20
1993	21.3	1.2	0.25	22.75
Total	100.2	17.0	4.20	121.40

Conclusions and Recommendations

The development of the legume inoculant industry started by the public sector in 1976 under the USAID loan in accordance with the establishment of Seed Centres in Thailand. The main objective of the program was to promote the use of inoculant in order to increase important legume products such as soybean, groundnut and mungbean to meet domestic demand. Most of the inoculant production was used in the government-supported programs.

Research on inoculant has long been conducted by many government agencies prior to the construction of the plant. After the construction, research and demonstrations have been conducted in various locations in Thailand. After the establishment of the Biological Nitrogen Fixation Resource Centre (BNF Resource Centre) at DOA in 1983, it was used as an international training centre for training in inoculant technologies for scientists from all over the world.

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With regard to the potential of the inoculant industry, the following recommendations should be considered.

1. More on-farm research and demonstrations on the use of inoculant should be conducted in order to convince farmers of the benefits of inoculant use.
2. Government should stop providing free inoculant to farmers and the price of inoculant should be determined by its cost of production.
3. Research on inoculant production technology should be conducted in order to obtain a high quality product.

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