SEQ 350 JOB BANGLA-003-019 PAGE 061 PAPER 13 61-69
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Expectations from BNF Research: Research Administrators' Point of View

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Introduction

The oil crisis of the early 1970s and the consequent escalation of prices of nitrogenous fertilizers sparked off a boom in BNF research that lasted through to the early 1980s. Optimistic claims were made about substitution of fertilizer N with biologically fixed N, and funds poured in to support research. Today, however, there seems to be little residual effect of this BNF boom in farmers' fields, in South Asia at least. One reason for this, of course, is that the oil crisis spurred the discovery of vast new oil and gas reserves, and prices of N fertilizers generally stabilized at levels affordable (with or without government subsidy) to all but the poorest of farmers. Another reason is that adoption of BNF technology by farmers has not been significant.

In India in particular, there have been several large-scale schemes to introduce *Rhizobium* inoculation for the major legume crops, but there is little evidence of its widespread adoption by farmers. This situation exists despite evidence from many experiments showing significant responses to inoculation, and calculations of economic viability. This contrasts with the situation in countries such as Australia, where such technology has been widely adopted. But there the circumstances are different, with mainly the introduced temperate legume species requiring specific strains of rhizobia. Moreover, such countries have large-scale, mechanized, and commercialized farming systems in which it is easier to introduce *Rhizobium* inoculation procedures. The only example of large-scale, sustained adoption of *Rhizobium* inoculation technology that we are aware of in Asia is that of soybean in Thailand (see Toomsan et al., pages 17–23 this Report). Here also, there appears to be a need for specific rhizobia for soybean.

In the light of such unfulfilled promise in Asia, it is not unnatural that research administrators are somewhat wary of new proposals for BNF research targeted at improving the lot of small, resource-poor farmers. In agriculturally important legumes, BNF research has hitherto been overwhelmingly directed towards

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Rhizobium inoculation technology, with the aim of enhancing N_2 fixation through the addition of superior *Rhizobium* strains. Other options, such as manipulation of agronomic practices to favor BNF or genetic alteration of the plant to increase symbiotic activity, have received less attention. This paper attempts to summarize the reasons for the earlier shortcomings, suggests a holistic approach to BNF research, and makes specific suggestions on approaches to future research and development.

Shortcomings of Inoculation Technology

There are various reasons for the limited adoption of *Rhizobium* inoculation technology by farmers in the tropics in general and in South Asia in particular.

Assessment of 'need-to-inoculate'. Recommendations on inoculation are often of a universal nature, to be applied across diverse environments and legume species, although there are marked, well established site-to-site differences in inoculation response. It is sometimes argued that, as all such differences in response cannot possibly be known or understood, inoculation may be regarded as an 'insurance policy' with a low premium. However, only affluent farmers are prepared to buy such insurance. Even if the cost of a packet of inoculum is low, there are unavoidable costs in terms of time and skill required for inoculation at the usually busy time of sowing. If a positive response to inoculation is not reasonably assured, farmers are not likely to want to invest their time and effort in it, let alone their money. Therefore, for effective extension of BNF technology, it is necessary to define situations in which a positive response to inoculation is, or is not, probable.

The main factors affecting response to inoculation are:

- The absence or inadequate numbers of rhizobia in the soil, native or introduced, that can effectively nodulate the target legume. Tropical legumes are largely promiscuously nodulated by the cowpea-group *Rhizobium* (or *Bradyrhizobium*) which are ubiquitous in soils where these legumes normally grow. Hence the limited response of these legumes to *Rhizobium* inoculation (Date 1977).
- Even moderate levels of soil mineral N inhibit nodulation (Harper and Gibson 1984), which is not overcome by rhizobial inoculation.
- There are wide variations among and within legume species in their ability to meet their own N needs through fixation.
- Other plant growth-limiting factors strongly interact with nitrogen fixation.
- *Rhizobium* inoculation procedures may damage seeds and thus reduce seedling emergence.

The INLIT (International Network of Legume Inoculation Trials) approach (Davis et al. 1985) of NifTAL (Biological Nitrogen Fixation for International Development), University of Hawaii, remains a valid approach to determine the need-to-inoculate. It consists of a noninoculated control, an inoculated treatment, a treatment with 'optimum' N fertilizer, and the presence or absence of another major limiting factor for the legume (usually phosphorus). As multilocational field trials are expensive, various preliminary tests can give an indication of the likely response. An example is the use of simple models relating inoculation responsiveness to the MPN of effective rhizobia and level of soil mineral N (Singleton et al. 1992).

Inadequate demonstration of inoculation technology. Activities in BNF technology have often remained within the discipline of soil microbiology, with inadequate interaction with other disciplines, let alone extension personnel. There is little evidence that the demonstration and extension process for BNF technology has been thoroughly planned and effectively applied in farmer's fields.

Quality control of inoculants. In the tropics, there are few inoculant production systems producing *Rhizobium* inoculum of consistently good quality over a reasonable period of time. Shortcomings and remedies in this respect have been described by Thompson 1984, and Thompson 1991.

Difficulties in using *Rhizobium* inoculants. In high temperatures typical of tropical and subtropical environments, *Rhizobium* inoculants in carrier packets tend to lose their viability, even if their numbers had been adequate initially. In these regions, the normal sowing times of legumes fall at the beginning and end of a long-day rainy season (in order to grow the crops on residual soil moisture). These are normally hot periods during which exposure of rhizobial cultures to high temperatures is almost unavoidable, even if refrigeration is available. Moreover, if the inoculum is a nonsterile one, the high temperatures may favor competitors to *Rhizobium*. More work is needed to develop procedures that minimize the adverse effects of high temperature.

Economics of *Rhizobium* Inoculation Technology

Calculations of the economic viability of inoculation technology have indicated high rates of return (e.g., Verma and Bhattacharyya 1992), but such calculations often have deficiencies. For example, production costs are often subsidized by government agencies, and personnel costs are sometimes ignored. Actual costs are therefore underestimated. Nonmonetary costs and miscalculation of returns based on inoculation responses extrapolated over regions have been referred to earlier in this paper. A more thorough and conservative accounting is desirable in order to convincingly present the likely returns on investment in *Rhizobium* inoculation technology.

The Research-Adoption-Impact Continuum

Proposals for BNF research must be considered in the light of the entire continuum from basic research to impact assessment. Given the increasing scarcity of resources, the bottom line for any research undertaking is more and more its impact,

Figure 1. Schematic representation of the research, development and adoption process over time, indicating relative involvement of ICRISAT and national agricultural research systems (NARS).

or likely impact. To facilitate impact assessment, both ex-post and ex-ante, an understanding of the whole research process is essential.

The research-evaluation continuum may be systematically viewed by using a general framework as outlined in Figure 1. The framework traces the development of the different components of the research process, its output, and logical consequences. The conceptualization of the framework starts with the consideration of research investments that fund the implementation of research projects. The new knowledge/technology generated is expected to bring forth changes in the production and consumption environment by making more of the commodity available in the market. To be more specific, the application of science-based technologies resulting from BNF research is expected to bring about increases in crop yields. Research on BNF is also expected to improve the efficiency of inputs through better agronomic practices and crop management. Ultimately, the changes in the production and consumption environment are translated into improvement in the welfare of farmers who use the technology as well as that of consumers who use the final products.

Before the final benefits of research accrue to the producers and consumers, two important conditions must be met. First, the research undertaken must be

SEQ 357 JOB BANGLA-003-019 PAGE-065 PAPER 13 61-69
REVISED 31OCT94 AT 13:20 BY KVP DEPTH: 63.09 PICAS WIDTH 45.06 PICAS

successful in achieving its objectives. This introduces the notion of probability of success or relative research capability. Second, the potential increase in production promised by a new technology is ultimately achieved only when it is adopted by farmers. This condition necessitates the consideration of the rate of technology adoption and the factors constraining it.

However, the measurement of the welfare gain to society is incomplete if it does not take into account the externalities which the technology involves. The externalities may be negative or positive. Classic examples of a negative externality are soil erosion in agriculture and the detrimental effects of chemical-based technology. The latter example includes the deleterious effect of pesticides on the health of farmers and their families, the transmission of chemical residues through the food chain to consumers, the toxic effect of chemicals on animals like fish, shrimp, frogs, and helpful insects in the farmers' fields, the contamination of ground and surface waters, and the reduction of soil microbial populations that help sustain soil fertility.

The positive externalities are incorporated in this framework through the concept of spillover effects. Three types of spillover effects are considered. The first type involves the across-location spillover effect in which a technology developed through research for one product in a specific location can be adapted to improve the production efficiency of the same product in other locations (geopolitical or agroecological).

The second type of spillover effect concerns the across-commodity applicability of the technology developed. For example, a cultural management technique developed specifically for groundnut may also be applicable to other legumes.

The first two types of spillover effects reflect the direct applicability of a technology, and are thus referred to as direct spillover effects.

A third type of spillover effect is referred to as the indirect or price spillover effect. A new technology (by virtue of increasing production) may have an effect on the price of a particular commodity at a particular location. In addition, it may also have an effect on the price of that commodity at another location (if the commodity is traded) and/or on the price of related commodities. This is particularly relevant when the elasticities of product demand are relatively small and/or the rate of product transformation among commodities is significant.

Another factor which has an effect on welfare gains accruing from research is government policy which can influence the production and/or consumption of a commodity, or the inputs used to produce it. Government policies can thus influence both the benefits flowing from research and their distribution.

The welfare effects of research can vary significantly with the research project, location, and commodity. The choice of a research project is likely to be influenced by the magnitude and distribution of these effects. Which of these effects are important requires clarification. For example, if two regions are part of one country and if total national welfare gain is the objective of the research institutions, then a measure of the research impact is provided by adding all the gains (or losses) of all sectors. If, however, the objective is to maximize gains to poor farmers only, the welfare gains within that subset are added to give a measure of how well the research option may satisfy that objective. Estimates of these welfare changes, if quantified, can be summarized in a form that will assist decision-makers in setting research priorities or making other allocation decisions. Other aspects that require consideration are: a) effect on income distribution and poverty; b) food security; c) human capital development; d) institution building and strengthening of national programs; e) sustainability and environmental impact; and f) implications of policy change.

It is thus clear that a whole spectrum of considerations has to be taken into account while assessing a research project. It is equally clear that a detailed understanding of the components of the research-evaluation continuum is necessary to arrive at a quantitative assessment of impact. Following is a sketch of the type of information needed to assess BNF research directed towards improving the N_2-fixing ability of chickpea (see Rupela, pages 75–83 this Report), both ex-post and ex-ante:

<----Stage 1---->	<----Stage 2---->	<----Stage 3---->	<----Stage 4---->
Conceptualization	Development of high-nod lines	On-farm testing	Extension and adoption
1988	1990	1995	1998

Stage 1 involved the development of the concept of genetic alteration of the plant for better nodulation through selection within existing cultivars. This stage led to the formulation of basic concepts and methodology for the development of the improved technology. Stage 2 involved selection of lines with superior N_2-fixing ability and their validation in on-station experiments. Stage 3 involves on-farm validation of the value of the selections. Stages 1, 2, and 3 represent the basic, applied, and adaptive research components in the development of this technology.

Stage 4 involves the demonstration, extension, and adoption of the technology among farmers. The process underlying the adoption of technologies is represented by the curve in Figure 1, in which adoption-related variables — adoption lags, rate of adoption, and ceiling level of adoption are highlighted. Introduction of a new technology does not usually lead to immediate adoption. The gestation period between the generation of a technology and its adoption varies with the sector, commodity, and even type of technology. Some farmers adopt a technology only after its effects have been convincingly demonstrated. Reluctance among farmers to adopt a technology may be due to difficulty in using it, nonavailability of the inputs required, market uncertainty, price fluctuations or preference for very low management crop technology. Thus, a sigmoid adoption curve is usually used to illustrate the adoption process; where the level of adoption is initially low, it rises at an increasing rate after sufficient diffusion is attained, and finally reaches a ceiling level of adoption. Adoption lag refers to the time interval between the introduction of a technology and the attainment of the ceiling level of adoption.

The quantitative assessment of impact is data-intensive. Data on the diverse factors involved at various stages of the research process are needed to estimate the likely impact of BNF research. An important feature of the BNF research process described above is that the expected research lag is about 10 years. This represents the time it takes for the envisioned technology to be achieved and made available to farmers. The probability of achieving the expected research results (probability of success) has to be estimated and used in measuring the impact, particularly for stages 1, 2, and 3. Estimates on the rate of technology adoption and ceiling level of adoption have to be made. The cost of implementation of the research in the first three stages should be taken into account in the assessment.

Suggestions for Attracting Administrative Support

Cost/benefit analysis. Rigorous cost/benefit projections are required to attract investment in BNF research. A prime requirement is to establish, for particular target legumes and cropping systems, the actual gains expected from improving BNF above the existing level, in comparison to achieving these gains by using mineral N fertilizer. This primarily requires assessment of the extent to which the legume can meet its needs through fixation. Essentially, need-to-inoculate studies, supplemented by more detailed studies on rate and time of application of N fertilizer, can accomplish this (although there would inevitably be some difficulties of interpretation related to fertilizer N-use efficiency and N metabolism within the plant). Also, the residual benefit of legumes, in terms of equivalents of N fertilizer applied to a subsequent crop, needs to be calculated. Further, the relative value of N derived from either fertilizer or organic sources needs to be estimated, from the viewpoint of environment protection and sustainability of cropping systems. These data provide a baseline against which to estimate gains that can be expected from improving BNF as a result of research or by direct application of known technologies. Allowing for factors such as probability of success, time lags, and ceiling level of adoption, reasonable estimates can be made for costs and benefits of a suggested research project and/or development effort.

Management and genetic options. This Working Group meeting offers an opportunity to evaluate management (primarily, inoculation technology) and genetic options for enhancing BNF, especially the new genetic options being proposed by Dr Rupela and his colleagues. If we can genetically alter the plant to better accept native rhizobia in an effective symbiosis that would both meet the legume's N needs as well as leave substantial residual N, then the aforementioned problems of inoculation technology can be bypassed.

Inoculation technology. If it is decided that further pursuit of *Rhizobium* inoculation technology is viable, then the shortcomings discussed earlier need to be comprehensively addressed.

Outlook for N fertilizer. The popularity of BNF research, and hence the extent of funding for it, is directly and closely related to the relative (compared with other agricultural inputs) price of N fertilizer. More emphasis should be given to comprehensive comparisons of BNF enhancement versus use of N fertilizer. This not only involves relative input costs, in relation to the benefits expected, but also the adverse consequences of use of either source of N. For example, reliance on N fertilizer can result in soil acidification, N leaching losses, and eutrophication of water bodies. Reliance on BNF can also lead to soil acidification (e.g., by proton excretion from legume roots) and inflexibility of cropping systems (particularly if legumes are a low-value cropping option).

Impact analysis. As outlined above, proposals for BNF research and development would be much more attractive to research administrators and donors if it could be clearly shown how the proposed activities fit into the research-adoption continuum. They need to be based on sound calculations of expected gains from research and other parameters of the adoption curve. Considering the past failures in adoption of BNF technology, there is scope for adoption constraint studies, to pinpoint bottlenecks. Impact analysis should be built into any proposed project. These steps do not seem to have been previously taken, but improvement of BNF would seem a readily quantifiable candidate for this suggested holistic approach.

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