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THE PERFORMANCE OF BIOLOGICAL NITROGEN FIXATION TECHNOLOGY IN THE TROPICS: Evidence From Northeast Thailand

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Keith Fuglie and Delane Welsch

Department of Agricultural and Applied Economics

University of Minnesota
Institute of Agriculture, Forestry and Home Economics
St. Paul, Minnesota 55108

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** Research Assistant, Department of Agricultural and Applied Economics, and Director of International Agricultural Programs, University of Minnesota, respectively.

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Interest in biological nitrogen fixation (BNF)[1] technology as an alternative to nitrogen fertilizer was given new impetus with the energy price shocks of the 1970s. Since that time, financial and scientific resources devoted to BNF research have increased significantly, especially in developing countries (App and Eaglesham, 1982). At least five of the International Agricultural Research Centers have established BNF research programs (Graham, 1982), along with scores of national agricultural research institutions in Latin America, Asia, and Africa.

Though the spectre of world food and fertilizer shortages are no longer imminent, interest in applying BNF technology in temperate and tropical regions remains keen. BNF technology is viewed as a means of reducing dependence on nitrogen fertilizer (and thus petroleum and natural gas), supplying nitrogen for food production to farmers lacking access to markets for fertilizers, and encouraging the production of grain legumes as sources of protein for the diets of rural poor. Forage legumes and nitrogen fixing trees are also being investigated for their potential to improve the productivity of farming systems.

The literature on biological nitrogen fixation is vast and rapidly increasing, but technological assessments on the realized

[1] Nitrogen fixation refers to the process of converting atmospheric nitrogen (N_2) to nitrogen compounds (ammonia, nitrate, urea) which can be used by plants. Industrially, this is accomplished using the Haber-Bosch process, which is very energy intensive, requiring very high temperatures and pressure to convert N_2 and H_2 to ammonia (NH_3). Certain microorganisms contain an enzyme catalyst called nitrogenase, which enables them to "fix" nitrogen biologically. Some of these microorganisms are free living and some are symbiotic, forming benefical associations with certain crop plants.

or potential contribution of BNF technology to agricultural productivity are few. Such assessments are necessary in order to identify technical and institutional constraints to technology diffusion and for the efficient allocation of research resources. In this paper we are concerned with such an assessment and present some evidence from Northeast Thailand to demonstrate the performance of selected applications of BNF technology in tropical agriculture.

During the past 15 years, Thailand has made a significant investment in BNF research and technology development. It now has facilities for large scale Rhizobium inoculum production, and has on-going research programs involving legume inoculation trials, rhizobium ecology studies, and the development of multiple cropping systems with legume components. In addition, in 1977 it established a research program to investigate the use of azolla as a green manure for rice, and more recently has begun studying agroforestry applications of biological nitrogen fixation. The results of these research efforts give us a body of data that can be used to determine what potential this technology may have for Northeast Thailand in the near future, and how research resources can be allocated to best take advantage of this potential.

In the next section of this paper, we review some of the recent experiences with BNF technology in tropical agriculture. We have limited our attention to three applications of BNF technology that are relatively well understood and thought to hold immediate potential for many tropical farming systems; namely, the inoculation of grain legumes with Rhizobium, the utilization of legumes in multiple cropping systems, and the cultivation of azolla as a green manure for rice.[1] In section III we show how the BNF research program in Northeast Thailand is organized. The performance of selected applications of BNF technology is assessed in sections IV through VI. In the final section we summarize the major findings of this study.

Several people and institutions lent invaluable assistance for the completion of this study. We would like to acknowledge the staff in the Faculty of Agriculture and Farming Systems Research Project at Khon Kaen University, especially Dr. Terd Charoenwatana, Dr. Banyong Toomsan, Ms. Nongluk Suphanchaimat, Mr. Attachai Jintrawet, and Ms. Suphonpen Chaiyasuj. Several individuals in the Department of Agriculture in Bangkok were also very helpful in providing information on the BNF research program in Northeast Thailand. In particular we would like to acknowledge Dr. Nantakorn Boonkerd, director of the BNF Resource Center and Dr. Chob Kanareugsa of the Rice Soil and Fertilizer Research Group. Financial assistance was provided by USAID and the Niftal Project, Hawaii. But any errors in the paper are the responsibility of the authors.

[1]There are other applications of BNF technology that hold significant economic potential for tropical agriculture as well. The use of pasture legumes holds great potential for improving the productivity of the CERRADOS and LLANOS savannas of Latin America (Dobereiner, 1978). Agroforestry applications (with Leucaena, for example) may help meet the growing demand for fuelwood, forestry products and animal fodder, and may contribute substantially to soil improvement and reforestation in many areas throughout the tropics (National Academy of Sciences, 1977). Other potential contributions, such as the transfer of nitrogen fixation association capability to cereal crops, will require long term research efforts (Hardy and Halvecka, 1975).

II. BNF TECHNOLOGY IN TROPICAL AGRICULTURE

In nature, biological fixation of atmospheric nitrogen is accomplished by a wide variety of bacteria. Some of these microorganisms are free living, but the ones of greatest agricultural interest are symbiotic, forming beneficial associations with certain plants. These symbiotic organisms provide fixed nitrogen to the plant, which in turn provides a protected environment and photosynthate (energy) for the organism.

The most economically significant associations occur between legumes (soybeans, peas, beans, peanuts, alfalfa, clover, Leucaena) and specific strains of Rhizobium. These plants have uses as food crops, livestock fodder, green manures, and forestry products. Another less well known association occurs between Anabaena (blue-green algae) and Azolla, an aquatic fern. Azolla has been cultivated as a green manure for rice production in China and Vietnam for several centuries.

Applied research on BNF technology in tropical agriculture has increased significantly since the early 1970s. The energy price shocks of 1973 and 1979 sparked renewed interest in developing substitutes for nitrogen fertilizer since industrial fertilizer production is very energy intensive. Some agricultural researchers felt that immediate benefits could be achieved by (1) transferring Rhizobium inoculation technology which had already been extensively developed in the United States and Australia to tropical countries, and (2) encouraging the use of legumes in multiple cropping systems (Dart, 1979; Halliday, 1982).

Experiences of the past decade and a half have revealed some the limitations of inoculation technology. Native Rhizobium strains are prevalent in tropical soils, especially where legumes have been previously grown. Inoculating legumes in these areas with new Rhizobium may have little or no effect on yield. The type of legume is also a factor, as some legumes appear to be fairly "promiscuous" in their associations with different Rhizobium strains, whereas other legumes are highly selective (Halliday, 1982). Inoculation trials in areas not previously planted to legumes illustrate the effect of Rhizobium selectivity. In Brazil, where soybean production has expanded significantly in the past decade, Dobereiner (1980, 1982) reports that domestically produced Rhizobium inoculant has made significant contribution to increasing soybean yields. But the recent rapid expansion of peanut production in Sudan has not benefited from inoculation (Hadad, 1986). In the latter case, peanuts were apparently able to form fairly effective associations with native "cowpea-type" Rhizobia that were already present in Sudanese soils. Similar results are reported in section V of this paper for Northeast Thailand.

But even in cases where legumes form BNF associations with native Rhizobium, it may be possible to achieve productivity gains by introducing improved cultivars (selected for their better BNF performance) and improved Rhizobium strains. Developing selection criteria and testing various cultivar-Rhizobium combinations is a major focus of applied BNF research in the tropics. And there appears to be a fairly wide range in

BNF capability among cultivars and Rhizobium in the genetic pool[1]. But improved strains of Rhizobium introduced through inoculation often have difficulty competing with native Rhizobium strains in forming associations with legumes. Researchers conducting inoculation trials with grain legumes in the tropics typically report a low proportion of improved Rhizobium strains in the root nodules and a wide variation in response to inoculation across plot locations. The poor performance of field inoculation techniques may be the key constraint to the success of inoculation technology (Burgess, 1983; Dobereiner, 1978).

Multiple cropping systems which include a legume component (either as an intercrop or in a sequential rotation) to maintain soil fertility have been practiced in temperate and tropical environments since Roman times. Cereal-legume crop rotations are a standard practice in the U.S. corn belt and in Australian wheat producing areas. Andean farmers commonly plant bean-maize intercrop patterns, and grain legumes grown in the winter season follow cereal summer crops in many parts of India. Over the past several decades, multiple cropping systems have been adopted in many of the rice producing areas of Asia as well, though these systems may or may not include a legume. The main factors enabling the adoption of rice-based multiple cropping systems have been the investment in irrigation systems and the

[1]The task of collecting and characterizing cultivar and Rhizobium associations for their BNF capability is formidable. The International Agricultural Research Centers are playing a leading role in this endeavor. In addition, the techniques used to quantify biological nitrogen fixation in plants have improved in recent years.

development of short season, photoperiod insensitive modern rice varieties (Barker and Herdt, 1979). Efforts to extend multiple cropping practices to rainfed areas using traditional photoperiod sensitive rice varieties have so far had only limited success (for example, see section IV of this paper). But there does not appear to be much evidence to suggest that legumes are playing a larger role in multiple cropping systems as a result of increased energy and fertilizer prices.

The potential of azolla as a nitrogen substitute in rice production has received more attention from BNF researchers than legume-rice crop rotations. Azolla as been a major source of nitrogen for rice in East Asia for centuries, especially in China (Lumpkin and Plucknett, 1982). It is currently being studied for its potential in several locations around the world, including the United States, Philippines, Thailand, India, and West Africa. Economic assessments of azolla as a source of nitrogen in rice production have been carried out by Anderson, et. al, (1983) for the United States and by Kikuchi, Watanabe and Haws (1984) and Rosegrant, Roumasset, and Balisacan (1985) for the Philippines. Section VI of this paper makes a similar assessment for Northeast Thailand. These studies conclude that azolla is only competitive in environments with very low agricultural wage rates, with artificially high nitrogen fertilizer prices (due to fertilizer import restrictions), or where some rice land is left fallow each year (such as with the land "set-aside" program in the United States, for example). Economic constraints to azolla use are its heavy reliance on phosphate fertilizer and insecticide, and the high cost of incorporating azolla into the paddy soil (either manually or mechanically).

These field studies on the performance of BNF technology in the tropics also point to another important result. Though BNF technology has the potential to be a substitute for nitrogen fertilizer, it will still require a sophisticated input delivery and support system. Producing and delivering quality inoculum, complementary inputs and management information can only be accomplished in areas where farmers have ready access to input markets and information services.

III. BNF RESEARCH IN THAILAND

In this paper we focus our attention on applications of BNF technology in the Northeast Region of Thailand (see Figure 3.1). This Region contains a third of the country's population and land area. About 75 percent of the agricultural crop land is devoted to rice production (almost all of which is rainfed) and the rest is planted to upland crops, cassava being the most important. The area planted to grain legumes constitutes only a small fraction (less than 3 percent) of total crop land, but is growing rapidly, at over 25 percent per year in the early 1980s (Office of Agricultural Economics, 1986). Agricultural producers use very few modern inputs and low soil fertility and erratic rainfall result in low cropping intensity and productivity. Research on biological nitrogen fixation is one part of a broader effort to develop improved agricultural technology for the Northeast Region.

A modest but diverse research program on biological nitrogen fixation has evolved in Thailand since the early 1970s. Interest in BNF technology received a major boost when domestic production facilities began making Rhizobium inoculum available on a large scale. Inoculum production had reached 30 tons a year by 1984, enough for 24,000 hectares. Nationally over 900,000 hectares were being planted to grain legumes (mungbeans, soybeans, and peanuts) at this time. In this section of the paper we identify the main topical areas of BNF research in the Northeast Region and discuss the important linkages between local research stations and research institutions in developed countries and the International Agricultural Research Centers.

The main emphasis of BNF research in the Northeast has been to improve the BNF performance of grain legumes (mainly soybeans and peanuts). Initially this work consisted of conducting inoculation trials at different locations in the Region. More recently this work has focused on determining the most suitable combinations of cultivars, Rhizobium strains, and fertilizer levels. Micronutrient constraints to BNF in grain legumes are also being investigated. Another line of research has sought to develop simple and effective inoculation techniques that will enable improved Rhizobium strains to dominate over native Rhizobium in forming associations with legumes. Finally, studies have been initiated on the ecology of Rhizobium under local environmental conditions (for example, to determine the seasonal fluctuations of Rhizobium populations in the soil).

A second research area is to find new niches for legumes in local farming systems. Extensive resources have been devoted over the last decade toward developing multiple cropping patterns to replace traditional monocrop practices in paddy and upland areas. Examples of proposed cropping systems are to grow peanuts or cowpeas in paddy fields in the early rainy season followed by transplanted rice and to grow peanuts intercropped with cassava in upland areas.

As mentioned in section II, efforts to promote more intensive cropping patterns have not had much success unless accompanied by irrigation facilities or shorter season varieties. But traditional photoperiod sensitive rice varieties appear to be particularly well suited for the rainfed environment of the Northeast Region (Pushpavesa and Jackson, 1979), and modern varieties have not been widely adopted (Office of Agricultural Economics, 1984). Furthermore, the prospects for new irrigation systems are severely constrained (Asian Institute of Technology, 1978). As a result, the adoption of multiple cropping systems in the Northeast Region has been very limited and site specific. Grain legumes, a small but rapidly growing component of agricultural production in the Region, are grown mainly as a monocrop in upland areas.

The use of azolla as a green manure for rice constitutes a third major area of BNF research in the Northeast Region. Research on azolla was initiated in 1977, and a series of multilocational trials were conducted in 1979, 1980, and 1982 (the economic assessment of azolla in section VI of this paper makes use of the data generated from these trials). Current research is focused on (1) comparing the productivity of different azolla varieties and determining optimum fertilization levels; (2) testing mechanical methods of incorporating azolla into the paddy soil; (3) controlling insect pests; (4) studying the effects of paddy water level on azolla growth; and (5) developing ways to maintain a stock of azolla over the dry season.

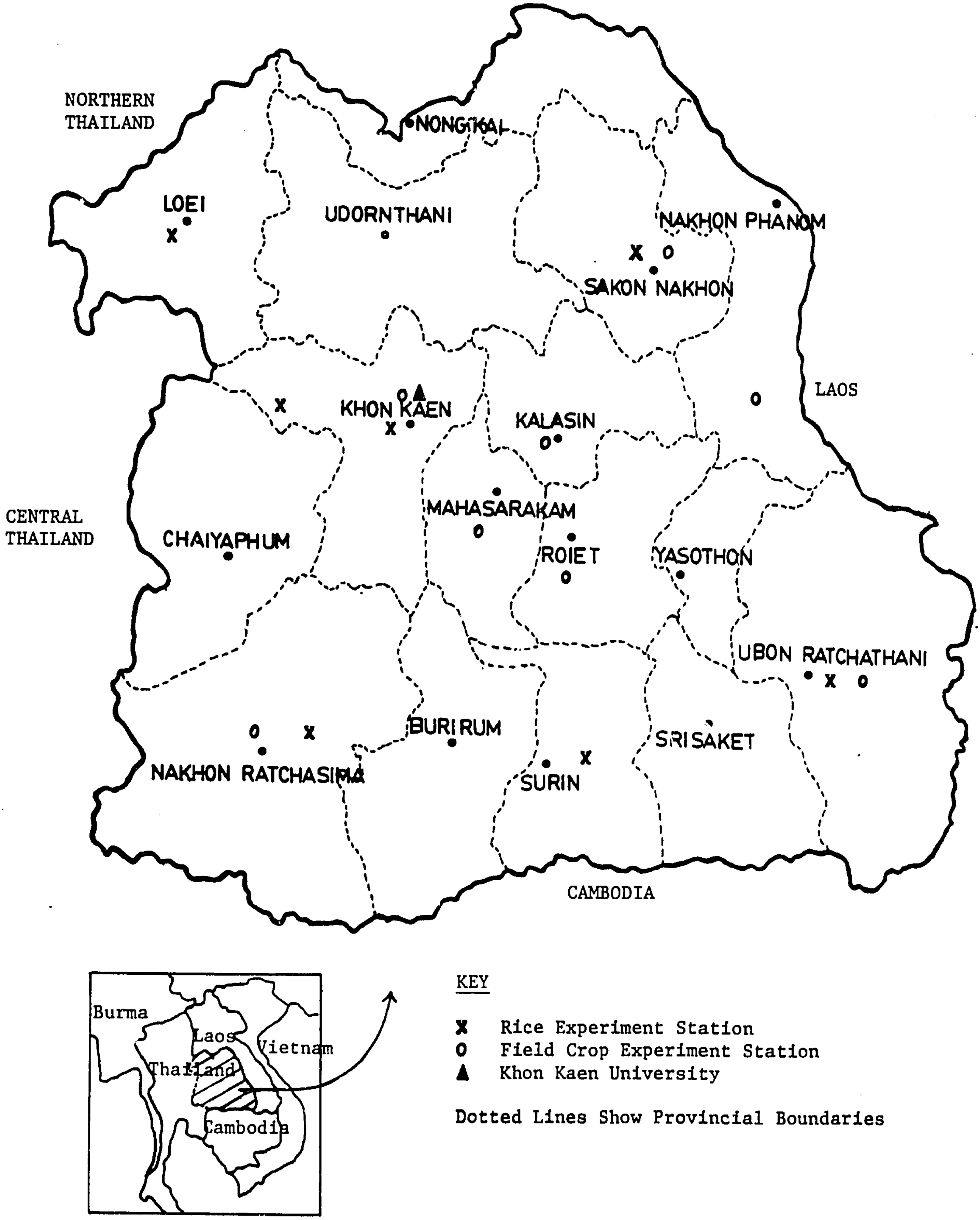
There are also research projects in the Northeast Region that are testing the performance of pasture legumes and tree legumes. This work is currently on a very modest scale. But the low productivity of traditional forage grasses and the increasing scarcity of fuelwood and lumber in the Region suggest that these research areas hold significant potential. Adoption of these technologies will be complicated by the village institutional environment, however, as pasture and woodlands tend to be used communally (KKU-Ford Cropping Systems Project, 1982).

The Department of Agriculture (DOA) is the central agricultural research institution in Thailand and maintains six rice research stations and eight field crop research stations in the Northeast Region. The main regional university (Khon Kaen University) also conducts some agricultural research, and has a small BNF research project with peanuts. Figure 3.1 shows the distribution of these research facilities in the Region.

The BNF research program has received significant support from foreign assistance agencies, which may have served to shift local priorities in favor of additional BNF research. The United States Agency for International Development (USAID), for example provided most of the funds to develop domestic Rhizobium production facilities. These agencies continue to provide financial support for collaborative research projects with research institutions in developed countries. Linkages with research centers in Australia, the United States, Canada, and Japan play an important role in making the latest research methods available to Thai scientists. The use of N15 isotope tracing techniques to quantify nitrogen fixation in soybeans, for example, is being carried out in collaboration with scientists from the Lethbridge Research Station in Alberta, Canada.

The International Agricultural Research Centers have so far played a relatively passive role in supporting BNF research in Northeast Thailand. Their main contributions appears to have been to provide new types of cultivars for field trials and to sponsor

FIGURE 3.1: THE NORTHEAST REGION OF THAILAND SHOWING THE LOCATION OF RICE AND FIELD CROP EXPERIMENT STATIONS



some regional conferences.

Another major component of the BNF research program are national and international conferences and workshops. These meetings give researchers the opportunity to present their own findings and to engage in useful discussions with other scientists. National workshops also provide a forum for research planning. The Annual Groundnut Research Workshop, for example, is a commodity based workshop in which major research results from the previous year are reviewed and Group Discussion Reports are prepared to suggest future research initiatives. This workshop covers not only BNF topics, but also peanut breeding, agronomic practices, pest control, and post harvest technology. International and regional conferences tend to be more subject-area-specific, and allow participants to hear from scientists who are at the leading edge of their discipline.

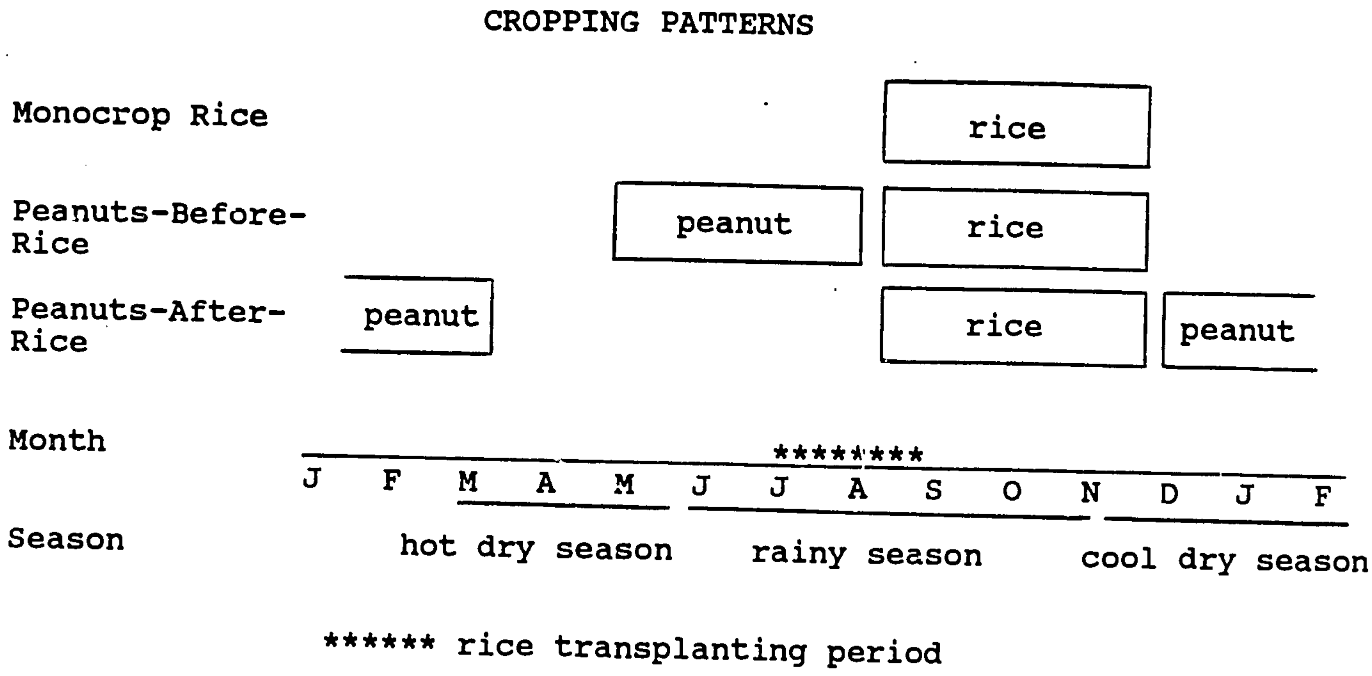
The institutional capacity for agricultural research in Northeast Thailand is almost entirely due to investments made during the past 20 years. The system is evolving from a highly centralized and concentrated organization (in Bangkok) to a system with more technical and scientific capacity and opportunity for initiative at individual experiment stations. The research program on biological nitrogen fixation technology is fairly modest but is investigating a wide range of applications. The linkages being created with research institutions in developed countries will allow Thai scientists to take advantage of new developments as they occur.

IV. INCORPORATING LEGUMES INTO CROPPING SYSTEMS

Legumes make significant economic, nutritive, and biological contributions in tropical farming systems. In the Northeast Region of Thailand, legumes are relatively minor crops but production is increasing rapidly. Though currently grain legumes are grown mainly in upland areas in a monocrop system, substantial research resources are being devoted to developing new multiple cropping systems involving legumes. Research trials have been carried out in both upland areas (such as with cassava-peanut intercropping) and in paddy areas (for example, with rice-peanut sequential cropping). But the adoption of more intensive cropping systems in rainfed agricultural areas (over 80 percent of the Region's crop land is rainfed) may be limited by technical and economic constraints. In this section we evaluate results from some on-farm trials with rice-peanut cropping sequences. We compare the performance of this cropping pattern to the returns from existing farm enterprises and also investigate legume-rice yield interactions. These results shed light on the nature of the constraints facing the development of new cropping systems.

Research on rice-peanut cropping patterns in rainfed agricultural areas has been under way for several years. Figure 4.1 shows some typical cropping patterns that have been tested. Peanuts have been investigated as an early dry season crop to be planted following the rice harvest and as an early wet season crop, to be grown before transplanting rice to the paddy field. In the 1984-85 season, researchers at Khon Kaen University conducted multi-location trials with a peanut-after-rice cropping

FIGURE 4.1: SOME PEANUT-RICE MULTIPLE CROPPING PATTERNS



Note to Figure 4.1:

The traditional cropping pattern in rainfed paddy areas of Northeast Thailand is monocrop rice. When rains begin in May or June, the paddies are cultivated and nurseries established. Farmers typically plant photoperiod sensitive, glutinous varieties of rice. Transplanting usually occurs in July and August, depending on rainfall. In many years, upper paddies are left unplanted because of insufficient rain.

Increasing cropping intensity is one way to enhance agricultural productivity. Peanut has been investigated as a possible "pre-rice" or "post-rice" crop. In the peanut-before-rice sequence, peanuts are planted in May and harvested before transplanting occurs. In the peanut-after-rice sequence, peanuts are planted in the cool dry season, after the rice has been harvested. The peanut crop relies mainly on residual soil moisture for its water requirements. Peanut residual plant matter may also serve as a green manure for rice or as a livestock feed.

pattern. Farmers provided labor and draft animals while the research team provided seed, a small amount of fertilizer and insecticide, and instructions on cultivation techniques.

Paddy land is typically left fallow throughout the dry season, though some farmers plant plots of corn or vegetables if shallow wells or ponds are available nearby for irrigation (hand-carried in buckets). Several farmers who participated in the peanut-after-rice trials also planted some of their paddy to these crops in the early dry season. These crops give a good indication of the alternative opportunities available for farm resources (i.e. an appropriate measure of their opportunity cost).

To evaluate the competitiveness of the proposed peanut-after-rice pattern we compared the net returns from peanuts with the net returns from corn and assorted vegetables that were grown at the same time. The results are summarized in Table 4.1. The figures shown are the net benefits, found by subtracting input costs (including labor costs) from the gross value of production (see Perrin, et. al., 1976, for a discussion of partial budgeting analysis). In some locations peanuts outperformed corn and vegetables. Overall, peanuts gave comparably lower but more stable net returns. Corn production can be highly profitable but is more risky. A moderately risk averse farmer might find peanuts-after-rice to be a viable cropping pattern for his or her farm.

The farmers taking part in these trials continued to be monitored by the research team during the 1985-86 and 1986-87

TABLE 4.1 COMPARING NET RETURNS FROM DRY SEASON CROPS

Location	Net Returns (baht/ha)		
	Peanuts	Corn	Vegetables
Ban Fang	288	11,294	12,300
Muang	-700	-106	-6
Nong Rua	3,166	-1,434	2,863
Kranuan	5,613	10,406	-1,750
Ban Phai	2,150	650	--
Average	2,103	4,162	3,352
Stn Dev.	2,480	6,159	6,261
C. V.	118%	148%	187%

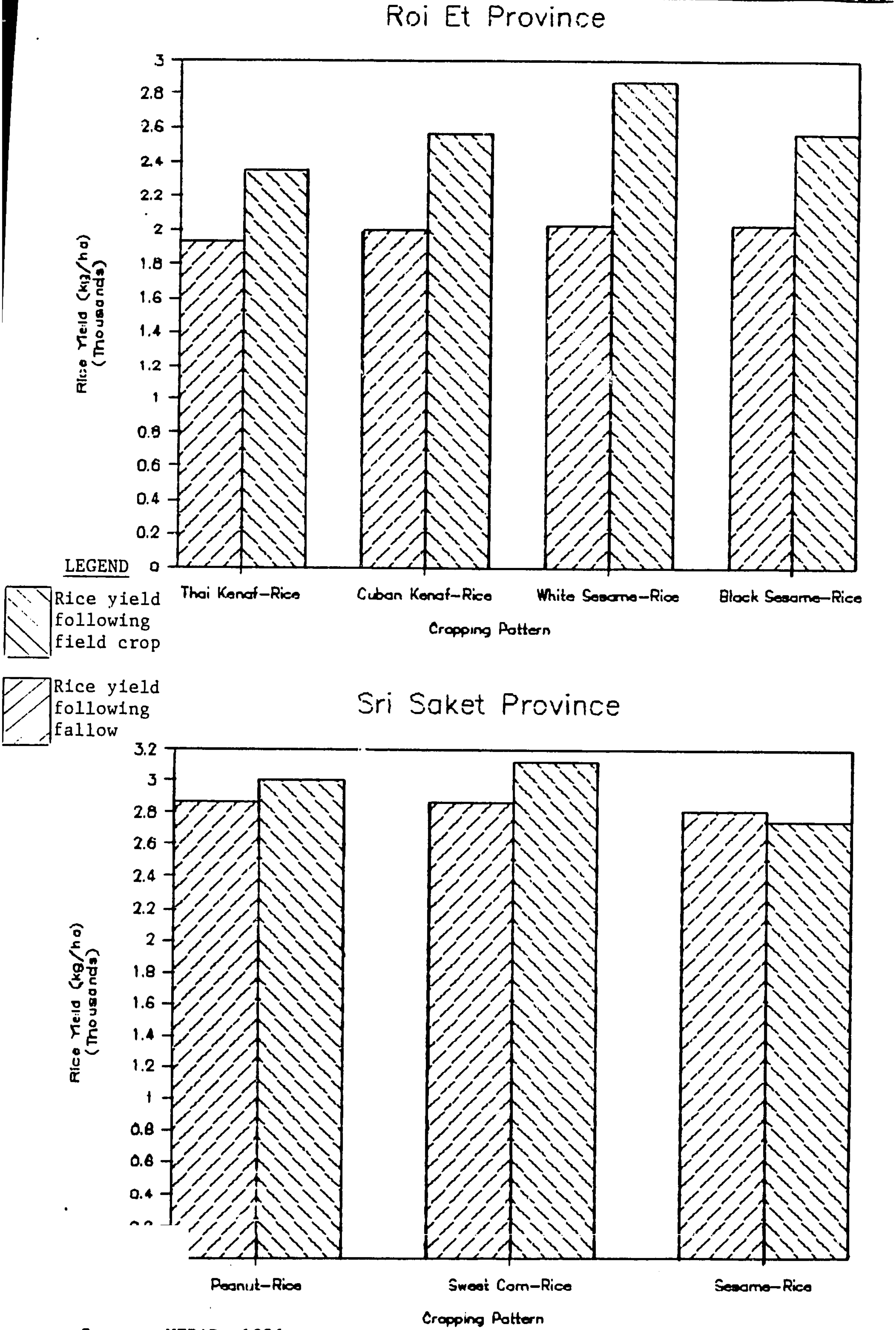
crop years. Several, though not all, farmers continued to plant small plots of peanuts after rice on their farms. The farmers who discontinued planting peanuts gave several reasons for doing so. The most important factor appeared to be the availability of soil moisture in the early part of the dry season and the level of the water table. Highly permeable soils or soils with a low water table simply cannot support a dry season crop without irrigation. Other constraints faced by farmers included the availability and cost of quality peanut seed and the difficulty in protecting the plots from livestock, which are left free to graze the rice stubble after harvest. These factors, particularly the first, will limit the widespread adoption of this cropping pattern in rainfed areas.

Another important consideration in the evaluation of multiple cropping patterns is the potential for crop interactions. Many legumes can serve as green manures for subsequent crops (a positive interaction) which can be enhanced through technological advances in biological nitrogen fixation. Negative interactions may also occur. For example, planting an early season crop may result in costly delays in planting the second crop.

Peanuts grown in paddy fields in the dry season appear to have little or no effect on rice yields in the following rainy season. To determine possible residual effects of peanuts on rice, several plots from the multilocational peanut-after-rice trials were selected and rice yields in the subsequent season were measured. Table 4.2 shows rice yields on plots that had been planted to peanuts and on adjacent plots that had been left fallow (control) during the dry season. These plots were monitored for two years in a row, though a few farmers quit growing peanuts the second year (these were dropped from this analysis). No significant residual effects were found (2.7 tn/ha for rice following peanuts compared to 2.6 tn/ha for rice following fallow fields) though there was considerable variation from location to location and from year to year (see Appendix A).

Significant crop interactions have been observed, however, with multiple cropping patterns involving crops grown in the early rainy season before rice. Results from cropping trials conducted by the Northeast Rainfed Agricultural Development (NERAD) Project in 1985 showed that rice yields increased when preceded by an early season field crop (Figure 4.2). This result

FIGURE 4.2: RESIDUAL EFFECTS OF EARLY WET SEASON FIELD CROPS ON RICE YIELDS



Source: NERAD, 1986

was observed for several kinds of field crops, not just legumes. Wilairat (1984) reported similar results in a study conducted in Khon Kaen Province in the 1983 wet season (Table 4.2). Rice yields were only 1.5 tn/ha when grown alone. Sesame-rice and mungbean-rice sequences increased rice yields to 1.8 tn/ha and a peanut-rice pattern increased rice yields to 2.0 tn/ha.

TABLE 4.2 RICE YIELDS FOLLOWING EARLY WET SEASON CROPS

Cropping Pattern	Rice Yield (tn/ha)
Peanut-Rice	2.04 a
Mungbean-Rice	1.78 ab
Sesame-Rice	1.79 ab
Fallow-Rice	1.52 b

Small letters denote significant differences between means. Means with the same letter are not statistically different (95% significance level).

(Adapted from Wilairat, 1984, p. 64, Table 5).

The causes of this interaction are not clear. But it does not appear to be solely due to increases in soil nitrogen made available from biologically fixed nitrogen in legume crop residual matter, as non-leguminous crops had a similar effect on rice yields.

In this section we identified some technical and economic constraints to the adoption of a proposed multiple cropping pattern and demonstrated the importance of taking into consideration the interactions between crop in evaluating cropping systems. In rainfed areas of the Northeast Region, farmers have adopted multiple cropping systems in some areas, but these appear to be location-specific and occupy relatively small areas. In the case of peanuts-after-rice investigated here, peanuts were found to give lower but more stable returns that other agricultural opportunities available to farmers. But these results were highly dependent on the availability of soil moisture in the early dry season, suggesting that this pattern may not be suitable for many paddy areas.

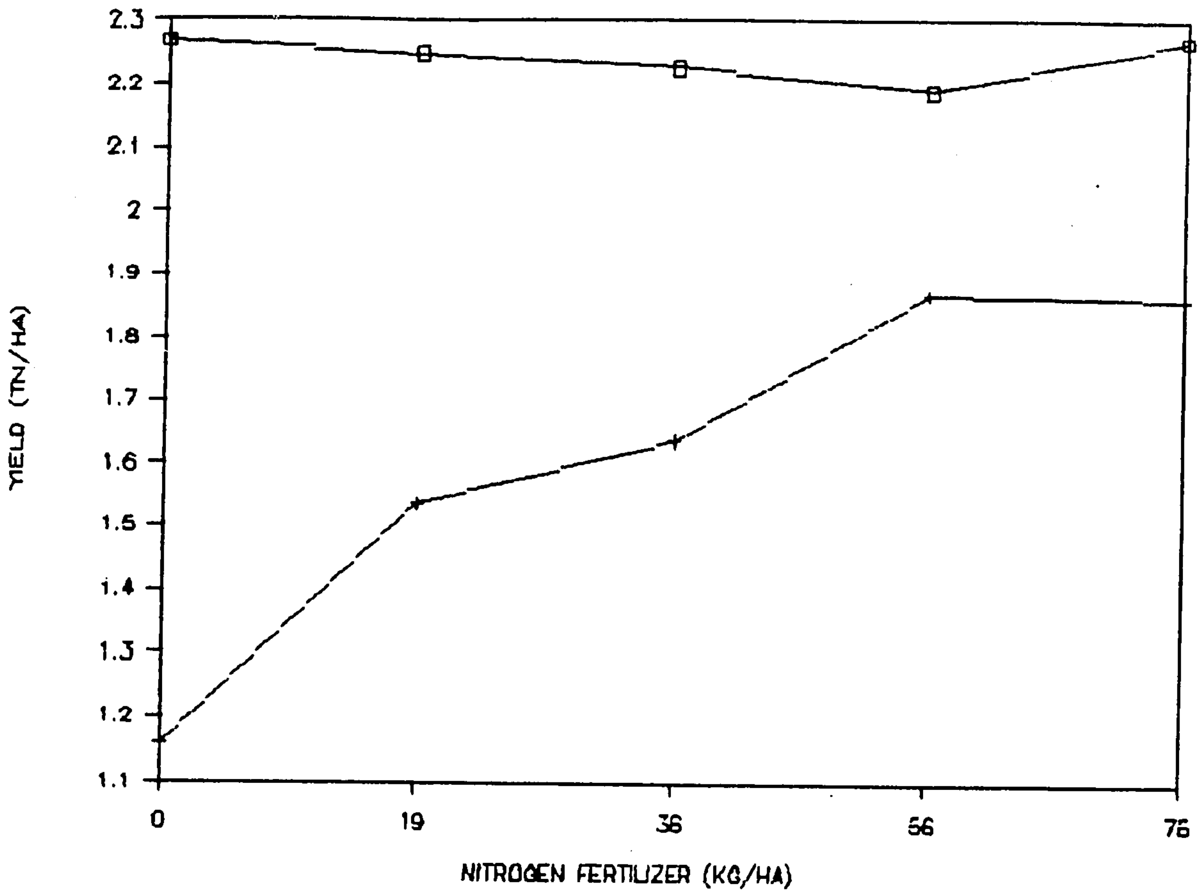
V. INOCULATION OF GRAIN LEGUMES

Inoculating legumes (usually accomplished by mixing Rhizobium-rich peat or soil mixture with seed just prior to planting) is one way that BNF can increase yields. In section II we outlined some general results from inoculation trials in the tropics. Below we summarize these data for Northeast Thailand. First we report on inoculation experiments conducted at research stations with soybeans, peanuts, and mungbeans. Then we present findings from some on-farm inoculation trials. Experiments conducted at a research station can be carefully controlled and measured but may not be very representative of farm level technology. On-farm trials that involve farmer participation, on the other hand, portray realistic farm conditions and enable researchers to solicit the perspectives of farmers about the new technology.

Inoculation trials with soybeans were first conducted in the Northeast Region in 1973 (see Boonkerd, et. al., 1979a, for a full description of these experiments). Soybeans were planted at three locations in the Region in plots that had never previously been sown to the legume. The response to inoculum was tested at several levels of nitrogen fertilizer.

At each location, soybeans responded vigorously to inoculation. Figure 5.1 plots the yield response to fertilizer (averaged across all locations) with and without inoculation. Inoculated plots outperformed uninoculated plots even at high rates of chemical fertilizer. Yield increased by over 1 tn/ha against the control plot (i.e. when no fertilizer was added). Researchers conducted further inoculation experiments in 1974 and

FIGURE 5.1: SOYBEAN RESPONSE TO NITROGEN FERTILIZER WITH AND WITHOUT INOCULATION



LEGEND

+ without inoculation

□ with inoculation

Without Rhizobium inoculation, soybeans in Northeast Thailand require considerable amounts of nitrogen fertilizer. Effective inoculation, on the other hand, can increase yield by up to 1 tn/ha. In this set of inoculation experiments, yields of inoculated plots exceeded yields of uninoculated plots even at high rates of fertilizer.

Source: Boonkerd, et. al., 1979a

1975 to evaluate the performance of a wide selection of Rhizobium japonicum strains on soybean yield (variety S. J.). Efficient strains increase yield by 40 to 100 percent over control plots (Boonkerd, et. al., 1979b).

In 1979, this work was extended to peanuts and mungbeans, and inoculation experiments are continuing in order to identify efficient Rhizobium strains and effective inoculation techniques. So far the experiments with peanuts and mungbeans have demonstrated only minimal yield response to inoculation and chemical nitrogen fertilizer (Vasuvat, et. al., 1979; Boonsam, et. al., 1984, 1985). Peanut and mungbean plants typically show extensive root nodulation (evidence of Rhizobium association) even in uninoculated plots. Native cowpea-type Rhizobium appear to form fairly effective association with these species of legumes.

Between 1984 and 1986, on-farm inoculation trials were conducted with peanuts in order to evaluate the performance of the technology under the management regime practiced by farmers. This approach allows researchers to solicit the opinions of farmers in addition to monitoring the performance of inoculum technology under actual farm conditions. The trials were conducted during the 1984-85 dry season, the 1985 wet season, and again in the 1985-86 dry season. Inoculation trials were carried out in several locations with farmers who were planting peanuts in paddy fields as either a pre- or post-rice crops in rainfed areas.

On-farm trials typically follow a very simple experimental design. In these trials, the only difference from farmer practices was to mix a portion of the peanut seed (Tainan 9 variety) with a peat mixture containing rhizobium immediately prior to planting. Each trial plot was about 1 rai (0.16 hectares), half of which was inoculated and half left uninoculated. Some phosphate fertilizer and furidol (pesticide) were applied during planting. Farmers in Khon Kaen and Surin planted peanuts in paddy (rice) fields shortly after the rice harvest. Husbandry practices involved thorough land preparation and relatively deep seeding (5-6 cm) using buffalo-drawn plows. In Nakhon Ratchasima, farmers planted peanuts early in the wet season (also in paddy fields). Following peanut harvest (in mid August) these fields were then transplanted to rice. Farmers used very little tillage and planted peanuts using a simple "jabbing technique," where a stick is used to make a shallow hole (2-3 cm) for seed which is then covered with soil. Little weeding or other crop activity was done in these fields until harvest time, when the crop was harvested by pulling up the plants and removing the pods by hand.

These trials failed to reveal any consistent pattern in the response to inoculation. Table 5.1 provides a summary of the data. During the 1984-85 dry season, only plant samples were taken from the plots. In Khon Kaen, inoculated plots appeared to do somewhat worse in terms of nodule formation and plant growth. In Surin, on the other hand, inoculation did appear to increase nodulation rather considerably. In the 1985 wet season, inoculated plots in Nakhon Ratchasima yielded somewhat less than uninoculated plots, though differences were not significant. No yield differences were observed in the third set of trials (in Khon Kaen) either.

TABLE 5.1: PEANUT RESPONSE TO INOCULUM: Results From On-Farm Trials

SEASON	LOCATION	NO. OF FARMS	INOCULUM RESPONSE uninoc.	inoc.	INDICATOR
Dry season 1984-85	Khon Kaen	3	52	36	nodules (#/plant)
			40	27	nodule wt.(mg/pl)
			6	4	plant wt. (g/pl)
	Surin	2	36	108	nodules (#/plant)
			17	63	nodule wt. (g/pl)
			14	16	plant wt. (g/pl)
Wet season 1985	Nakhon Ratchasima	6	1638	1500	yield (kg/ha)
Dry season 1985-86	Khon Kaen	2	1325	1325	yield (kg/ha)

plant wt. is plant dry weight
yield is fresh yield

Working closely with farmers in on-farm trials allows researchers to assess farmers' attitudes toward using new technology. There is some concern that farmers may be adverse to using inoculants. Halliday (1982) reports that farmers in Brazil discard free inoculum rather than coat their seeds with the "dirty" peat mixtures. But the farmers in the on-farm trails in Northeast Thailand were anxious to try the inoculum and there did not appear to be any attitudinal barriers to its use. There was good participation at village meetings and several farmers were willing to repeat the experiments for a second year. The relatively inexpensive cost of inoculum (less than $3.00 per ha) was another factor in its favor. Timely delivery of quality rhizobium may present a problem, however, as the rhizobium quickly looses its vitality if not kept cool and in the shade. For these trials, inoculum was provided by the researchers, but in the future farmers will have to obtain it from private dealers or from extension services. Some farmers were also concerned that excessive handling of the seed during mixing with Rhizobium might damage the seed. But overall, farmers were clearly willing to try this technology.

The evidence presented above and in section II may seem to suggest that the extension of inoculant technology should be limited to legumes (such as soybeans) that do not form associations with native Rhizobia. Though this will be one source of immediate and significant gains from BNF technology, one should not discount the potential for enhancing the performance of other legumes through <u>incremental</u> improvements in BNF capacity. By selecting and breeding cultivars on the basis of their BNF capability and by selecting the most efficient Rhizobium strains, the productivity of legumes in tropical agriculture can gradually be increased. Researchers at the International Crop Research Institute (ICRISAT) have, for example, identified a particular peanut variety ("Robust-33") that exhibits superior BNF capability and yield performance when inoculated with efficient Rhizobium strains (Nambiar, et. al., 1982). A limiting factor appears to be the availability of effective and simple inoculation techniques that will enable introduced Rhizobium to predominate over existing Rhizobium in the soil.

VI. AZOLLA AS A SOURCE OF NITROGEN IN RICE PRODUCTION

In this section of the paper we examine the economic feasibility of using azolla in rice production in Northeast Thailand. Since azolla is still in an experimental stage in the Region, we rely upon data from rice experiment stations rather than farm survey data to construct production parameters.

Azolla can be grown in the paddy field prior to rice transplanting, intercropped with rice after transplanting, or both. Ample water supplies are critical for the growth of azolla, however (40-50 mm of paddy water depth are recommended throughout the growth period). Azolla growth will be retarded if the water depth decreases, and the fern will die if the paddy remains completely dry for one or two days (Lumpkin and Plucknett, 1982). Azolla is best suited for irrigated areas and rainfed areas with dependable water supply or substantial catchment areas. This will limit its applicability to many of the marginal rainfed rice environments found in the Northeast Region.

Experiments with azolla have been carried out at several locations in the Region (Jantawat, 1985, contains the data and a description of these trials). Below we combine the data from these locations and from three years of trials (1979, 1980, and 1982) to obtain fairly representative estimates on the performance of azolla in suitable areas of the Northeast. These experiments combined nitrogen fertilizer (N) treatments with azolla grown under three management regimes. The first method is to grow azolla before transplanting rice (A1). The second is to sow azolla at or after transplanting (A2). The third alternative is to cultivate azolla both before and after transplanting (A3).

Quadratic response functions of the yield response to chemical nitrogen fertilizer under different azolla management regimes are given below:

$$(6.1)\ \text{(no azolla)}:\quad YIELD = a_i + 24\,N - 0.12\,N^2$$

$$(6.2)\ \text{(azolla = A1)}:\quad YIELD = a_i + 628 + 15\,N - 0.12\,N^2$$

$$(6.3)\ \text{(azolla = A2)}:\quad YIELD = a_i + 357 + 21\,N - 0.12\,N^2$$

$$(6.4)\ \text{(azolla = A3)}:\quad YIELD = a_i + 808.$$

The intercept terms are given by a_i ($i = 1$ to 6 for six locations), which range from 874 to 3703 kg/ha. Experiments with chemical fertilizer were not conducted in the case where azolla was grown both before and after transplanting (A3), thus nitrogen response coefficients could not be estimated in equation (6.4).

Growing azolla in the rice paddy prior to transplanting results in an additional rice yield of 628 kg/ha on average and reduces the response to chemical fertilizer. Inoculating the paddy with azolla after transplanting gives additional yields of over 350 kg/ha and growing azolla both periods added over 800 kg/ha. Research on azolla in the Northeast is now focused most heavily on growing azolla after transplanting (A2), as this method appears to be most suitable for rainfed environments.

An additional advantage from azolla production is weed control (Kikuchi, Watanabe, and Haws, 1984). Azolla grown as an intercrop quickly multiplies to cover the paddy surface and stifles out weeds, thus reducing or eliminating herbicide and weeding costs. Few herbicides are used on rice in Northeast Thailand, but the value of family labor used on weeding amounts to about 55 baht/ha (World Bank, 1985, Table 6.14, p. 143).

A cost budget for azolla production is given in Table 6.1. Detailed cost budgets are not available for Northeast Thailand, so for this analysis, we borrowed the material and labor estimates from the Philippines (reported in Rosegrant, et. al., 1985) and used local input prices and farm wages to construct the cost estimates[1]. The total cost of growing azolla before transplanting amounts to nearly 1200 baht/ha. The cost of growing azolla after transplanting is roughly half of this (due to lower labor and cultivation costs), at about 640 baht/ha. Growing azolla both before and after transplanting costs about 1650 baht/ha. Some economies are accrued since the nursery and multiplication bed only need to be prepared once.

The cost budgets are composed of three main components: labor and bullock costs, phosphate fertilizer costs, and insecticide costs. These cost budgets demonstrate the labor-intensive nature of azolla production, as labor and animal requirements are the most expensive feature. In addition, insecticide comprised nearly a third of the total cost of producing azolla as an intercrop with rice (A2). Azolla cultivars are very susceptible to insect pests.

[1]Though the assumptions on resource requirements for growing azolla are from the Philippines, the cost estimates for Northeast Thailand appear to be fairly reasonable. The Rice Soil and Fertilizer Research Group, for example, estimated that the total resource cost of producing azolla after transplanting in Ubon Ratchathani Province in 1986 would be 744 baht/ha using a water buffalo for plowing the paddy field and 1062 baht/ha using a rotor tiller tractor (Rice Soil and Fertilizer Research Group, 1986). This compares quite well with our estimate of 640 baht/ha using water buffalo.

TABLE 6.1: COST OF AZOLLA PRODUCTION IN NORTHEAST THAILAND

Item	Quantity	Cost (baht)
A. Nursery Bed (40 square meters)		
Azolla starter inoculum	8 kg	24
Land preparation	.25 MAD	21
Superphosphate fertilizer	1 kg P2O5	14
Fertilizer application	.25 MD	6
Seeding and topping azolla	.25 MD	6
Insecticide	20 g ai	20
Total		91
B. Multiplication Bed (600 square meters)		
Land preparation	.33 MAD	28
Superphosphate fertilizer	1.3 kg P2O5	18
Fertilizer application	.33 MD	8
Seeding and topping azolla	.5 MD	13
Insecticide	30 g ai	30
Total		97
C. Azolla in rice field (1 ha)		
1. Grown before transplanting		
Land preparation	8 MAD	680
Superphosphate	8 kg P2O5	90
Fertilizer application	1.5 MD	38
Seeding and topping	2.0 MD	50
Insecticide	150 g ai	150
Total		1008
2. Grown after transplanting		
Incorporating azolla into soil	5 MD	125
Superphosphate	8 kg P2O5	90
Fertilizer application	1.5 MD	38
Seeding and topping	2.0 MD	50
Insecticide	150 g ai	150
Total		453
D. Total costs of azolla production		
1. Azolla grown before transplanting		1196
2. Azolla grown after transplanting		641
3. Azolla grown before and after transplanting		1649

MAD = man-animal day; MD = man-day; ai = active ingredient

To assess the economic feasibility of azolla in Northeast Thailand, we compare the cost of using chemical nitrogen fertilizer to the cost (minus the savings from weed control) of producing nitrogen through azolla. This is the method used by Rosegrant and his colleagues (1985) in their assessment of azolla in the Philippines, though they ignored the weeding factor.

The total cost of using chemical fertilizer on a typical farm is around 20 baht/kg. This includes interest charges on loans made through the informal sector and labor costs of applying fertilizer. "Fertilizer equivalents" of azolla production are determined by finding the rate of chemical fertilizer that would be required to achieve the same additional yield as the azolla treatment, using the production parameters of equation (6.2).

Table 6.2 compares the cost of chemical nitrogen fertilizer to the cost of producing nitrogen from azolla. These results show that nitrogen from azolla costs almost twice as much as nitrogen from chemical fertilizer under the cost structure of Table 6.1.

TABLE 6.2: COST OF NITROGEN FROM CHEMICAL FERTILIZER AND AZOLLA

Source of nitrogen	Nitrogen equivalent (kg/ha)	Cost of nitrogen (baht/kg)
Chemical fertilizer	--	20.0
Azolla before transplanting	30	40.0
Azolla after transplanting	16	37.0
Azolla before and after transplanting	43	37.0

We can also determine the economic feasibility of azolla using a partial budgeting approach (Perrin, et. al., 1976). Optimal fertilizer rates and yields implied by each management regime are compared, based on the production function estimates in equations (6.1) through (6.4). This is essentially the approach used by Anderson, et. al. (1983) to measure the profitability of azolla in the United States.

Table 6.3 shows the net benefits from azolla production determined from this second approach. We have assumed a fertilizer/rice price ratio of 10, based on a marginal value of rice price of 2 baht/kg (which takes into account the costs of harvesting, hauling and threshing additional grain yield). Optimum chemical fertilizer application rates are given in the second column. Some chemical fertilizer is still economical even when azolla is grown before or after rice. But the benefits from azolla are not enough to offset it cost. Growing azolla as an intercrop results in a loss of 184 baht/ha, which is significantly better than the performance of the other azolla management options.

TABLE 6.3: NET BENEFITS FROM AZOLLA PRODUCTION

Nitrogen source	Optimal Chemical Fertilizer Rate (kg/ha)	Net benefits (baht/ha)
No azolla	58	--
Azolla before transplanting	21	-652
Azolla after transplanting	46	-184
Azolla before and after transplanting	0	-794

Both methods of determining the economic feasibility of using azolla as a source of nitrogen for rice in Northeast Thailand show that under current technology and prices azolla is not a profitable alternative. However, the production parameters may change through research and technology development aimed at reducing the costs of azolla production. If azolla production costs can be reduced by 200 baht/ha, then growing azolla after transplanting rice will become profitable. Cultivating azolla before transplanting rice or a combination of these will only become profitable if production costs are reduced by 700 to 800 baht/ha (25 baht = $1 U.S.).

Research on azolla utilization should focus on rice growing areas where nitrogen is in greatest demand, namely, in the areas with the best supply of water. In the rainfed rice growing environments found in Northeast Thailand, there is substantial variability in the average water supply to the rice fields during the monsoon season. Figure 6.1 profiles the kinds of paddy environments found in the Region. Lower paddy areas are those rice areas near the bottom of a watershed or near a water course. These rice paddies are the most productive. Moving up the topology one encounters middle and upper paddies, which are only planted to rice in normal or high rainfall years (and left fallow in low rainfall years). The difference in elevation between these paddy types may be as little as one or two meters (KKU-Ford Cropping Systems Project, 1982).

The average yield response to nitrogen fertilizer varies considerably across this topology of rice fields. Figure 6.2

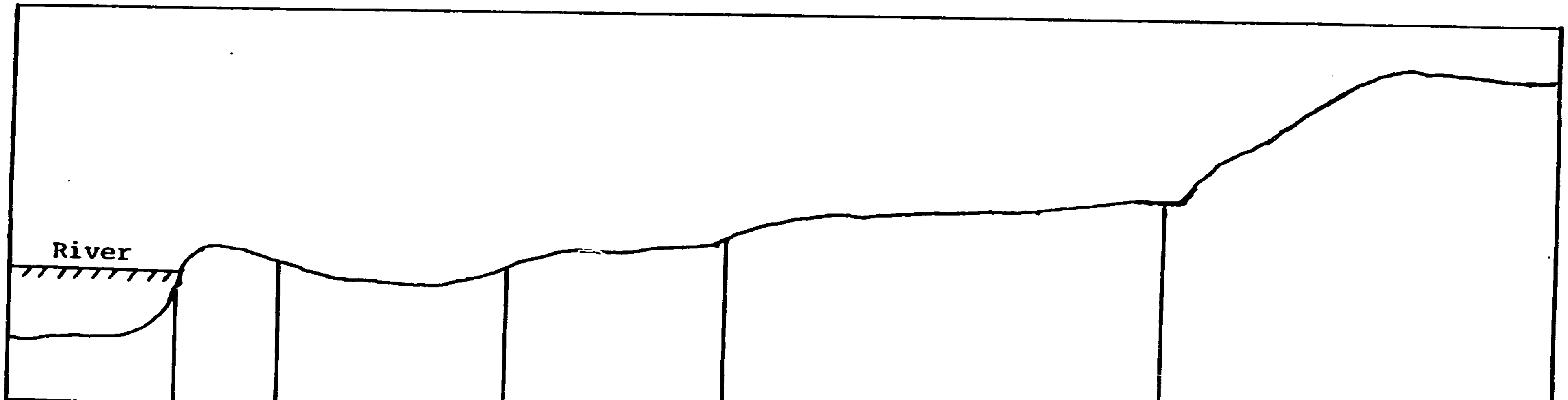
illustrates the increases in yield due to additional nitrogen for each paddy type[1]. In lower paddy areas, an additional 10 kg/ha of nitrogen will increase yields by about 130 kg/ha, compared to only about 60 kg/ha in middle and upper paddies. Lower paddy areas should be the focus of research on azolla technology in the Northeast Region. These make up roughly 1 million hectares of rice land in the Region, or about one-fifth of the total[2].

These results give an indication of what the azolla research program must achieve in order to make azolla competitive with nitrogen fertilizer and suggest some areas upon which research should be focused. For example, the development of mechanical cultivation and incorporation devices may reduce labor costs, and insecticide requirements may be reduced through azolla varietal selection for pest resistance. This research should be concentrated on growing azolla as an intercrop in irrigated and lower paddy rainfed areas where the growing conditions are most suitable and the demand for nitrogen is most pronounced.

[1]These estimates are adapted from Fuglie, 1988. The lower paddy fertilizer trials were conducted in Khon Kaen Province (Chumpae area) from 1978 to 1983 in "Phimai Soil" (Thai classification system) using RD6, a glutinous, photoperiod sensitive variety. The middle paddy trials were carried out in Ubon Province during 1978, 1979, and 1980 in "Roi Et Soil" using RD2, a glutinous, photoperiod insensitive variety. The upper paddy trials also took place in Ubon Province and in "Ubon Soils" during 1978 and 1979. RD2 was also used in these trials. These fertilizer trials were conducted by the Rice Soil and Fertilizer Research Group in the Department of Agriculture, Bangkok, under the direction of Dr. Chob Kanareugsa and Mr. Prasit Mongkolporn.

[2]Phimai Soils are in the Inceptisol-Tropaquept Soil Group, found in river basins. If one includes Entisol-Ustifluvent Soil (river levees and alluvial complexes) with this group, one arrives at the 1 million hectare figure. The data on soil classification and area is from Guide to Soil Series and Classifications of Thailand, 1981.

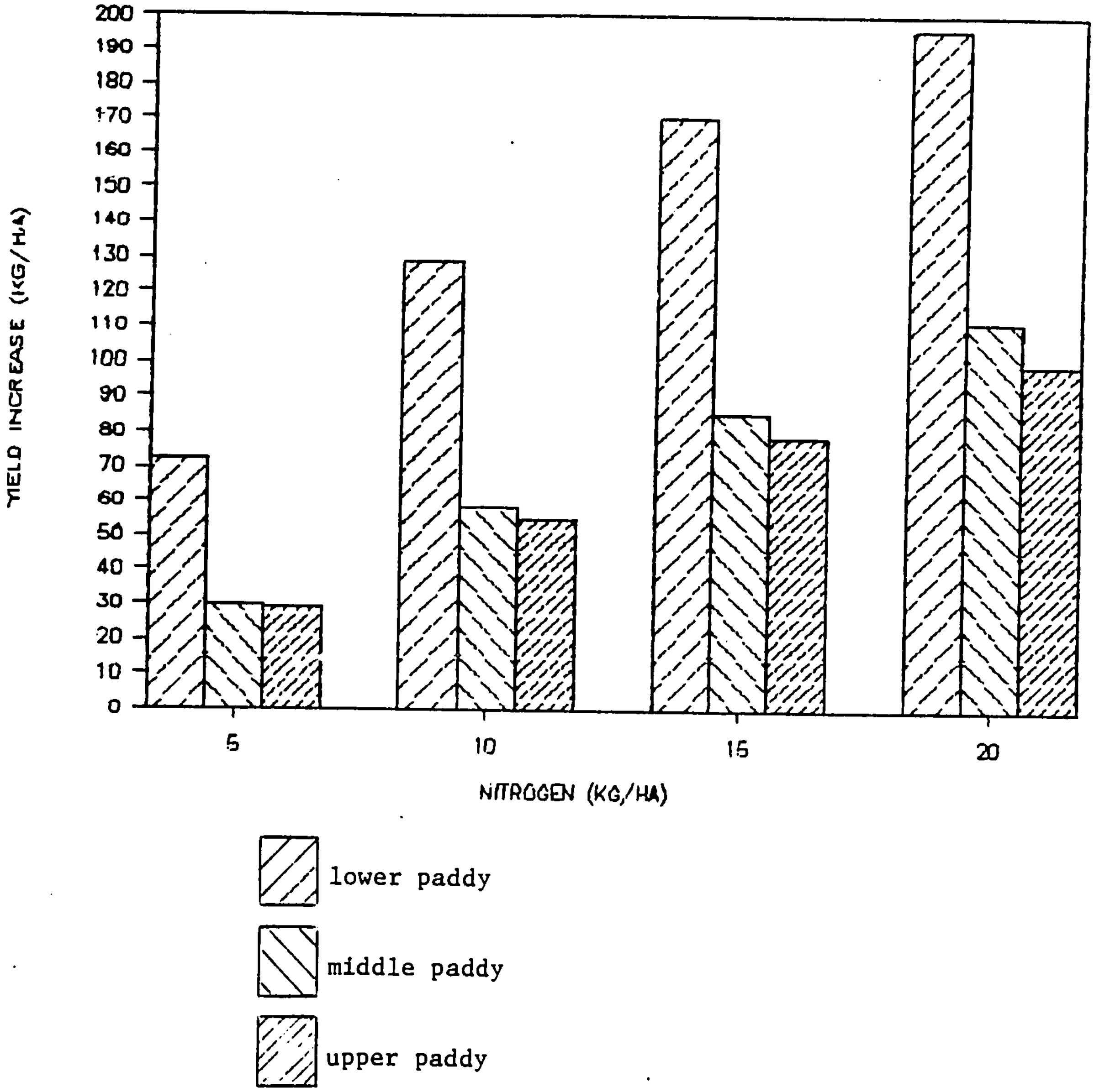
FIGURE 6.1: CROSS-SECTION PROFILE OF A WATERSHED



Landform	Levee	Low paddy	Middle paddy	Upper paddy	Upland
Soils	Usti-fluvent	ALLUVIAL Tropaquepts	LOW HUMIC GLEY Paleaquults	LOW HUMIC GLEY Paleaquults/Paleustults	PODZOLIC Paleustults
Predominant Crops	Garden Crops	Paddy Rice good yield but with flood risk	Paddy Rice medium risk	Paddy Rice -when rain is plentiful, fallow 7 out of 10 years, high risk and low yields	Cassava, Kenaf, Sugar Cane

Source: KKU-Ford Cropping Systems Project

FIGURE 6.2: RICE RESPONSE TO NITROGEN IN RAINFED PADDIES



VII. SUMMARY AND CONCLUSIONS

In the preceding sections of this paper we discussed various applications of BNF technology in Northeast Thailand. Our attention focused on (1) multiple cropping systems with legumes; (2) inoculum technology; and (3) azolla utilization as a green manure in rice production.

A BNF research program was initiated in Thailand about 15 years ago and significant progress has been made in developing domestic research capacity in this area. Inoculant production proceeds on a large scale, and a modest but diverse program of applied BNF research and technology development is under way. Thai researchers have made vigorous use of opportunities for collaborative research with research institutions in developed countries to support their programs objectives.

Inoculation trials posted dramatic yield response with soybeans but only marginal response with peanuts and mungbeans. The latter two crops, however, are the most important grain legumes in the Region, and current research focuses on improving BNF capabilities of these crops (especially peanuts). New cultivars and Rhizobium strains are being screened for their nitrogen fixation abilities. These research efforts should contribute to gradual improvements in legume yields. The lack of effective inoculation techniques is a key constraint to fuller utilization of BNF potential.

The adoption of multiple cropping systems is constrained by technical and economic factors. Simply attempting to add a new crop to an existing cropping system is likely to be successful only in isolated areas. More intensive cropping systems will require new technologies that will reduce the resource requirements of each crop in the system (such as shorter season varieties or mechanized cultivation and harvesting), or will extend the growing season (i.e. irrigation).

Utilization of azolla as a source of nitrogen in rice is currently constrained by the high cost of azolla production, the largest components of which are insecticide, phosphate fertilizer, and labor costs. Current research activities should reduce these costs substantially over the next few years. Nevertheless, the use of azolla will probably be restricted to irrigated areas or the better rainfed areas. Much of the rice land in the Northeast Region is too marginal (insufficient and undependable water supplies) for using of azolla.

The view that applications of BNF technology in the tropics can achieve rapid productivity gains with only a minimal reliance on modern inputs and supporting infrastructure is overly simplistic. Most gains from BNF technology will be gradual and incremental, and will require continued support of research and development programs. Furthermore, the technologies will still require an infrastructure that can deliver these technologies and complementary inputs to the farm.

APPENDIX: RESIDUAL EFFECTS OF PEANUTS ON RICE

The results of a study on the residual effect of peanuts on the subsequent rice crop are reported in this Appendix. Using rice crop cut surveys, measurements were taken directly from farmers' fields for two seasons. Though using data from farmer-managed plots increases the difficulty of controlling for all relevant factors in an experiment, it provides a better evaluation of farm-level technology than researcher-managed experiments.

This study differs from previous studies of the residual effects in peanut-rice crop rotations in the Northeast Region (Wilairat, 1983; NERAD, 1986) in two important respects. First, instead of conducting researcher-managed cropping trials, actual farm practices were observed and measured. Though the control over the experiment is diminished (since the plots are farmer-managed), the data reflect actual (not potential) farm conditions. Second, the peanuts-after-rice cropping pattern was studied rather than the peanuts-before-rice pattern. In the peanuts-after-rice pattern, there is a five- to six-month fallow period between the peanut harvest and rice planting.

Farms selected for the study were located in four districts of Khon Kaen Province (Muang, Nong Rua, Ban Fang, and Kranuan), and were studied for a two-year period. Initially, at least three farms were selected in each district, though in the second year some farmers discontinued planting peanuts. All the farms were fairly typical of the area, being owner-operated, of average size, and with a mix of paddy and upland crop area. Most of their rice production was for domestic consumption. All of the rice plots were rainfed except for two farms in Muang district, which had access to a small pond for some irrigation.

Once the farms had been selected for the study, two types of data were collected. First, farmers were interviewed about their agronomic practices such as fertilizer use, varietal selection, tillage methods, and their experience with growing peanuts. Second, rice crop cut surveys were conducted to get accurate measures of yields. For each farm, a treatment plot which had been planted to peanuts-after-rice the preceding season and a control plot (only planted to rice the year before) located nearby were selected. Each plot was 0.05 to 0.1 hectare in size. Four 4m x 4m subplots were randomly selected from each plot, harvested, dried and weighed. The average yield from the subplots was extrapolated to give estimates of yield per hectare.

The semi-structured survey on management practices revealed fairly consistent agronomic practices across the sample of farms, though some farmers had more experience than others with this cropping pattern. All farmers used RD 6 rice variety except for two who used native varieties. Very little or no fertilizer was applied to either the rice or peanut crop. When fertilizer was used, typically about 10 kilograms of formula (15-15-15) would be broadcast per hectare. Some farmers also added small quantities of animal manure to their rice plots, and one farmer added some manure to his peanut crop. Transplanting occurred in July and August and rice harvesting in November and December. A frequent complaint of farmers was that insect pests reduced rice yields.

Peanut yields were generally quite low, but most farmers reported that there were positive residual effects on the subsequent rice crop. There was apparently a fair amount of variation in residual management, however. Only a few farmers deliberately worked the peanut crop residual matter into the soil. Two farmers who had been growing peanuts-after-rice for several years reported that they would vary the paddies planted to peanuts each year, since each dry season only a portion of their total paddy was planted to peanuts.

The results of the crop cut survey showed considerable variation in rice yields across locations and between years. Yields varied from 1.31 tons per hectare (rough paddy) to 5.08 tn/ha. There was no consistent pattern to the treatment (peanut residual) effect. Table A.1 summarizes these data. Averaged across all plots, rice yields on the treatment plots yielded 2.74 tn/ha while the control plots gave 2.64 tn/ha, or about 4 percent less. But this difference is not statistically significant.

TABLE A.1: RICE YIELDS (TN/HA) FROM THE CROP CUT SURVEY

LOCATION	YIELDS					
	1985			1986		
	farms	treatment	control	farms	treatment	control
Muang	3	2.76	2.91	2	2.87	3.20
Ban Fang	3	3.09	1.70	1	2.63	2.69
Nong Rua	3	2.08	2.02	2	1.62	2.16
Kranuan	3	3.70	3.74	3	3.20	2.72
Average		2.91	2.59		2.58	2.69

Overall Average: Treatment = 2.75 Control = 2.64

These results fail to show any significant residual effects from peanuts grown in a peanut-after-rice sequence. This may be partly due to the management practices of farmers. But perhaps more important is the lack of nitrogen demand in the rice crop in this region. In this environment, farmers are unable to achieve effect water control, which is a key compliment with fertilizers and modern varieties in obtaining high yields. Nitrogen response functions that have been estimated for rainfed paddy areas in this region show a relatively low response to fertilizer (Fuglie, 1986).

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