Maximizing fertilizer use efficiency

FAO FERTILIZER AND PLANT NUTRITION BULLETIN

6

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

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Fertilizer and Plant Nutrition Service
Land and Water Development Division

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FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
Rome, 1983

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GLOSSARY

FAO	Food and Agriculture Organization of the United Nations
CGIAR	Consultative Group on International Agricultural Research
IRRI	International Rice Research Institute
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IARI	Indian Agricultural Research Institute
ICAR	Indian Council of Agricultural Research
IVRI	Indian Veterinary Research Institute
NDRI	National Dairy Research Institute
NEERI	National Environmental Engineering Research Institute
Kharif	Wet (season)
Rabi	Dry (season)

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INTRODUCTION

This Seminar, held against the background of the contribution already made to agricultural production in India by fertilizer and in the certainty that efficient fertilizer usage has a yet greater contribution to make in the future brought together some 450 participants from all over India, representing Central and State Governments, universities, research institutes and fertilizer industry. Twelve scientists invited from a number of countries and from international agencies also took part. The accent throughout was on increasing fertilizer use efficiency. Rising costs of fertilizer, the need to conserve world resources of energy and the national need to make the best possible use of scarce resources in raw materials and finance all place an obligation on agriculture, while reaping the obvious benefits which accrue from increased fertilizer usage, to ensure that fertilizers are used economically, in other words, so that the maximum possible economic benefit is obtained from every kilogramme of fertilizer applied. It does not need to be said that the need for efficiency in fertilizer usage is just as, if not more, important to the farmer himself.

Apart from the formal introductory session dealing with national policies and aims and with the global picture of fertilizer efficiency together with general considerations relating to the evolution of policies designed to further the efficient use of fertilizers, over fifty papers dealing with a whole range of topics from the behaviour of nutrients in the soil, through their effects on crop growth to the contribution they can make to rural and national advancement, were presented to the meeting. These papers contain a wealth of information to which it would be quite impossible to do justice in this brief account of the proceedings which is, of necessity based upon the recommendations which emerged from the Seminar, drawing only sufficient information from the papers to illuminate the conclusions to which the delegates came at the end of the deliberations. The fact that no reference is made to one or another paper is no reflection on the author. A full list of the papers is given in Appendix A and no doubt requests to authors for further information would be met.

This account falls into nine sections. Chapter 1, by way of introduction, deals with the aims of agricultural policy in India, with the general problems of improving fertilizer use efficiency which is at the present time regrettably low, and that not only in India, and with general policy considerations.

Chapter 2 outlines the programme followed and lists the recommendations. The recommendations are grouped in such a way as to facilitate discussion of the Seminar material; the order of listing should not be taken to imply any priorities, indeed, it may be that in order to be fully effective the recommendations should be taken as a whole; they are inevitably inter-connected.

Chapter 3 concentrates on agricultural extension. The need for improvement in methods and for an all-out effort in this field is emphasized in the recommendations, almost one-third of which related to extension and development, indicating perhaps that delegates felt that knowledge and experience accumulated so far was sufficient to bring about very significant improvement if only it were to be applied on a sufficiently wide scale.

Chapter 4 deals with the basis for fertilizer recommendations. A mass of data is available on crop response to fertilizers in India but there are widespread doubts as to whether these are the right kind of data on which to found recommendations for farmers. In practice, it appears, there is too great reliance on blanket recommendations and there is a need to refine these to suit individual conditions of site and crop.

Chapter 5 is, in effect, an extension of Chapter 4, dealing with the part to be played by soil analysis in arriving at sound fertilizer recommendations.

Chapter 6 deals with the problems of increasing efficiency of nitrogen and phosphate fertilizers and in this mention is made of the special problems associated with the rice crop.

Chapter 7 deals with the important question of integrated nutrient supply under the aspects of nutrient conservation, exploitation of biological fixation of nitrogen and the contribution to be expected from the inclusion of legumes in the rotation.

Chapter 8 concerns the dry lands which make up such a large proportion of the land surface of India and where both crop yields and fertilizer usage are now very low.

1. SETTING THE SCENE

The importance of fertilizers to India and some of the main problems which have to be solved in this field were outlined by Rao Birendra Singh, Minister for Agriculture and Rural Reconstruction in the Government of India, in his inaugural address.

In the thirty years since 1950 food grain production has risen from 51 million to 131 million tons per year. A profound change in Indian agriculture over the past twenty years has been the achievement of self-sufficiency in food grains through great improvements in agricultural technology with increasing use of energy inputs to sustain the higher yields now possible. The increase in grain production of over two and a half times in thirty years has been accompanied by, and would not have been possible without, the increase in fertilizer consumption - from some 70,000 tons in 1950 to 5.3 million tons ($N+P_2O_5+K_2O$) today. Projections show that consumption is likely to reach nearly 10 million tons by the middle of this decade.

All this is to the good but, as the Minister pointed out, we have to reckon, for the foreseeable future, with high energy costs and, in consequence, high fertilizer prices. In these conditions it is a priority task to improve the efficiency of fertilizer use, in other words to make the best possible use of this essential but relatively expensive resource. "The utilization efficiency of fertilizers in farmers' conditions in India, though it varies under different cropping conditions, is generally low. In the case of wetland rice from 30 to 40 percent and from about 55 to 60 percent for irrigated rabi crops". Hence, "there is a need for a more systematic and accurate estimation of the actual losses in different regions and different crops, as these assumptions have considerable implications for policy decisions".

The Minister made a special plea that the research worker should direct his efforts to the needs of the practical farmer, that the methods evovled in research should be cheap enough for him to adopt and practically possible. To illustrate this point, he quoted the example of two techniques which research had shown to be effective in improving the efficiency of nitrogen fertilizer for rice: sulphur-coated urea and mudball urea. The former was too expensive (and sulphur too scarce); the latter fell down because the physical work needed to prepare sufficient balls for application in any significant area made the technique a practical impossibility.

A second main point in his address was that more effort must be directed toward making better use of animal wastes, now largely used as fuel. Techniques are available which allow the extraction of the energy content of the wastes for use as fuel (gas) while conserving the nutrient content.

A special plea was made for the inclusion of more attention to fertilizer usage in rural extension programmes. "The State Governments and Agricultural Universities should prepare location-specific manuals on fertilizer use efficiency for the guidance and use of field officers". He pointed out that the fertilizer industry had a key role to play - "Their promotion programmes now require a new focus. Their aims can no longer only be geared to increased use of fertilizer. The slogan now should be increased use with increased efficiency". The fertilizer industry also had an obligation to evolve intrinsically more efficient products - one manufacturer's pilot plant for the manufacture of supergranule urea was an example of the kind of project which is needed.

Distribution of fertilizer to the farmers needed to be improved and, here, the decision of Central Government to bear the cost of transport to Block level should be of assistance; the efforts of all concerned, from Central Government through State Government, manufacturers and handling agencies were all required to ensure that fertilizer came nearer to the doorsteps of more farmers than has been possible hitherto.

The maximization of fertilizer efficiency is, perhaps, a particularly urgent problem for India but it is also a world-wide problem and should receive the maximum support of the international agencies.

The ideas put forward by the Minister were further developed by Dr. M.S. Swaminathan, Member, Planning Commission, in his address to Session I of the Seminar. He spoke about the need to improve fertilizer efficiency and to increase fertilizer consumption essentially in the context of the Sixth Development Plan, 1980-1985 which has the target of producing, by 1985, 139 million tons of cereals, 14.5 million tons pulses and 14 million tons oilseeds, with special priority on achieving self-sufficiency in oilseeds and pulses. These targets cannot be reached without the use of fertilizers nor are they possible unless the efficiency of fertilizer is increased above its present level. That there is plenty of scope for increasing efficiency is evidenced by the facts that while the Indian average response of cereals is only about 9 kg grain per kg of fertilizer nutrient, the figure for the State of Punjab is about 15 kg and, in experiments, response is of the order of 25 kg per kg nutrient.

True, there is a need for further and intensified research into the improvement of fertilizer efficiency but there is an even greater need to improve the transfer of knowledge from research to the farmer. Papers presented at this Seminar contain a wealth of information but the difference between average yields obtained by farmers and those on experiments, indicates what could be achieved if only present knowledge were to be applied universally; it also shows that up to now farmer eduction has been woefully inadequate.

Generally speaking, farm management in India is not efficient and its improvement must be a priority aim of any programme. A basic requirement is land reform in order that the resources in soil and water can be more fully realized. Agricultural improvement will not be possible unless it is considered to be a part of rural improvement as a whole. There is a need to improve employment opportunities for landless labourers in the rural areas; employment can be found in some of the capital works of construction for drainage and irrigation, roads, etc. There is a need to improve marketing and farm trade; increased yields are of no use to the farmer unless his surplus production can be marketed at a profit. It is only within the framework of total rural improvement that the full benefits obtainable from fertilizers can be realized.

Dr. Greenwood, in his paper "Fertilizer Use and Food Production - World Scene", highlighted the extent to which crop yields in the tropics are limited by lack of plant nutrients. While potential yields in these areas are theoretically 50 percent higher than those realizable in temperate zones, because there are more days in the year when plants can grow, the input of solar energy is higher and the higher temperature allows the growing of plants with a more efficient photosynthetic pathway, the soil's ability to supply nutrients is lower. Unless fertilizers are applied, yields in the tropics are seldom more than 5 percent of the potential. There is a remarkably high correlation between average cereal yields in various countries and average rates of fertilizers used, in fact 83 percent of the variation in yield is apparently accounted for by fertilizer usage. Of course, other factors such as wider availability of improved varieties, better plant protection and better general standards of farming go hand-in-hand with fertilizer use, so it is not just the level of fertilizer usage which is responsible for these differences. Nevertheless, there is no other one factor which correlates so well with national average yields.

Nitrogen and phosphate fertilizers are everywhere comparatively inefficient; less than 50 percent of the nitrogen and only 15 percent of the phosphate applied worldwide is recovered by the crop to which it is applied. Nitrogen use efficiency can be improved by various techniques including timing and splitting of dressings to suit crop needs, placement, use of ultra-large granules, nitrification inhibitors and coated fertilizers. Phosphate presents a particularly difficult problem: while degredation of phosphate in the soil can be reduced by placement of granules, this practice is prejudicial to early growth because it limits P concentration immediately next to much of the root system. Potassium efficiency is usually higher, though in soils with low base exchange capacity leaching may be considerable and measures similar to those used for nitrogen may be needed. Some wastage occurs through luxury consumption - the tendency for plants to take up potassium in excess of their requirements when availability in the soil is high.

The conventional method of basing fertilizer recommendations on responses obtained in series of fertilizer experiments was questioned, since predictions given by such methods are frequently very poor and also because of the sheer impossibility of carrying out, and evaluating, sufficient experiments on all crops and all soils. A more mechanistic or 'modelling' approach as is being applied with some success in the UK, USA, Germany and the Netherlands for predicting nitrogen requirements could result in better predictions. Rapid methods of analysis for soils and crops which can be used in the field need to be further developed.

Man is generally a wasteful creature judging by his careless attitude to the conservation of nutrients within the soil - plant - consumer cycle. In view of the general poverty of soils, the relatively high cost of fertilizers in terms of both money and energy and the need to increase crop production, the importance of conserving the nutrients contained in farm and urban wastes, and returning them to the land, cannot be over-emphasized.

This paper ended on a cheerful note. Calculations show that if 10 t/ha of food is a reasonable estimate of potential yield, then one hectare could provide the energy and protein requirements of 30 people. In fact, the calculation shows that one hectare would provide well above the minimum requirements. If this is true, a world population twice as great as the present could be fed from only 2.7×10^8 hectares, about one-fifth of the present world arable area. But, growing such crops would be possible only if soil nutrient deficiencies were made good by fertilizers.

The other broad topic covered in the introduction was that of devising economic policies for optimizing fertilizer use. A review of the recent progress in fertilizer use in India suggests that Government's policies have been effective and that India's experience could be of great help to other developing countries wishing to promote and optimize the use of fertilizers in increasing agricultural production. Successful fertilizer policy depends very largely on the availability of a good data base and the cooperation between the Government and the Fertilizer Association of India has been immensely valuable in this regard.

Fertilizer policy and food policy are closely related. They must aim to establish and maintain a produce price/fertilizer price ratio that is a sufficient incentive to the farmer who produces the food without prejudice to the consumer, many of whom in India have earnings considered to be below the poverty line. When increasing fertilizer prices on the world market adversely affected fertilizer consumption in 1975/76, the Government was quick to improve this ratio through a number of measures. The cost of fertilizer to farmers was lowered by reducing duties on imported phosphate and subsidizing domestic phosphate manufacture; controlled prices of potash were also reduced. These measures rectified the imbalance between nutrients which had been increased by price changes. In 1976/77 the Government reduced the controlled price of urea and then increased the procurement prices for crops, thus further improving the price ratio.

The Government has also taken steps to improve the distribution of fertilizers to the farmers, working through both public and private enterprise. Adequate, properly located and efficient facilities for the distribution and sale of fertilizers are of paramount importance in avoiding losses and ensuring that the farmer can get the material when and where he needs it.

Though there has been immense progress, there is still much to be done. Present nutrient consumption at about 30 kg/ha is still very low. Though food production has increased it has barely kept pace with the increase in population. Population will continue to increase and there are limited possibilities to increase the area under crop so it is inevitable that the additional food required must come through intensification. With average cereal yields of only about 1 t/ha, while some progressive farmers are already getting 5 or 6 tons, there is ample scope for intensification in which increased fertilizer usage and improved fertilizer efficiency will play a large part.

2. PLAN OF THE SEMINAR AND RECOMMENDATIONS

Following the setting of the scene , more than 50 papers were presented in 11 sessions over four days.

1. Nutrient transformation and losses
2. Efficient fertilizer use management for crops. Wetland crops, upland cereal grains, fibre crops, plantation crops.
3. Edaphic factors affecting fertilizer use efficiency
4. Increasing fertilizer use efficiency
5. New forms of fertilizers
6. Supplementary sources of nutrient supply
7. Fertilizer use and dryland agriculture
8. Integrated nutrient supply system
9. Fertilizer use economics
10. Extension approaches
11. Developmental strategies

There was, inevitably, some overlap between these headings and there were also some gaps in the coverage. Thus this account does not follow the form of the session titles; it is based rather on the recommendations which emerged at the end of the conference.

The recommendations constitute an indication of which current problems were regarded as being the most important. Nine of the 32 recommendations related directly to agricultural extension and development strategy showing, perhaps, that delegates felt that there was not so much a need for more knowledge but rather a great need for the more effective translation of existing technology into practical use. Eight of the recommendations concerned aspects of the recycling of nutrients and the exploitation of biological sources of nitrogen. There was evident concern to improve the basis for fertilizer recommendations with improvements in the use and interpretation of soil analysis and further investigation into crop response to fertilizers. Two recommendations called for investigations to improve the efficiency of nitrogen fertilizers and two, similarly relating to phosphate. There were recommendations for further study to improve the particularly low efficiency of fertilizers applied to wetland rice and to improve application methods for dryland crops. It is, maybe, surprising that there was no recommendation that more attention should be paid to the economics of fertilizer use and the majority of authors contented themselves with straight forward yield data with little attempt to determine optimum economic rates.

The recommendations which follow have been grouped in such a way as to facilitate the following discussion which is based upon them. The order in which they appear should not be taken to imply any order of priority.

2.1 THE RECOMMENDATIONS

2.1.1 General

1. It is clear that the new agricultural technology based on high genetic potentials for yield and the application of optimum rates of fertilizers, which Indian scientists have evolved during the past fifteen years, has helped the country and is still relevant. However, this technology was essentially based on the western model and was evolved during a period when energy resources, including fossil fuels, and fertilizer feedstocks were abundant, inexpensive and readily available. The resultant technology helped to create high levels of production but was not necessarily very efficient in terms of the energy input-output ratio.

For the present, no other high yield technology is available and countries like India should continue to make full use of it. An important component of this technology is the use of generous dressings of fertilizer. Nevertheless, in the context of the changed world energy situation it is important that, at the same time, conscious, planned and determined research efforts be initiated at this stage to give a different direction to the agriculture of the future in the developing countries, so that, in ten or fifteen years from now, the present dependance on non-renewable resources of energy could be greatly reduced.

The highest priority should be accorded to all those agronomic and other experimental approaches which promise to improve fertilizer use efficiency. This will itself form a part of the total research effort while, in the long term, a great deal of basic research in the field of biological nitrogen fixation will be needed. Countries like India, which today have an enormous investment in the chemical fertilizer industry, should also be investing a small fraction of these funds in setting up centres of microbiological research. While it is unrealistic to expect that the present production technology using fertilizers can be replaced in the near future, a beginning should be made immediately in seeking long term solutions to these problems. While the highest research policy bodies in India should direct their attention to this approach it is also recommended that international agencies, both FAO and research consortiums like the Consultative Group on International Agricultural Research (CGIAR), should be actively concerned.

2. Fertilizer is a costly input; it involves the annual turnover of more than 5 million tons of nutrients and an expenditure of billions of rupees. There is, however, no national institution which can guide systematically, coordinate and monitor various facets of fertilizer use in the different soil-climatic regions of the country for the various crops. It is recommended, therefore, that the Government of India consider setting up a National Fertilizer Institute to develop expertise on soil-plant systems and to promote the adequate, economical and efficient use of fertilizers.

3. Since fertilizer use efficiency is a matter of global concern, it is recommended that the subject should receive support in terms of commitment of resources and efforts in inter-governmental organizations such as FAO and UNIDO. FAO might consider the feasibility of convening expert consultations with the objective of formulating concrete programmes in this respect. Such expert groups could identify problem areas and propose action programmes.

2.1.2 Extension and Education

4. Much knowledge of various aspects of fertilizer use efficiency has been accumulated over the years but the transfer of technology to the farmers' field has not kept pace with the growing literature on the subject.

While there is still a need for further investigations and research into means to increase fertilizer use efficiency, the State Governments, Agricultural Universities and the Fertilizer Industry must launch, without further loss of time, a campaign for extending the known technology to farmers.

5. An appropriate monitoring group should immediately be formed in each State, to direct and check the implementation and evaluation of the campaign. The extension agencies have the main role in this campaign but the fertilizer industry and other agencies should also be involved; the Agricultural Universities may also consider whether some of their senior students might lend a helping hand in such campaigns. A multi-media approach should be used to arouse the consciousness of the farmers and to impart to them the necessary skills.

6. The Training and Visits (T & V) System already introduced in many States should be actively involved in the transfer of technology on the efficient use of fertilizers. The entire system of training of extension staff at various levels must be renewed with a view to strengthening the components which relate to efficient fertilizer use.

7. The State Governments and the Fertilizer Industry should organize large numbers of demonstrations on selected practices which will increase the efficiency of applied nutrients.

8. As a basis for the overall extension campaign, the research experience accumulated so far should be rigorously selected and crystallized into a national manual. This manual should delineate broad guidelines applicable to each region. These guidelines must be further refined at the State level to render them more site-specific.

9. The concept of the integrated nutrient supply system should form an important part of the extension programme. This embraces the harvesting of nitrogen in the farm through green manuring and the use of biological nitrogen fixation and the conservation of plant nutrients through the recycling of organic wastes. It is recommended that at least one demonstration highlighting integrated nutrient supply should be organized in each block all over the country in each cropping season. One important aim of such demonstrations would be the training of farmers from the neighbourhood.

2.1.3 Prediction of Crop Response to Fertilizer

10. At the present time, the prediction of crop response to fertilizer is based on statistical data from large numbers of field trials, involving great expenditure of time and resources; the method may not yield accurate results. It is desirable to explore the possibility of adopting a 'mechanistic' or 'modelling' approach in which the latest knowledge of soil science and plant nutrition is incorporated for predicting response to nutrients for any soil-crop characteristic. Since this approach has been tried successfully in a number of developed countries, it would be desirable for some Indian experts to make a first-hand study of the approach and make suitable recommendations.

2.1.4 Soil Testing

11. Soil testing is a highly professional and technical service and therefore it should be entrusted to technologists well versed in soil science and agronomy. It is recommended that the technical staff of the soil testing laboratories and the field staff who actually take the samples from the farmer's field should be carefully trained and given regular refresher courses.

12. A necessary precondition for efficient and accurate soil test

results is perfect calibration of laboratory equipment. There are no arrangements at present to take care of this problem and it is recommended that the necessary infrastructure to ensure maintenance and periodic calibration of instruments should be created. The time between collection of samples, analysis and the issuing of recommendations should be reduced to a minimum.

13. It is necessary to monitor that the soil testing laboratories are giving out correct analyses and making precise recommendations. This can be done by establishing a central laboratory in each major State which would send check samples to each laboratory and verify the accuracy of analysis and resulting recommendations for fertilizer use.

14. The linkages between the three distinct agencies - the soil testing laboratories, the All India Coordinated Project on Soil Test - Crop Response Correlation and the Extension Agencies are very weak and it is recommended that a suitable mechanism should be evolved for providing horizontal and vertical linkages between these organizations.

15. It is recommended that the Soil Survey Organization should also be involved so that the soil testing laboratories can have the benefit of information on site characteristics and profile properties obtained through soil surveys.

16. There is a need to monitor changes in soil fertility resulting from the use of fertilizers so that data become available on which to base recommendations for adjustment of fertilizer recommendations. Selected soil testing laboratories in the country should identify bench mark soils in their vicinity and carry out on them annual analysis of samples.

2.1.5 Nitrogen Fertilizers

17. The utility of neem (melia azadirachta linn.) cake as a nitrification inhibitor has been well established. This programme should be extended wherever feasible. There is a need to collect information on the distribution of the neem tree and extent of areas, to obtain estimates of neem cake availability and the possibility for collection and processing of the fruit; the cost of collection and processing must be ascertained. The technology for blending neem cake powder with urea on a commercial scale requires investigation and the possibilities for blending at the farm level should be examined. Extension literature on the benefits to be expected from using neem cake and on methods for blending will be required.

18. Deep placement of super-granules or briquettes of urea for the rice crop greatly increases efficiency of the fertilizer. A multi-pronged effort is required to popularize the technique. This will include increased production of super-granules and briquettes by the Indian Farmers Fertilizer Cooperative Ltd. in their pilot plant and the establishment of pilot plants by other producers. In the field, application techniques must be developed and popularized; manual and mechanical methods both have possibilities.

19. Liquid fertilizers are widely used in some countries and may hold promise also for India. A proper study should be conducted to determine the feasibility of using fluid fertilizers in India from the points of view of: a) convenience; b) cost of production; c) possibility of blending nutrients in accordance with local needs and of blending fertilizer with pesticides if required; d) streamlined and economic distribution.

2.1.6 Phosphate Fertilizers

20. Suitable cropping sequences should be developed by the ICAR for recovering native and locked-up phosphate in the soil. It is recommended that efforts be intensified for developing technology, the adoption of

which would result in the solubilization of such phosphates especially in those soils where there has been a heavy phosphate build up due to continuous application.

21. About 30 percent of the agricultural land of the country is on acid soils and the phosphate requirements of such soils can be met by applying powdered rock phosphate. It is therefore recommended that suitable extension and development programmes should be devised to popularize the use of rock phosphate on acid soils. Rock phosphate is likely to be cheaper and less energy intensive than any water soluble phosphate but just as effective on acid soils.

22. It is recommended that the Fertilizer Industry step up its research and development effort to evolve new products which are intrinsically more efficient and economical in use than conventional fertilizer materials.

2.1.7 Integrated Nutrient Supply

23. Cultivated fodders and grain legumes can fix atmospheric nitrogen: berseem in particular has been shown to fix over 400 kg/ha atmospheric nitrogen through Rhizobium symbiosis. Renewed emphasis should be laid on the use of green manure for obtaining at least an average yield of 3 t/ha rice or wheat under practical farming conditions.

24. The use of biological nitrogen fixation (BNF) should be intensified. They are location specific, thus work to identify strains suited to different areas should receive close attention. An integrated approach to production, distribution and usage will be required if impact is to be made on the farm. Exchange of experience with countries like Australia, New Zealand and Brazil in this respect will be useful.

25. Aquatic weeds such as water hyacinth could be treated as a resource rather than a nuisance and could be used for manuring either by composting or through suitably designed biogas plants.

26. There is a need to generate more data on the nutrient value of organic manures and on the efficiency of fertilizers when used in conjunction with organic materials in various crop-soil situations and crop sequences. It is recommended that ICAR and the Agricultural Universities and also the Fertilizer Industry undertake time-bound research work for this purpose.

27. Large quantities of cattle shed waste, now burnt as fuel can be made available for nutrient replenishment of the soil without sacrificing their fuel potential through the establishment of a network of biogas units. It is recommended that the programme should receive special attention in areas covered by cattle cum dairy development schemes such as Operation Flood.

28. Basic research is required on the microbiology of the anaerobic digestion of cattle manure with a view to reducing the retention period which may, in turn, reduce the size and cost of the plants.

2.1.8 Agronomy

29. Rice accounts for 32 percent of the area under crops in India and contributes 40 percent of the total grain production. The lower efficiency of fertilizer, particularly in wetland rice, is well known. It must receive priority attention.

30. It is claimed that application of low or moderate rates of fertilizer to dry land crops can raise crop yields significantly, but this requires correct placement of the fertilizer and for this a bullock-drawn

fertilizer drill is needed to ease the task. It is recommended that extension effort in this direction be intensified; quality fertilizer drills must be made available at reasonable prices and extension programmes must be carefully drawn up and implemented in each State.

31. The campaign recently launched by the Government of Karnataka State for increasing fertilizer use efficiency in dry land areas should be studied and similar campaigns launched in other States. ICAR's All India Coordinated Project on dryland farming should provide technical backing for such a programme. Selected dry farming districts should be identified immediately and the already available technology transferred to these districts through the joint efforts of the Government, Industry and the Extension Agencies.

32. Sugarcane is a large consumer of fertilizer, but, in many areas high rates of fertilizer have not been found to give proportionate response. Fertilizer recommendations in such areas should be critically reviewed taking into account, inter alia, varietal requirements and should be modified where necessary. A systematic effort should be launched by the Central Sugarcane Directorate. The Sugarcane Research Institute and the Cooperatives and factories should undertake the education of farmers in the more efficient use of fertilizer for this crop.

2.1.9 Fertilizer Supply

33. Block level planning of fertilizer requirements including close specification of fertilizer types should be introduced in all States. The supply of fertilizer in accordance with real requirements and in good time would do much to improve the efficiency of fertilizer usage. Proper arrangements for supply are critical for the success of any fertilizer programme.

3. AGRICULTURAL EXTENSION

The extent of the differences between average yields obtained by farmers and the yields possible with improved practices is illustrated by Table 1 which shows the overall Indian picture for grain crops.

Table 1 YIELD GAPS IN CEREAL CROPS

Crop	Indian national average yield	Average yield in demonstrations
	t/ha	t/ha
Rice	1.32	5.18
Wheat	1.48	3.66
Maize	1.04	3.43
Millet	0.43	2.62
Sorghum	0.73	4.23

Thus the average yields obtained by farmers are only from about 16 percent (millet) to 40 percent (wheat) of those normally obtained in demonstrations, while the latter are far from representing what can be achieved since the best demonstration yields recorded are from 20 to 80 percent better than the demonstration average and these are still lower than yields from some experiments.

Table 2 shows how farmers' performance varies between selected States; it also includes data from a survey of farmers' knowledge of improved technology. It is notable that in the Punjab, where wheat yields are the highest and most nearly approach yields on demonstrations, farmers' knowledge scores are very much higher than elsewhere. Dr. K.N. Singh, in his Seminar paper, says: "Though there are many factors responsible for the technological knowledge and production gaps, like poverty, lack of resources, non-availability of inputs and credit, high cost of inputs, unremunerative prices etc., the farmers' ignorance and lack of knowledge of and skill in the modern technology is crucial in impeding agricultural progress. This in turn is due to weak linkages between research, extension and client (farmer) systems, weak information and communication system, incompetent men, the farmers' characteristics and level of development, and above all, lack of understanding and emphasis on the role of extension education and communication in the transfer of technology".

The Indian Council for Agricultural Research (ICAR) which as well as being responsible for guiding the Agricultural Universities in research and education, directly administers 34 research institutes. Three of the national institutes (Indian Agricultural Research Institute (IARI), Indian Veterinary Research Institute (IVRI) and the National Dairy Research Institute (NDRI)) have teaching functions and divisions of extension education; most of the other institutes have small extension units.

The 21 Agricultural Universities engaged in teaching, research and extension education. Their specific extension functions are: training of extension personnel; collecting research findings and passing them on to extension staff and the media; producing information materials and teaching aids; carrying out a limited programme of demonstrations and identifying

Table 2 FARMERS' YIELDS AND DEMONSTRATION YIELDS OF WHEAT IN SELECTED STATES AND SMALL FARMERS' KNOWLEDGE OF NEW AGRICULTURAL TECHNOLOGY

State	Wheat yield (t/ha) 1977-78			Percent of small farmers with knowledge of new technology (1975)			
	Farmers' Average	Demonstration Average	Demonstration Best Yield	Improved Seed	Fertilizers	Green Manure	Plant Protection
Punjab	2.54	4.45	6.34	96	94	71	65
Gujarat	1.78	3.50	5.60	36	37	14	19
Rajasthan	1.42	4.65	9.90	44	36	22	23
Uttar Pradesh	1.43	4.60	7.20	62	50	39	42
Madhya Pradesh	0.91	3.45	5.09	27	31	14	17
Maharashtra	0.79	2.38	4.70	36	37	14	19

Adapted from Seminar paper of Dr. K.N. Singh problems in the field; providing an effective farm advisory service to farmers and all concerned with agricultural development; testing the applicability of research findings to different soil, agro-climatic and socio-economic conditions.

The National Extension Service: This system is the responsibility of the National and State Governments and is primarily responsible for farmer education. It is organized vertically from State to Division to District, to sub-Division, Block, Village, and finally, to the farmer. Other departments concerned with development are similarly arranged and at Block level the efforts of all are coordinated through a Block Development Officer.

A number of specialized extension agencies such as the Small and Marginal Farmers' Development Agency, Drought-prone areas Development Agency, are also involved.

Apart from what may be termed the "official" agencies, the agricultural supply industries - fertilizer manufacturers, pesticide companies, suppliers of farm machinery - and the nationalized banks are also active. Some voluntary bodies are also concerned in rural extension work.

The media - radio and television and agricultural magazines, of which there are 250, play an important part in communicating with the farmer. However, the efforts of all concerned are not always perfectly coordinated.

Under the system described above, which was introduced in 1953, an inherent weakness lay at the grass roots, i.e. in the village extension worker. He was a multi-purpose worker, expected also to deal with matters other than agriculture, so that his agricultural technical knowledge was rather poor, a defect which became more evident as farming technology advanced. Furthermore, he was given too large an area and too many farmers to look after.

It was realized that the professional standards of the agricultural extension worker had to be raised and that this involved his specialization in agriculture and freeing him from other duties. It was also realized that he must be given a limited target in terms of area covered and the number of farmers for whom he was to be responsible.

Under the "Training and Visit System of Extension" first introduced in the Chambal Command Area in Rajasthan State with the help of the World Bank, the village workers' responsibility was limited to 500 families in irrigated areas or about 800 families in non-irrigated areas. His task was further simplified by working through "contact" farmers in each village, the contact farmer, sharing his experience with his fellows, thus constitutes another link in the extension chain. The village extension worker is supported by subject matter specialists at block, sub-divisional and district level.

In charge of the village level worker (VLW) is the Agricultural Extension Officer (AEO), who supervises 8 VLWs and above him is the sub-divisional extension worker assisted by subject matter specialists. Normally the large unit consists of the sub-divisional officer with his specialists covering 3 to 5 Blocks with 80-100 VLWs.

The essential feature of the system is training. The subject matter specialists are trained by research workers; they in turn train the VLWs who, on their visits pass on the information through the contact farmers. The arrangement has a two-way function in that it offers a line of communication also from the farmer back to the research worker who is thus kept informed of needs in the field. Both training and visits are carried out on a regular schedule once a fortnight.

In the early stages of fertilizer promotion the aim is simply to get farmers to use fertilizer and, up to now, the question of achieving maximum efficiency in their use has not been taken into consideration. As the new technology is taken up by farmers the emphasis has to be shifted to obtaining maximum efficiency. The necessity for this is underlined by the relatively high cost of fertilizer materials and the relative lack of means for the farmer to purchase. Efficiency in use should become the cornerstone of fertilizer extension work.

Fertilizer is only one of the means of increasing production, albeit a most important one. The message about efficient fertilizer use has to be passed on in the context of the efficient use of other inputs in the framework of the whole agricultural system. Thus the fertilizer extension programme must be suited to the soil and climatic conditions of the area and to the cropping system followed, and should be presented as a component part of integrated nutrient supply, involving the conservation and utilization of agricultural and domestic wastes, the incorporation of legumes into the rotation and, where appropriate, the use of azolla and blue-green algae as a source of nitrogen.

In order that the integrated extension programme should be fully effective, it is necessary to involve departments other than agriculture and there is a need to involve staff of the irrigation departments and others, e.g. the staff of the fertilizer agencies, who are in close contact with the farmers.

There has been considerable investigation in India into the question as to which are the most effective methods for transferring information. From the Seminar papers a summary view emerges that the relative effectiveness of different methods varies according to the status of the farmers. The more advanced are well able to profit from specialist advice and from the media while the less advanced are more susceptible to demonstration on the farm. It seems to be universally recognized that the different methods can have a synergistic effect, e.g. reinforcement of the message contained in a demonstration by radio talk, poster demonstration, film show, group discussion or other means. This suggests that there should be close cooperation between the agricultural extension service and the media so that programmes can by synchronized.

Considerable emphasis was placed in papers, and in the discussion, on the importance of on-the-farm demonstrations. It was suggested that there should be a national programme of demonstrations of fertilizer and other input efficiency and, that where the T & V extension system is being followed, these demonstrations should be sited with the contact farmers who should be selected to be representative of the different types of farmers in an area. Such demonstrations, of a more or less permanent character, would become the focus of local extension effort and could be used for one-day courses for neighbouring farmers. It is possible that they might also be used as channels of distribution for fertilizers, seeds and other inputs.

A notable feature of agricultural extension work in India is the extent to which the fertilizer industry has been involved and in some cases has even given the lead. An example is the "Whole village adoptive research-cum-demonstration project" of the Fertilizer Association of India to which reference is made in Chapter 7.

4. THE BASIS OF FERTILIZER RECOMMENDATIONS

In India, as elsewhere in the world, fertilizer recommendations to practical farmers rest on the results of field experiments carried out first on experimental stations and then extended under practical farming conditions. An enormous amount of response data has been accumulated from trials of quite simple design sited on small farms; the work done on the rice crop in the early 1950's was an example to others of the utility of the simple unreplicated trials. When sufficient of such results are available from an area with similar soil, climatic and cultural conditions, statistical treatment gives a measure of the reliability of the data. This work has been intensified since the early days and continues to the present.

The carrying out of large numbers of such trials, many thousands in India for the rice crop alone, raised two very serious problems: high cost in time, money and commitment of staff and the sheer difficulty of sorting and evaluating the vast mass of data generated. It is hardly surprising then that Recommendation No. 10 implies dissatisfcation with the present state of affairs and grasps at the suggestion that some other approach to the problem could be preferable. Such a view should not be taken to imply a criticism of the work that has been done in the past which has made possible the formulation of recommendations upon which the farmer can act with a fair degree of certainty of a successful outcome; it has certainly shown the way in the early stages of fertilizer adoption.

An example of the approach is given by the ICAR experiments on irrigated rice on cultivators' fields in which 2,294 trials were carried out in the period 1974/75 to 1977/78 and which were described by Messrs Mahapatra and Bapat in a paper to the Seminar. The aim of the trials was to classify areas for responsiveness to major and minor nutrients, the country having been demarcated by the National Commission on Agriculture into different agro-climatic regions, according to which the results are grouped in Table 3. The trials were sited in randomly selected fields in randomly selected villages. At each site the trial tested selected treatments, usually not more than 12 in number without replication on the site. Figure 1 gives the country-wide mean results for selected treatments from the trials while Table 3 shows mean results for the individual areas. The general conclusion drawn by the authors was that good and economic responses would be obtained almost universally to 80 kg/ha N and 40-60 kg/ha P_2O_5. Responses to potash were rather smaller but application of this fertilizer would give good returns except on the kharif crop in the Central Highlands. As a practical recommendation for general use, they incline to the view that 60 kg N, 30 kg P_2O_5 and 30 K_2O/ha could be relied upon to give moderate and profitable responses, while there was widespread response to applications of zinc sulphate. However, it is evident from the table that there was a good deal of variation in response between the areas, and doubtless there was considerable variation within areas, so that while the blanket recommendation mentioned above could be relied upon to give a worthwhile return in increased crop, it would seldom result in the optimum yield and, hence, in optimum fertilizer use efficiency. It is a good starting point but needs to be refined to give even better practical results.

Figure 1 RESPONSE OF RICE TO NITROGEN, PHOSPHATE, POTASH AND ZINC
(Weighted averages of ICAR experiments 1974 - 1978)

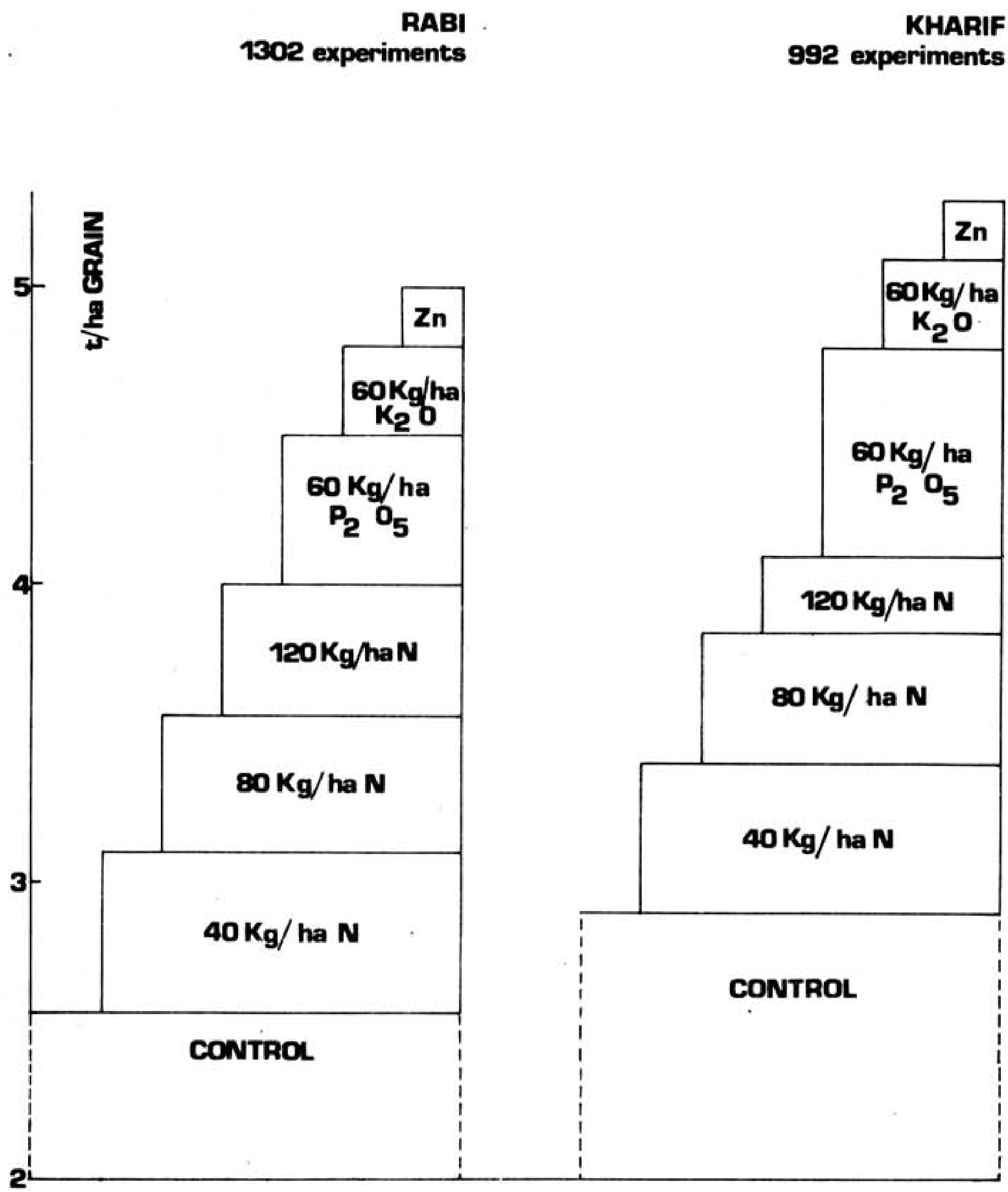


Table 3 RESPONSE BY RICE IN TRIALS ON FARMERS' FIELDS TO SELECTED FERTILIZER TREATMENTS, 1974/75 - 1977/78

(Adapted for this Seminar from Mahapatra and Bapat. T/ha unhulled rice. Mean yields and responses weighted for number of trials in areas)

Region*	No. of Experts	Yield w/o fertilizer	Response to 120 kg/ha N	Response to 60 kg/ha P_2O_5 at 120 N	Response to 60 kg/ha K_2O at 120 N, 60 P_2O_5	Response to 25 kg/ha $ZnSO_4$ at 120 N, 60 P_2O_5, 60 K_2O
	Rabi Crop					
I	23	2.72	0.93	0.52	0.25	0.35
II	27	3.34	1.07	0.83	0.56	0.29
III	333	2.05	1.63	0.57	0.23	0.18
IV	386	2.35	1.40	0.67	0.34	0.22
V	98	2.10	0.94	0.35	0.21	0.10
VI	435	3.19	1.19	0.66	0.31	0.32
	Karif Crop					
I	45	3.10	1.24	0.74	0.50	0.31
IV	356	2.68	1.42	0.67	0.37	0.21
V	81	2.21	0.92	0.47	0.07	0.16
VI	510	3.08	1.08	0.66	0.30	0.24

* Region I - Humid Bengal-Assam (West Bengal)
II - Humid Eastern Himalaya (Manipur)
III - Sub-humid Sutlej-Ganga alluvial plains (Bihar, Uttar Pradesh, Punjab)
IV - Sub-humid East and South-East Uplands (Andra Pradesh, Madhya Pradesh, Orissa)
V - Semi-arid lava plateaux and Central Highlands (Maharashtra)
VI - Humid to semi-arid Western Ghats (Tamil Nadu, Karnataka, Kerala)

A paper by Messrs Singh and Krishnan to the Seminar gave an economic assessment of ICAR experiments in which increasing dressings of 2:1:1 fertilizer were applied in trials on farmers' fields in the two seasons 1977/78 and 1978/79. Optima were calculated from the response function derived from the four equally speced (0 - 240 kg/ha) rates of fertilizer tested and the results by region are summarized in Table 4 which shows also the calculated rate of fertilizer needed to achieve optimum economic yield.

Table 4 ECONOMIC ASSESSMENT OF FERTILIZER RESPONSE ON IRRIGATED RICE AND WHEAT

Region	No. of Experts	No fert. yield (t/ha)	Yield with 240 kg/ha fert.* (t/ha)	Calculated optimum rate of fert. (kg/ha)	Calculated optimum yield (t/ha)
	Karif Rice				
Northwest	151	3.43	5.96	265	6.06
North	104	2.08	4.22	302	4.55
Eastern	376	2.15	4.85	323	5.34
Central & Western	142	2.37	4.37	292	4.60
Southern	613	3.01	5.27	207	5.09
	Rabi Rice				
Southern	592	3.21	5.15	208	4.99
	Wheat				
Northwest	412	2.03	4.13	250	4.16
North	383	1.78	4.45	333	4.89
Eastern	501	1.34	3.58	275	3.70
Central & Western	608	1.70	3.21	216	3.10
Southern	412	1.14	2.31	159	2.07

* N - 120 kg/ha, P_2O_5 - 60 kg/ha, K_2O - 60 kg/ha

Large responses were obtained and, clearly, application of the highest rate of fertilizer applied gave a good and profitable return in all cases, but it is unfortunate that the range of rates tested was so limited that the calculated optimum yields and fertilizer rates frequently lay outside the range actually tested so that these calculated optima are largely speculative. In cases where the calculated optimum rate was in excess of the maximum tested, application of 240 kg/ha would give a better Value Cost Ratio (VCR) than the optimum rate. VCRs for the 240 kg/ha dressing varied between 1.16 and 3.15 for wheat and between 1.6 and 2.53 for rice.

Among the many experimental results quoted in papers to the Seminar very little attention was paid to profitability of fertilizer treatment which is clearly of the greatest importance. Data for the economic return from applying recommended rates of fertilizer to a range of dryland crops is given in Table 5, also taken from the paper by Messrs Singh and Krishnan in terms of Value Cost Ratio.

Table 5 ECONOMIC RETURN FROM APPLYING RECOMMENDED RATES OF FERTILIZER TO DRYLAND CROPS - TRIALS ON FARMERS' FIELDS 1977/78 and 1978/79

Crop	No. fert. yield (t/ha)	Fert. recommended kg/ha N, P_2O_5, K_2O	Response to rec. rate (t/ha)	Net profit (Rs/ha)	Value Cost Ratio
Rice	1.07	60-60-30	1.15	354	1.52
Wheat	0.68	60-60-30	0.83	258	1.38
Maize	0.95	60-60-30	1.24	435	1.64
Sorghum	1.08	60-60-30	1.05	264	1.39
Sorghum dry season	0.58	60-60-30	0.64	loss	-
Millet	0.46	60-60-30	0.35	loss	-
Gram	0.78	20-40-20	0.71	778	3.17
Groundnut pods	0.90	20-60-40	0.68	715	2.40
Mustard	0.40	60-40-20	0.52	698	2.27

It was only for the pulse and oilseed crops that the return from fertilizer was sufficiently attractive financially to allow the recommendation to use fertilizer to be made with any confidence. A Value Cost Ratio less than 2, although related to a tangible net profit is not generally thought sufficient to cover the risks implicit in dryland cropping though it may be perfectly acceptable for irrigated crops where the risk is not so high.

Messrs Singh and Krishnan also presented results of experiments which had sought to establish a relationship between soil analytical data and response to phosphate and potash, but no clear trend emerged. It seems likely that soil P and K values are related with other factors of soil fertility and that therefore it cannot be expected that there will be a simple relationship.

The examples discussed above represent only a tiny fraction of the work on fertilizer response that has been done in India in recent times. Recommendation No. 10 indicates some unease in this matter but it is beyond doubt that this work has been a most valuable contribution and that, though the modelling concept deserves serious consideration, it must be some years until it can be expected to have a practical outcome. Fertilizer practice in any country results from a combination of experimental investigation and experience; experience alike of research worker, advisor and the farmer himself.

The complexity of the factors which affect fertilizer response is great and there can be no doubt that it will be some considerable time before they are all thoroughly understood. On the other hand, the need for sufficient experimental data from conventional field experiments on the whole range of crops grown under all the different conditions in India is a need which must appear impossible practically to satisfy by these means. Hence, it is necessary to seek alternative solutions to the problem and for this reason there was great interest in the suggestion of Dr. Greenwood, based on experience in other countries, that a better approach to the problem than that offered by plastering the country with myriad field experiments on a whole range of crops might be offered by the "mechanistic" method of crop modelling. If the essential factors of site and soil which affect fertilizer response on the one hand, and the characteristics of the different crops which determine the plant's need for and ability to exploit the soil for nutrients on the other, can be identified and quantified, it should then be possible to build them into a model of crop behaviour from which it should be possible to predict the crop's response to, and its requirement for, nutrients and, at the same time, greatly reduce the need for field experiments. Up to now, somewhat approximate general recommendations have served India well but, as fertilizer usage progresses there must be a need for greater precision, on the one hand to enable farmers to achieve yields nearer to the potential and on the other hand to obtain the maximum possible efficiency in the use of scarce resources of nutrient. In its simplest terms this means avoidance of waste through excessive applications, a waste which occurs all too easily because the farmer may tend to think that if a little is a good thing then a lot must be even better, and the avoidance of missing the opportunity offered by applying too little fertilizer to correct a crop-limiting nutrient deficiency.

5. SOIL TESTING

It is evident from the recommendations that there is a general dissatisfaction in India regarding the use of soil analysis to aid in the prediction of crop response to applied nutrients and in making fertilizer recommendations. On the other hand, that there are in India no less than 273 laboratories engaged in soil analysis is sufficient indication of the importance which is attached to this work. Four recommendations call into doubt the accuracy and standardization of field sampling and laboratory work but it must be doubtful to what extent these possible shortcomings are responsible for the apparent lack of faith in the utility of soil analysis in guiding fertilizer recommendations. Standardization and improvement of these services should, in themselves, present no insuperable problem.

Considering the importance which is evidently attached to this subject, there was remarkably little factual information in papers presented to the Seminar on the correlation of soil analysis with fertilizer response. Velayuthan et al. reviewed the subject.

Early work aimed to establish three soil levels for the major nutrients (low, medium and high); generalized recommendations were based on the medium category and fertilizer recommendations modified upward or downward in a somewhat arbitrary manner for low and high soils respectively. Though the system had limitations, trials indicated that recommendations based on soil analysis were usually superior to general blanket recommendations.

A good deal of work has been done by measuring response to increasing rates of the three nutrients on plots in which varying levels had been established in a pre-treatment phase by applying increasing dressings of fertilizers under uniform cropping. From the resulting response surfaces optima for the individual fertilizer nutrients (amounting to upward or downward modification of the standard recommendation according to soil nutrient status) can be calculated, taking into account the crop price/ fertilizer price relationship. The method is said to have given good results.

Some idea of the small certainty in predicting fertilizer requirement in relation to soil analysis can be gained from selected results quoted by Mahapatra and Bapat for rice in experiments sited on fields on particular soil types selected as being of varying fertility status as indicated by soil analysis. It is evident from Table 6 that soil analysis was of very limited value in predicting response to P and K.

One would not expect to obtain a close correlation from such a grouping of results but Table 6 can only indicate that response to a nutrient is not simply a matter of soil content of that nutrient.

Some other results quoted by this author showed that the concept of a critical level of soil P was useful, response to a standard dressing of 60 kg/ha P_2O_5 being on average some four times greater on soils below the critical level than it was on soils above that level, and this held for contrasting soil types.

Table 6 RESPONSE OF KHARIF RICE TO 60 KG/HA P_2O_5 AND 60 KG/HA K_2O APPLIED WITH ADEQUATE DRESSINGS OF THE OTHER TWO NUTRIENTS (t/ha)

District (State)	Soil Nutrient Level (PK)	Response to P	Response to K	S.E. of Response
Bhagalpur (Bihar)	LM	0.62	0.25	0.040
	LM	0.71	0.26	0.039
	ML	0.61	0.26	0.033
	LL	0.87	0.28	0.121
Nalgonda (Andrha Pradesh)	LM	0.96	0.27	0.119
	LH	0.80	0.57	0.132
	MH	0.90	0.41	0.149
Pondicherry	LL	1.03	0.63	0.103
	LM	0.87	0.57	0.097
	ML	0.87	0.51	0.172
Banda (Uttar Pradesh)	LM	0.88*	0.17	0.100
	LH	0.79*	0.21	0.103
	MM	0.84*	0.16	0.090
Bilaspur (Madhya Pradesh)	LH	1.59*	0.11	0.197
	MH	1.17*	0.28	0.240
	HM	1.32*	0.12	0.160

L - Low
M - Medium
H - High
* Response to 120 kg/ha P_2O_5

It seems quite evident that response to a particular nutrient is affected by a multiplicity of factors only one of which is the soil content of that nutrient. While one or other methods of soil analysis may prove to be superior on a particular soil type or under given conditions, in general, particularly on farmers' fields, other conditions are extremely variable and frequently mask, or interfere with, the effect of a single nutrient. It seems to be the experience in other countries that the use of soil analysis is more helpful when there are extensive areas of uniform soils and where farming methods have reached a uniform and relatively advanced standard. While soil analysis may appear so far to have been of limited value in India, where quite evidently conditions on the farms are extremely variable, there is at least sufficient indication of its utility to suggest that investigations should proceed and that, as knowledge accumulates and the understanding of all the factors which affect crop growth improves, it will become increasingly important as an advisory tool. At the present stage, where general fertilizer recommendations appear to be modest in comparison with optimum recommendations it may not be important to try to introduce too much refinement into the recommendations, but, as fertilizer use spreads among the farmers and as crop yields and fertilizer rates rise, it will become increasingly important to introduce more refinement in order to ensure that the optimum economic return is obtained; it can hardly be doubted that then soil analysis will have an increasing part to play.

A point that is worth considering is whether simple, quick field tests could not be used for on-the-spot advice. While these may not be as "accurate" as formal laboratory methods, they could well be sufficiently so for practical advisory purposes, especially so as the formal, and much more expensive methods do not appear to be giving a return commensurate with their cost. There are also simple (colorimetric) methods for determining nutrient content of plant tissue; these have been valuable in some developed countries for adjusting nitrogen dressings in accordance with plant development, thus achieving greater precision in fertilizer usage than is possible by soil analysis alone.

Recommendation 16 draws attention to the desirability of using soil analysis to monitor changes in the soil resulting from fertilizer application over a period and to see how these changes may be affected by cropping sequence and the removal of soil nutrients in harvested produce. Whatever may be the limitations of soil analysis in comparing one site with another, it is always of value in following changes on a particular site. A useful bank of information could be accumulated by this kind of work on "benchmark" sites representative of specific soil types.

6. EFFICIENCY OF FERTILIZERS

Papers of the Seminar discussed the fate of nitrogen, phosphate, potassium, iron and zinc when they are applied to the soil since a knowledge of the transformations which take place and affect the availability of nutrients to crops is essential. This may explain the low efficiency of some nutrients under various conditions and suggest means of improving efficiency. The main problems concern nitrogen and phosphate fertilizers; only minor problems are encountered with potassium. Low fertilizer efficiency is a greater problem in flooded rice soils than in upland farming, so particular attention was paid to the rice crop.

6.1 NITROGEN

An introductory paper by Messrs Hauck and Bock, dealing with nitrogen losses from the soil-plant system, pointed out that at least one quarter of all the nitrogen applied as fertilizer in the world leaks out of the system. This is equivalent to an energy loss of 10^{17} joules.

A main source of loss is denitrification - the biological reduction of nitrate and nitrite to nitrous oxides and elemental nitrogen. There is always some loss by this pathway but losses are particularly severe in waterlogged soils. The extent of the loss commonly ranges from 10 to 45 percent of N applied as fertilizer.

Severe losses can occur by volatilization of ammonia when ammonium salts or urea are used and the authors gave a range of loss from 1 to 50 percent. These losses are greater on high pH soils and the losses from urea applied to rice are particularly severe. Another important source of loss is by leaching of nitrate which is very mobile in the soil; its extent depends on soil type, rainfall, drainage conditions and crop cover. Minor sources of loss are leaching from living plants and volatilization of ammonia from decaying crop residues.

It is difficult to measure the extent of nitrogen loss; estimates made from tracer studies tend to be under-estimates. While it is possible to measure directly the evolution of N_2 and nitrous oxides under controlled (laboratory) conditions, this is not possible in the field and over the life of a crop.

Much can be done to minimize losses by management: control of irrigation, timing and splitting of fertilizer application to suit the needs of the crop, placement of fertilizer below the soil surface. Possibilities are also offered by coating urea granules to control the rate of dissolution in the soil and by the addition of chemicals which reduce the activity of nitrifying organisms, though such methods involve an increase in fertilizer cost. There should be a possibility of inhibiting urea activity in order to reduce the evolution of ammonia but, as yet, chemicals suitable for mixing with urea are lacking.

Mr. de Datta, quoting results obtained by IRRI, drew attention to different methods for improving the efficiency of N fertilizer on rice: by timing of application of fertilizer and by a combination of coating and deep placement. In the trials of which results are given in Table 7 the farmer applied nitrogen 8 and 38 days after transplanting (DT) in the dry season and 10 DT and 5-7 days from panicle initiation in the wet season; research worker's timing was one-third at transplanting, one-third at 20-30 DT and one-third at 5-7 days before panicle initiation.

Half the rate of nitrogen normally used by the farmer proved to be equally efficacious when applications were correctly timed.

Table 7 EFFECT OF RATE OF NITROGEN AND TIMING OF APPLICATION ON RICE YIELD

Nitrogen applied (kg/ha)	Grain yield (t/ha)	
	Farmer's timing	Research timing
Dry Season		
112	6.7	6.9
50	6.2	6.8
100	6.9	7.0
150	7.6	7.4
Wet Season		
62	6.1	6.7
29	5.7	6.4
58	6.1	6.4
87	6.4	6.7

Figure 2 illustrates the results obtained by applying increasing rates of nitrogen alternatively in two splits to the soil surface, as coated granules applied to the surface and as coated granules applied by deep placement.

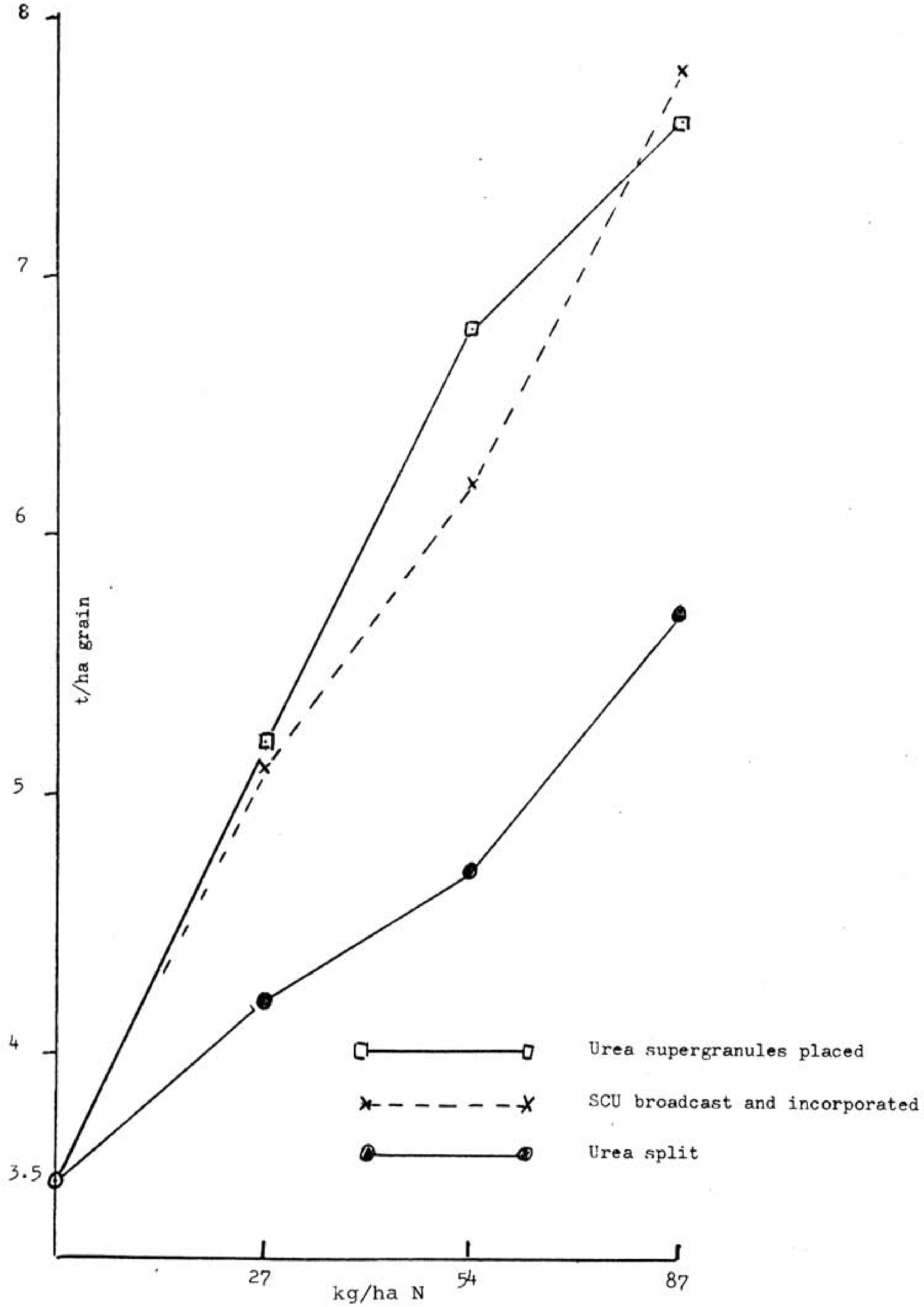
Coating the urea to control the rate of dissolution greatly increased efficiency as also did deep placement. Both methods involve some penalty, the former increasing fertilizer cost, the latter being more laborious, a difficulty which might be overcome if suitable machinery became available for use by farmers.

In India work has been done to investigate the effect of the following on nitrogen use efficiency (Shinde, Pillai and Vedauyas Rao):

- Split application;
- Deep placement of urea supergranules or briquettes in the rooting zone;
- Coating of the nitrogen fertilizer;
- Blending or coating urea with non-edible oil-cake having nitrification inhibiting properties;
- Mixing nitrogen fertilizer with farmyard manure or compost.

Work has also been done on increasing the N supply to the crop through blue-green algae, Azolla fern, etc.

Figure 2 EFFECT OF FORM OF UREA AND APPLICATION ON RICE YIELD (IRRI)



The mean results from 24 trials at 7 centres on kharif rice crops summarized in Table 8 show that both sulphur-coated urea and deep placed supergranules performed much better than split applications of urea to the surface. Sulphur coated urea (SCU) has the disadvantage of high cost and the lack of supplies of sulphur in India, so deep placement is the preferred method. These trials covered diverse soils from calcareous heavy clays irrigated to lighter soils lacking proper water control and clay soils with impeded drainage, so that it seems that the technique can be recommended for a wide range of conditions.

Applying synthetic nitrification inhibitors with nitrogen fertilizer is a technique used with success in some fields in other countries, but work with these materials, which are expensive, has shown that they offer little or no advantage compared with split applications of urea. On the other hand, coating or mixing with neem-cake, which is locally available, has proved very effective and has markedly improved the efficiency of fertilizer N, as indicated by data for N uptake by the plant (Table 9).

It is suggested that some of the earlier work using neem-cake which gave patchy results, may have been affected by imperfection of the blending methods used but the more recent work using coal tar solution as a sticker has given more consistent results of which those quoted in Table 9 are an example. These results are also of significance in indicating the advantage of neem-cake coating in the absence of controlled irrigation. Though splitting the application does markedly improve the efficiency of urea applied to rice, successful use of the technique depends upon correct timing of the applications which is not possible without very good control of irrigation, and farms where water control is inadequate are too numerous.

The nitrification inhibiting property of neem-cake is thought to be due to the nimbinan acrid alkaloids which they contain and there are other non-edible oil cakes, e.g. _karanj_, _mahua_ and _sal_ indigenous to India which contain similar compounds and have been shown to be as effective as neem-cake or even more so.

It is clear from the work so far done that the coating of urea with neem-cake is a promising technique, but coating must be uniform and so far it does not seem that large-scale manufacture of such materials has been attempted. Though the neem tree (_Melia azadirachta_) is widely distributed, the scale of availability of the material is not known and little is known about the possibilities for large-scale collection and processing and how the economics of such a venture would work out. These aspects must be investigated. It is also possible that a simple technique could be devised for coating urea which could be used by the farmers themselves.

Other non-edible oilseeds indigenous to India with nitrification inhibiting properties are: Karanj (_Pongamia glabra_), Mahua (_Madhuca indica_) and Sal (_Shorea robusta_). It is estimated that about 1 million tons of these and neem might be available annually. Apart from their use in agriculture, there is some current interest in their use to supply oil for soap manufacture.

Many years ago these non-edible cakes were investigated as possible nitrogen fertilizers but, in general they were found to be inferior to the edible oilseed cakes as manures due to the lower rate of nitrification in the soil; this was later attributed to their content of bitter substances. Table 10 compares neem-cake, mahua cake and N-Serve as nitrification inhibitors.

Table 8 GRAIN YIELD OF RICE AS AFFECTED BY MODIFIED UREAS AND APPLICATION METHOD (Mean of 7 Centres, 1975 - 1979)

Treatments	Grain Yield (t/ha)
No nitrogen fertilizer	3.12
28 kg/ha N split	3.68
28 kg/ha N as SCU	3.88
28 kg/ha N as supergranules	3.93
56 kg/ha N split	4.09
56 kg/ha N as SCU	4.48
56 kg/ha N as supergranules	4.57
80 kg/ha N split	4.39

Table 9 EFFECT OF NEEM-CAKE COATED UREA ON YIELD OF IRRIGATED AND RAINFED RICE - KHARIF 1978

Treatment	Grain yield (t/ha)		Percent fertilizer N recovered in grain and straw	
	Irrigated	Rainfed	Irrigated	Rainfed
No N fertilizer	3.65	3.07	-	-
Urea 3 splits	5.98	4.41	40.3	21.9
Neem-cake coated urea 1 application	6.72	5.58	65.9	46.5

Table 10 NITRATE CONTENT (ppm N) OF SOIL INCUBATED WITH N-SERVE AND NATURAL NITRIFICATION INHIBITORS (150 kg/ha N applied)

N Source	Days Incubation			
	2	4	8	30
Urea	239	89	241	167
Urea +neem seed crushed	136	69	126	120
Urea +neem-cake extract	117	76	178	141
Urea + mahua cake extract	133	80	164	141
Urea + N-Serve	-	115	216	154

Table 11 is of interest in demonstrating the greater residual effect on the following wheat crop of differently prepared urea. Neem-cake urea was less effective on the crop to which it was applied (rice) but was more effective than other materials for the following wheat crop which measured residual effects.

Table 11 DIRECT AND RESIDUAL EFFECTS OF DIFFERENT UREA FORMS APPLIED TO RICE (Mean yields of 2 rice and 2 wheat crops)

Source	Grain yield (t/ha)	
	Rice	Wheat
Urea	3.4	2.4
SCU	4.4	3.1
Lac coated urea	3.9	2.9
Neem-cake coated urea	3.8	3.3

Neem-cake coated urea has also performed well in tests with maize, potatoes, sugar cane and cotton.

Experimental slow-release N fertilizers have been manufactured in India on a trial scale by oxidizing coal with nitric acid and subsequent ammonification. Though they have shown useful slow-release properties when applied to rice, these products are very hygroscopic and difficult to handle, so do not seem to be a practicable proposition.

6.2 PHOSPHATE

The efficiency of phosphatic fertilizer in terms of P uptake by the crop to which it is applied is universally low, though it can be improved by careful timing and placement, and averages only about 20 percent. The mechanisms which are responsible for this universally low efficiency were discussed in a general review paper by Professor Larsen. He pointed out that the rate at which the pool of phosphate available to the plant can be replenished from the stock of insoluble soil phosphate, into which a large proportion of fertilizer phosphate is converted, is so low as to be unable to make any significant contribution to plant nutrition so that, on P deficient soils, repeated applications of P fertilizer are needed to maintain crop yields. There is no prospect of saturating the P fixation capacity of Indian soils by heavy applications of phosphate fertilizer - the cost would be prohibitive.

Two things are of great practical importance regarding the use of phosphate fertilizer in India: a large proportion of soils is acid in reaction and on such soils it is to be expected that ground rock phosphate may be as effective, or nearly so, as the much more expensive water soluble fertilizers; a large extent of the phosphate rocks occurring in India cannot be used, at reasonable cost, for the manufacture of soluble P fertilizers. The work reported by Mr. Panda in a Seminar paper, on the effiency of partly acidulated rock phosphates and mixtures of soluble and insoluble materials, is therefore of particular interest since it offers possibilities of using the local raw material and of considerable economy in cost over using soluble phosphate fertilizers. As an example, the results of a three year trial carried out in 1971-1973 comparing superphosphate, two types of rock phosphate and mixtures of local rock with superphosphate for rice are summarized in Table 12.

Table 12 RELATIVE RICE YIELDS (NO PHOSPHATE = 100) WITH VARIOUS PHOSPHATE FERTILIZERS (Mean of 3 Seasons)

P Source	kg/ha P_2O_5 applied		
	50	100	200
Superphosphate (S)	129	131	-
UAR Rock	-	143	178
Mussorie Rock (M)	-	138	164
80 percent M and 20 percent S	132	148	-
50 percent M and 50 percent S	138	165	-

Both rock phosphates performed better than superphosphate when applied at the equivalent rate, while the efficiency of the Mussorie rock was improved by mixing with superphosphate. The explanation of this effect is that the monocalcium phosphate in superphosphate reacts in the soil solution liberating some phosphoric acid which reacts with the insoluble phosphate in the rock to produce $Ca(H_2PO_4)_2$ which in turn reacts to produce more phosphoric acid. Further, the soluble P applied is immediately available to the crop, acting as a starter dose.

Somewhat similar results were obtained with groundnut as the test crop (Table 13).

Table 13 RELATIVE YIELDS (NO PHOSPHATE = 100) OF SHELLED GROUNDNUTS WITH VARIOUS PHOSPHATE FERTILIZERS

Source	40 kg/ha P_2O_5 applied
Superphosphate (S)	151
Pelophos (30 percent water soluble)	177
Mussorie rock (M)	156
80 percent M + 20 percent S	178

Some similar results from Assam State were quoted by Messrs Bora and Nath in which, in trials on farmers' fields, the efficiencies of Mussorie rock and a mixture with superphosphate (80 percent M + 20 percent S) averaged 104 and 114 respectively (superphosphate = 100), though the results showed some erratic features. Comparison of two phosphate types at Jorhat (sandy loam, pH 4.9) showed a distinct advantage for superphosphate on both the rice crop to which it was applied and the succeeding rice crop which received no fertilizer, but, at Titabar (clay, pH 4.0 and high organic matter) the advantage was distinctly with Mussorie rock.

It seems that, at least on some of the more acid soils, ground Mussorie rock is as efficient (and much cheaper) source of phosphate as superphosphate and that the partially acidulated rock or a mixture of rock phosphate with a proportion of soluble phosphate may offer further advantage.

A great deal of work has been done in India on the fate of phosphate applied to soils and this was reviewed by Goswami. It is important to have a knowledge of the forms into which phosphorus is transformed in the soil, since crops take up most of the fertilizer P <u>via</u> these reaction products. The great problem is that so large a proportion of the applied phosphate is converted to insoluble forms which are to all intents and purposes of no use to crops and though, under certain conditions, these insoluble forms may be partly solubilized through the activity of micro-organisms in the rhizosphere, there have been no results from work under field conditions which would suggest cropping or management practices which might favour this process, and thus make available some of the phosphate which has been "banked" in the soil as a result of past applications of fertilizers. It is interesting that, in the anaerobic conditions of a flooded rice soil, previously unavailable phosphate is solubilized through the reduction of ferric to ferrous iron and thus becomes available to the rice which, in consequence, may not suffer from P deficiency. Later in growth when soil conditions become aerobic due to oxygen diffusing through the roots and through draining the water off the field, iron is re-oxidized, ferric phosphate is formed and protected by the ferric hydroxide so that it is non-available and a succeeding wheat crop may then show P deficiency. Under such situation application of phosphate fertilizer would be preferable in the dry season compared to the wet season.

7. INTEGRATED NUTRIENT SUPPLY

The concept of integrated nutrient supply is a broad one embracing consideration of the nutrient cycle between the soil, the crop and the animal, the question of correct nutrient balance in fertilizer use, including trace elements, combined use of organic manures and fertilizers, the exploitation of biological sources of nutrients (nitrogen fixation) and the matching of nutrient supply to the cropping system as a whole and not merely to the needs of specific crops.

Discussion of the topic must start with conservation of the very large quantities of nutrients which are involved in the soil - crop - animal - humal cycle. In his paper introducing Session IX of the Seminar, Dr. D.R. Bhumbla, on the basis of the 1972 Cattle Census of India, estimated total production of dung by cattle, sheep, goats and poultry at approximately 780 million tons of which he reckoned some 150 million was inevitably lost to farming. An estimate of the nutrient content of animal and crop wastes is given in Table 14, alongside the consumption of fertilizer nutrients for 1978/79.

Table 14 NUTRIENT CONTENT OF ANIMAL AND CROP WASTES IN INDIA AND TOTAL CONSUMPTION OF FERTILIZER NUTRIENTS

Source	Quantity (million tons)	Nutrients contained therein (million tons)		
		N	P_2O_5	K_2O
Dung	630	1.26	0.63	0.94
Urine	100	0.60	0.10	0.50
Farm wastes	85	0.34	0.09	0.34
Total		2.20	0.82	1.78
Fertilizers 1978/79		3.40	1.10	0.60

To the above quantities of nutrients which are "at risk" in the farm cycle must be added an estimated 2.5 million t N, 0.9 million t P_2O_5 and 0.8 million t K_2O contained in human wastes from a population of 638 million (Messrs Shende and Sundaresan, this Seminar). Thus the amounts of nutrients in all waste products exceed the amounts applied in fertilizers by some 1.3 million t N, 0.6 million P_2O_5 and 2.0 million t K_2O. Such estimates are necessarily very approximate but, however inaccurate they may be, they underline the necessity of taking all steps possible to prevent undue loss from the system. Apart from the nutrient content of these wastes which must have a potential value at least double the amount the country spends in fertilizers, organic manures have other beneficial effects on soil structure and crop growth. Furthermore, they have a large energy content which could be realized without prejudice to the manurial value of the residues and waste products.

Traditionally, cattle dung and crop residues are used as fuel. Provided the ash is returned to the soil, this practice does not involve much loss of mineral nutrients but Dr. Khandelwal (this Seminar) estimates that about half the available dung and one-fifth of crop residues which are burned each year contain 1.6 million t N (a higher estimate than that of Dr. Bhumbla) which is lost to agriculture, while there must also be a considerable loss of sulphur. Dr. Khandelwal's estimates are given in Table 15.

Table 15 AVAILABILITY AND CONSUMPTION OF ANIMAL AND CROP WASTES IN INDIA

Source	Availability/Consumption (million t)	
	1970	2000
Dung (dry matter)	146	180
Crop residues	200	375
Burned as fuel (dung)	72	83-121
Burned as fuel (crop)	40	58- 85
Nitrogen lost	1.6	2.5-3.0

1.6 million tons nitrogen would supply 10-12 kg/ha N over the whole agricultural area of the country.

7.1 BIOGAS FROM FARM WASTES

If these farm wastes were used as feedstock for biogas plants the greater part of their N content would be preserved, while large amounts of organic matter would also be available and could be applied on farms to the benefit of soil structure. The National Dairy Research Institute estimates that the potential biogas production from 179 million cattle and 58 million buffalo could amount to 66 Gm^3* while a further 3.2 Gm^3 could be produced from small stock and poultry. To treat just one-third of the available material would require 10 million family-sized biogas units, which, at the rate proposed in the 5th Development Plan (construction of 20 000 per year) would take 500 years! This is a daunting prospect. Development in plant design has greatly reduced construction costs which hindered progress in the past and it is suggested that a target of one million plants for the Sixth Plan would be a realistic aim. A million units would save up to 4.5 million tons of firewood per year and the by-product slurry would supply about 200 000 t nutrients ($N+P_2O_5+K_2O$). Trials have shown that 63 percent of the nitrogen, and all the other nutrients except some sulphur are conserved in the slurry. The conservation of trace elements is reckoned to be particularly important.

The manurial benefits of biogas slurry are twofold. In the first place the organic matter improves biological activity in the soil and promotes the stability of soil aggregates, improving the moisture characteristics of the soil. Secondly, the direct nutrient effects are considerable. As yet there is limited data on the manurial effects of the slurry

* G (gigao = 10^9)

but the example quoted in Table 16 from the National Dairy Research Institute shows that 2.5 t dried biogas slurry was equivalent to 40 kg/ha N as fertilizer.

Table 16 EFFECT OF BIOGAS SLURRY ON OAT FODDER YIELD

Treatment	Yield of fodder oats (t/ha)
No manure	27.3
20 kg/ha N	28.3
40 kg/ha N	29.5
2.5 t/ha biogas slurry	29.2

There is a need for further investigation into the manurial value of slurry and for research into methods of storage, handling and application which will minimize losses of nitrogen through volatilization etc. Further work should be done on plant design with a view to reducing costs and making maximum use of local materials. It appears that, so far, biogas treatment of farm wastes has not proved to be financially very attractive in developed countries but the economics should be more favourable in many developing countries with the availability of cheap labour for construction and the more pressing need to economize in expenditure on fertilizer.

7.2 SEWAGE EFFLUENT

28 million people out of 109 million living in urban areas are on main sewerage systems producing an estimated 3635 million litres sewage a day. Treatment facilities are inadequate with consequent polution hazards. In 1971, about 40 percent of sewage was used to irrigate some 12 000 ha. Rates of application varied but, in general, were very high, resulting in waste of water and nutrients and soil deterioration. Both the 1971 figures and a NEERI survey in 1974 indicated excessive rates of application of N (400-6 000 kg/ha N) per annum, a finding which suggests that better use could be made of these wastes if they were diluted with plain water (to reduce the N rate to a reasonable level) and supplemented with phosphate and potash to make good deficiencies. Results from wheat crops grown on sewage for 8 years are given in Table 17.

TABLE 17 WHEAT YIELDS (AVERAGE OF 8 YEARS) FROM SELECTED SEWAGE TREATMENTS (t/ha grain)

Sewage dilution	Without fertilizer	With supplemental fertilizer*
Well water	1.4	2.7
1:0	2.3	3.0
2:1	2.1	2.8
1:1	2.2	3.0
1:2	1.9	3.0

* N, P and K fertilizer added to bring total application up to 100 kg N, 60 kg P_2O_5, and 60 kg K_2O/ha.

There was a benefit of making up the deficiencies of phospate and potash in the sewage which in the raw state contributed 180, 50 and 56 kg/ha N, P_2O_5 and K_2O respectively. This indicates that diluting the sewage increased the efficiency of utilization of sewage N by the crop. As regards practical application, it is clear that better returns in terms of nutrient utilization can be obtained from sewage if it is diluted to bring the N contribution down into line with the crop's requirements provided other nutrient deficiencies are made good with supplementary fertilizer. Since sewage composition varies greatly, the degree of dilution needed, depending on N content, and the required additions of P and K can only be determined on the basis of regular analysis of the sewage.

7.2.1 Domestic Sewage

Rural areas do not have large-scale sewerage systems and the conservation of domestic wastes then has to be tackled on a much smaller scale. Three main requirements of a domestic system for dealing with household wastes are: that it should overcome the health hazards intrinsic in primitive systems (or lack of system) for the disposal of human waste; that it should conserve as much as possible of the plant nutrient content of the waste; that it should be cheap enough and simple enough to construct to be within the resources of the villagers. NEERI has designed a hand-flush waterseal pit latrine which offers several advantages for use in rural areas. This is a modification of the ordinary pit latrine, using twp pits alternately, the wastes being introduced by pipe from a water-sealed pan. The design is such that it can be installed in the rear verandah of a house with access to a courtyard, the area needed for two pits being about 11 m^2. An obvious precaution is to site the pits at least 15 m from the nearest source of water.

1 000 of these latrines have been built in 8 villages around Nagpur and an important aspect of the campaign has been the education of the villagers to ensure their cooperation. This concentrated on the sanitation aspects, i.e. the prevention of the spread of water-borne intestinal diseases and worms. The possibility for obtaining humus and plant nutrients was also stressed and this the villagers found particularly appealing. Used by the average family, one standard pit is filled in about 5 years and yields about $1m^3$ of manure estimated to be worth some Rs 500 in fertilizer equivalent. The cost of construction at 1980 prices is only about Rs 500 and the pit will have a life of about 25 years. It seems that the nutrient value of the manure may be over-estimated, particularly as regards N content, since there must be losses involved in the anaerobic fermentation process and in leaching.

NEERI estimates that if only 25 percent of the rural population was equipped with such sanitation systems, the resulting saving in plant nutrients would be 300 000 t N, 100 000 t P_2O_5 and 15 000 t K_2O per annum, while the improvement in health standards in villages which at present have no sanitation would be an even greater benefit.

7.3 BIOLOGICAL FIXATION OF NITROGEN

Information so far accumulated in India and in other countries indicates that the biological fixation of nitrogen from the atmosphere could make a larger contribution to the nitrogen requirements of crops than is now the case with consequent saving in the manufacturing and transport costs of fertilizer. Sources of biological nitrogen are of two main kinds. Rhibozium - legume symbiosis, in which the legume may itself be a crop of intrinsic value, i.e. a grain legume or a fodder legume included in the farm rotation. Otherwise the legume may be a crop of no particular food value inserted in the rotation for the purpose of green manuring, or a shrub or tree, grown on waste land, road sides, bunds, etc., the leaves of which can be used as a mulch. A special case is the use of Azolla fern either as a mulch or intercropped with rice. The other source of biological nitrogen is the free-living micro-organisms of the soil, a special case is the exploitation of blue-green algae in rice fields.

Grain legumes are grown on 24 million ha in India (Dr. Bhumbla, this Seminar) and produce about 11 million tons grain equivalent to about 3 million t protein. Yields are low and there is obviously scope for improvement of varieties and for the improvement of nodulation by inoculation with the appropriate strain of Rhizobium. Yields of these crops must be improved so that they can compete economically for a place in the rotation.

Work at various research institutes has shown up the contribution which leguminous crops can make to soil fertility. IARI experiments showed that grain cowpea provided 12-23 kg/ha N for the following cereal crop. A summer crop of gram (Phaseolus aureus) in addition to yielding a ton of pulse increased the yield of the following maize crop by 0.5 t /ha (Table 18).

Table 18 EFFECT OF SUMMER LEGUME ON YIELD OF MAIZE AND WHEAT

Rotation	Grain yield t/ha		
	Gram	Maize	Wheat
Maize-wheat	-	5.01	4.62
Gram - maize - wheat	1.10	5.50	4.47

The way in which gram may respond to inoculation through better nodulation is indicated in Table 19.

Table 19 RESPONSE OF GRAM TO INOCULATION WITH RHIZOBIUM
(Mean of 18 crops on 5 sites)

Treatment	Grain yield (t/ha)
Not inoculated	1.85
Inoculated	2.21

In earlier days, farmers in parts of India were encouraged to grow green manures which were thought to supply 20-40 kg/ha N to the following crop, but the advent of nitrogen fertilizer took away much of the attraction. With the rising price of nitrogen, the situation has been reversed and the possibilities for green manuring deserve another look. Recent work shows that the nitrogen contribution of a green manure like Sesbania can be much greater than 20-40 kg/ha, see, for example, Table 20 where green manure supplied the equivalent of 80-100 kg/ha N. The explanation for this difference is probably that the modern rice varieties are more resistant to lodging while the old varieties could only tolerate small N dressings. In many cases, particularly where irrigation water is available, it is possible to grow a summer green manure before planting the rice and recent work has shown that the rice should be planted immediately after the green manure is buried.

Table 20 EFFECTS OF FERTILIZER NITROGEN AND GREEN MANURE ON RICE YIELD
(Mean of 2 crops 1974 and 1975)

N fertilizer (kg/ha N)	Grain yield (t/ha)	
	No green manure	Green manure
0	3:02	5.82
40	4.06	6.33
80	5.71	6.74
120	6.18	7.71

Nitrogen fixing blue-green algae occur widely in the rice fields of India but there are differences of opinion regarding their practical utility, estimates of N fixation varying from almost nothing to 50 kg/ha. The frequency of occurrence of nitrogen fixing organisms shows considerable regional variation - from 87 percent of examined soil samples in Uttar Pradesh down to only 7 percent in West Bengal. In experiments where cultures of blue-green algae were added there have been reports of savings in N fertilizer as high as 30 percent but also reports of negligible effects. Clearly the matter needs further investigation.

The use of azolla fern as an intercrop with rice or as a mulch, has shown that, depending on conditions, very considerable amounts of N may be fixed and there are reports that azolla can replace about 30 kg/ha fertilizer N. The properties of different strains of the fern are under investigation and it has been demonstrated that the fern requires a good supply of phosphate. Again, further investigation is needed.

7.4 INTEGRATED NUTRIENT SUPPLY IN PRACTICE

Interesting developments in farmer education on integrated nutrient supply were described by Dr. Singh et al. in a paper dealing with the "Whole village adoptive research-cum-demonstration project". This was undertaken by the Fertilizer Association of India with the assistance and cooperation of State departments of agriculture, Agricultural Universities, ICAR institutes, banks and local organizations. It covered twenty villages.

The main feature of the programme was the calculation from crop analyses of nutrient balance sheets for the crops grown in the village. These balance sheets were prominently displayed and used in farmer education. In each case there was a considerable back-up effort including assistance in preparing farm plans, provision of agricultural advisors, credit as needed, guaranteed supply of seed, fertilizers, plant protection chemicals and other inputs, assistance in conservation of farm wastes including the installation of biogas plants to increase the availability of organic manures, improvement in irrigation, etc.

As an example of the effectiveness of the programme in increasing farmers' appreciation of the need for nutrient management, Table 21 included here to indicate the progress made in four selected villages. As farmers came to understand that crops removed nutrients and that they needed to make good these removals, nutrient consumption increased very substantially and crop yields rose.

Table 21 NUTRIENT CONSUMPTION AND CROP YIELDS IN SELECTED VILLAGES

Village	Year	kg/ha NPK*	Crop yield t/ha			
			Rice	Wheat	Sorghum	Groundnut
Nagiaposhi	1975/76	43	2.2	-	-	-
(Orissa)	1977/78	68	2.6	-	-	-
Heranj	1974/75	76	2.5	1.5	-	-
(Gujarat)	1976/77	110	2.7	-	-	-
Somatne	1974/75	10	2.1	1.1	1.6	0.9
(Maharashtra)	1977/78	128	3.1	3.2	2.7	2.3
B. Koduru	1974/75	57	3.4	-	-	-
(Andrha Pradesh)	1977/78	227	6.2	-	-	-

* $N+P_2O_5+K_2O$

The programme has led to better appreciation of the manurial value of recycled organic wastes and the inclusion of leguminous crops in the rotation. The concept of the nutrient balance sheet has been widely appreciated and farmers have come to understand how to relate nutrient requirement to expected yield and that previously their use of nutrients, particularly in non-intensive systems, was far from adequate.

8. DRYLAND AGRICULTURE

The work of the All-India Coordinated Research Project for Dryland Agriculture was extensively reviewed by Dr. Venkateswarlu. Fertilizer usage on dryland crops is at present low, and this is assumed to be due to the fact that dryland farming is a high risk operation, and crop yields are generally low. There is much greater certainty of profit when fertilizers are used on irrigated crops. However, the dryland project has shown that, provided cultural standards are high enough, fertilizers can be profitable for rainfed crops. It is generally accepted that in areas where adequate rainfall is a virtual certainty, recommendations for fertilizer use can be based on the optimum of the response curve as is the case for irrigated crops, but, where rainfall is uncertain, it is sensible to recommend lower rates, i.e. to be concerned only with the linear part of the response curve.

Soil organic matter content, and consequently nitrogen supply, is universally low, phosphate deficiency is widespread but soil potash supplies seldom limit crop yield. Experimental data over a wide field indicates very satisfactory response of the main crops to nitrogen, ranging from about 15 to 30 kg grain per kg N applied. Though direct responses to phosphate are not so spectacular, the limiting effect of phosphate supply becomes more apparent when potential yields are raised by using nitrogen, resulting in large N and P interactions as in Table 22.

Table 22 NITROGEN AND PHOSPHATE INTERACTIONS ON DRYLAND CROPS

Centre	Crop	Control yield (t/ha)	Response in t/ha (grain)		
			N	P	N+P
Hyderabad	Sorghum	0.67	0.11	0.39	1.57
Bangalore	Ragi	1.76	0.39	0.17	1.30
Rajkot	Sorghum	0.39	0.01	-0.17	0.53

The amount of water available to the crop is of paramount importance as concerns both yield and response to fertilizer. Water-supplying power of the soil is largely governed by depth and texture as exemplified by Tables 23 and 24.

Table 23 INFLUENCE OF SOIL DEPTH IN VERTISOLS ON CROP YIELD

Depth (cm)	Stored water (cm)	Crop yield t/ha		
		Sorghum	Safflower	Gram
30	9	1.3	0.35	0.62
60	18	2.14	0.49	0.71
90	27	-	1.05	1.19

Table 24 INFLUENCE OF SOIL TEXTURE ON WHEAT YIELD ON SUB-MONTANE SOILS

Texture	Stored water (cm/180 cm)	Grain yield (t/ha)
Loamy sand	24.2	2.41
Sandy loam	27.1	3.55
Clay loam	44.3	4.16

A number of measures can be taken to minimize run-off and/or to improve water storage in the soil, including contour farming, bed and furrow systems, graded border strips or dead furrows, according to local conditions while run-off can be collected into farm ponds for use in irrigation. The spectacular yield-increasing effect of limited life-saving irrigation is exemplified in Table 25 where the effect of applying just 5 cm water was to increase yield from 25 to over 200 percent.

Table 25 EFFECT OF MINIMUM IRRIGATION ON CROP YIELD

Region	Crop	Years averaged	Yield (t/ha)	
			No irrigation	One irrigation of 5 cm
Dehra Dun	Wheat	4	2.14	3.55
Varanasi	Barley	2	2.60	3.36
Agra	Wheat	4	1.92	4.11
Bijapur	Sorghum	5	1.65	2.36
Bellary	Sorghum	4	0.43	1.37
Solapur	Sorghum	5	0.98	1.82
Rewa	Rice	4	1.62	2.78
	Wheat	4	0.57	1.88
Anand	Tobacco	4	1.21	1.81

Table 26 taken from Kanwar (this Seminar) compares the Indian average yields for the semi-arid territories (SAT) with yields obtained by ICRISAT showing that yields of cereals could be six times higher than the present average and those of pulses up to four times as high. It is thought that it should be possible to increase yields over all the drylands of India by two to four times.

The importance of high standards of cultivation for improving fertilizer efficiency is illustrated by the results of a field-scale trial by ICRISAT quoted in Table 27.

Table 26 AVERAGE YIELD OF CROPS IN INDIAN SAT AND POTENTIAL YIELD WITH NEW TECHNOLOGY

Crop	Average yield in SAT (30 years) (t/ha)	Yields at ICRISAT Centre (t/ha)	
		Low fertility, average management	High fertility, Good management
Sorghum	0.84	2.63	4.90
Pearl Millet	0.51	1.64	3.48
Chickpea	0.74	1.40	3.00
Pigeon Pea	0.60	1.00	2.00
Ground-nut	0.79	1.71	2.57

Source: ICRISAT Progress Report 1979

Table 27 EFFECT OF CULTIVATION METHOD AND VARIETY ON RESPONSE OF DRYLAND SORGHUM TO FERTILIZER (Mean of 2 years)

Variety/Cultivation Method	Grain yield (t/ha)
Local variety, traditional growing	0.85
Local variety, traditional growing + fertilizer	1.61
Local variety, improved cultivation + fertilizer	2.22
HY variety, traditional growing	0.92
HY variety, traditional growing + fertilizer	2.16
HY variety, improved cultivation + fertilizer	3.63

It would appear that the prospect of improving cereal yields in the SAT is good because suitable high yielding, fertilizer responsive crop varieties are already available. So far, the prospect for pulse crop improvement is rather limited, since the general yield level is so low and though responses, particularly to phosphate have been recorded, there is a lack of high yielding fertilizer responsive varieties of these crops. Probably the most promising crop in this category is the soyabean which has had much attention from plant breeders in other parts of the world.

8.1 PRACTICAL ACHIEVEMENT IN THE IMPROVEMENT OF DRYLAND FARMING

An intensive campaign has been in operation in Karnataka State (Chandrasekhariah and Talur, this Seminar) with the objective of improving dryland farming. Of approximately 11 million hectares of agricultural land in the State, only 9 million have any access to irrigation and 3.5 million ha have unassured rainfall of 453 to 889 mm/per annum. Results in terms of increased grain production have been spectacular as can be seen in Table 28 which gives State average yields for 1978/79 and the corresponding figures for 22 years previously. Maize yields in the State are now the highest in the country.

Table 28 AVERAGE YIELDS OF GRAIN CROPS IN KARNATAKA

Crop	Yield (t/ha)		Percent increase
	1956/57	1978/79	
Rice	1.13	2.08	84
Sorghum	0.32	0.88	172
Ragi	0.79	1.42	80
Maize	0.82	2.96	262
Millet	0.21	0.47	124
Wheat	0.21	0.67	216

Total food grain production per hectare has increased by 133 percent and the State is now self-sufficient in grain despite having reduced the area under crop by 0.8 million hectares. Chief factors contributing to this increase are high yielding varieties, increased fertilizer use and better plant protection measures.

Soil and water conservation lay at the foundations of the improvement programme which has operated through Block demonstrations and the 20 village collaborative projects. The following measures have been recommended:

- Contour bunding on Red and Medium Black soils. Small bunds are built across the slope at intervals of 10m and the intervening land levelled;
- All cultivation, ploughing, harrowing and sowing carried out on the countour;
- Ploughing immediately after harvest or after pre-monsoon showers to conserve the water from early showers;
- Deep ploughing once in three years recommended on black soils;
- Application of organic manures 2 - 3 weeks before sowing (at the rate of 13 cartloads per hectare);
- High-yeilding, short-season varieties which are drought resistant and responsive to light fertilizer dressings;
- Double cropping or inter-cropping wherever possible;
- Use of soil tests to determine fertilizer rates;
- Fertilizer application by combine drill at sowing;

- Maintenance of plant population by gap-filling;
- Inter-row cultivation and weeding;
- Adjustment to abnormal weather conditions - plant protection.

Block demonstrations have been used since 1974 in collaboration with the Agricultural University, the fertilizer manufacturers and financial institutions. These are large-scale demonstrations extending to 20 or 25 hectares and involving all categories of farmers who receive no subsidy and have to pay for all their inputs. Regular advisory and demonstration visits are paid and this brings about close association of extension workers and farmers and also provides valuable experience for the former, giving them confidence in the new methods.

8.1.1 Village Projects

Clusters of 20 villages were selected in three Blocks and the scheme was started in the latter part of 1977. As in the case of the Block demonstrations, the various input agencies, the Agricultural University, other institutions and the Taluk Development Boards were involved. Each of the input agencies adopted one or two villages for their special attention. District teams under the leadership of the Principal Agricultural Officer met monthly, the team consisting of the Block Development Officer, all input and credit agencies and the extension wing of the Agricultural University. Below this District team, the village team was similarly made up from local representatives and this team met more frequently to lay down programmes for each participating farmer.

Fertilizer use is an integral part of the dryland technology which is demonstrated. Farmers are advised to place fertilizer with a seed-cum-fertilizer drill. Results are most impressive - for example, placing only 25 kg/ha N and 12.5 kg/ha P_2O_5 to the side and below the seed increased sorghum yield from 0.40 to 0.85 t/ha. Split application of nitrogen is recommended for kharif crops while, for rabi crops, it is better to place the whole dressing at sowing time in order to make the best use of the limited supply of soil moisture.

An example of the progress achieved in one 20 village area with 1835 ha farmed by 1361 farmers is given in Table 29. Crop yields have increased by about three times since the start of the scheme.

Table 29 YIELDS IN THE CHINTAMANI PROJECT AREA (KOLAR DISTRICT)

Crop	Grain yield (t/ha)			
	Pre-Scheme Survey	1977/78	1978/79	1979/80
Ragi	0.76	0.85	1.40	2.43
Groundnut	0.64	1.00	1.30	1.70

State-wide progress is indicated not only by the increase in average yields referred to above but in the increase in fertilizer consumption which has moved from less than 4,000 t in 1956/57 to 0.37 million t in 1979/80 - a 93-fold increase. Fertilizer usage now averages 42 kg/ha ($N+P_2O_5+K_2O$) in this State where 81 percent of farming is rainfed.

9. CONCLUSION

The question must always be asked at the end of a conference "Was it all worthwhile, are we any further forward?" There is no doubt that this Seminar on Fertilizer Use Efficiency was successful. In the first place, it presented the opportunity to bring together many people from all over India and from the various sectors which are concerned with agricultural development; many of these had never before had the chance to meet and discuss their problems.

The Seminar resulted in an assessment of progress in fertilizer use in India, which over the past ten years or so has been truly impressive. It marked a stage in this work at which the emphasis is beginning to shift from simple promotion of fertilizer use to a concern to obtain the maximum economic benefits in terms of units of agricultural product per unit of fertilizer consumption, an emphasis which is the more important in the environment of scarcity of energy and other resources. The importance of fertilizer use efficiency is particularly evident in India where financial and raw material resources are short and where the average farmer also finds it difficult to meet the cost of farming inputs.

The technical papers gave some idea of the tremendous effort which has been put into agricultural research with fruitful results but they also showed up the gaps in knowledge and suggested some lines of research which should be pursued in the future.

Perhaps the over-riding impression from the Seminar was that a high priority had been given to translating the findings of research into farming practice and that it was realized that even greater efforts are yet required in this field. India can be proud of the way in which the various different interests have whole-heartedly collaborated in the work of agricultural extension. This Seminar concerned fertilizers: it made it clear that the fertilizer industry is making, through the Fertilizer Association of India, a significant and objective contribution to agricultural development.

The Seminar Recommendations point out clearly the way ahead. The progress to be made, perhaps reported at a conference a few years hence, is awaited with confidence.

APPENDIX A

PAPERS PRESENTED AT THE SEMINAR

The Inaugural Session was addressed by :

Shri A.J.S. SODHI - Joint Secretary, Ministry of Agriculture, Government of India

A.S. ALWAN - FAO Representative in India

H.E. PER GULOWSEN - Norwegian Ambassador in India

Shri RAO BIRENDRA SINGH - Minister for Agriculture and Rural Reconstruction, Government of India

Shri S.S. MAHDI - Commissioner (FP), Ministry of Agriculture, Government of India.

TECHNICAL PAPERS PRESENTED

SESSION I POLICIES, GLOBAL AND NATIONAL PROJECTIONS

1. An opening address was given by Dr. M.S. Swaminathan, Member Planning Commission, Government of India.

2. Fertilizer Use Efficiency - Present Status and Future Trends - Global Scene, D.J. Greenwood.

3. Economic Policies for Optimizing Fertilizer Use, J.W. Couston.

SESSION II NUTRIENT TRANSFORMATION AND LOSSES

1. Comments on Nitrogen Loss from Soil-Plant Systems, R.D. Hauck and B. Bock.

2. Phosphate Transformation and Losses, S. Larsen.

3. Critical Review on Nutrient Transformation and Loss Under Varying Conditions of Soil and Plant Systems, N.N. Goswami.

4. Potassium Transformation and Losses in Various Soil-Plant Systems - A Review, G.S. Sekhon and S.K. Bansal.

5. Zinc Transformation and Losses Under Varying Conditions of Soil and Plant Systems, J.C. Katyal.

6. Critical Review on Iron Transformation and Losses Under Varying Conditions of Soil and Plant Systems, H.G. Singh and S.C. Agarwal.

SESSION III EFFICIENT FERTILIZER USE MANAGEMENT FOR CROPS

1. Fertilizer Nutrient Use Efficiency in Wetland Rice Soils, S.K. de Datta.

2. Nitrogen Use Efficiency of Rice in Waterlogged Soils, L.N. Mandal.

3. Nutrient Use Efficiency in Rice under Different Soil and Agro-Climatic Conditions, I.C. Mahapatra and S.R. Bapat.

4. Research on Fertilizer Phosphorus Management for Rice in Acid Soils of Assam, P.K. Bora and A.K. Nath.

5. Nitrogen Use Efficiency for Rice - AICRIP Experience, J.E. Shinde, K.G. Pillai and K. Vedauyas Rao.

6. Review on Nutrient Use and Efficiency under Different Soil and Agro-Climatic Conditions - Upland Cereal Grains, K.R. Kulkarni.

7. Nutrient Use Efficiency under Different Soil and Agro-Climatic Conditions - Fibre Crops - Cotton, Chokhey Singh.

8. Fertilizer Management for Plantation Crops to Maximize the Efficiency of Use of Applied Nutrients, E.V. Nelliat, P. Gopalasundaram, K. Sivaraman and A.R. Roy.

9. Relative Nutrient Use Efficiency of Sugarcane under Different Agro-Climatic and Soil Conditions, S.C. Srivastava.

10. An Approach to the Efficient Use of Fertilizers in the Cultivation of Rubber, N.K. Soong.

<u>SESSION IV</u> EDAPHIC FACTORS AFFECTING FERTILIZER USE EFFICIENCY

1. Fertilizer Use and Dryland Farming Systems, J.S. Kanwar.

2. Fertilizer Use Efficiency in Relation to Water Management, S.S. Parihar and B.S. Sandhu.

3. Effect of Soil Physical Conditions on Fertilizer Use Efficiency, R.P. Gupta and P.N. Chowdhary.

4. Samaclonal Variation - A Cell Culture Option for Plant Improvement, W.R. Scowcroft.

5. Edaphic Factors Affecting Fertilizer Use Efficiency - Agronomic Manipulations, Y.P. Morachan.

6. Weed Control and Fertilizer Use Efficiency, H.K. Pande and H.S. Gill.

7. Fertilizer Use Efficiency in Direct Seeded Rice in Relation to Herbicide Application, G. Sankaran and A. Mohamed Ali.

8. Fertilizer Use Efficiency under Field Conditions, D.N. Puri and S.K. Raheja.

9. Implements for Fertilizer Placement, P.N. Pangotra.

<u>SESSION V</u> INCREASING FERTILIZER USE EFFICIENCY

1. Soil Testing - Its Correlation, Calibration and Use, R.A. Olson.

2. Soil Tests for Judicious Fertilizer Use, N. Velayutham, G.R. Maruthi Sankar and K.C.K. Reddy.

3. Plant Analysis as a Tool for Efficient Fertilizer Use, T.R. Subramanian.

4. Mode of Application for Increased Efficiency of Fertilizers, H.D. Sharma, B.R. Tembhare and S.D. Choubey.

5. Increasing Fertilizer Use Efficiency through Incorporation of Legumes in Cropping Systems and Foliar Fertilization, Rajat De.

6. Role of Pyrites in Increasing Availability of Phosphorus, A.N. Pathak.

SESSION VI NEW FORMS OF FERTILIZERS

1. Exploitation of Indigenous Resources for Slow-Release Nitrogen Carriers, Rajendra Prasad, S. Singh and J. Thomas.

2. Prospects on Use of Partial Water Soluble and Partial Citrate Soluble P in Phosphatic Fertilizer in Varying Soil-Plant Systems, N. Panda.

3. Non-Pressure Fluid Fertilizers: Advantages and Disadvantages for Use in Developing Agriculture, R.D. Hauck and B. Bock.

SESSION VII SUPPLEMENTARY SOURCES OF NUTRIENT SUPPLY

1. The Role of Green Manures in Efficient Fertilizer Use, B.D. Patil and S.D. Rai.

2. Nutrient Utilization from Sewage Effluent for Crop Irrigation, G.B. Shende and B.B. Sundaresan.

3. Neeri Latrines as a Tool for Recycling of Nutrients from Human Wastes in Rural Areas, S.R. Kshirsagar.

4. Biogas System to Conserve Nutrients for Agriculture and Aquaculture, K.D. Khandelwal.

SESSION VIII FERTILIZER USE AND DRYLAND AGRICULTURE

1. Fertilizer Use and Dryland Farming Systems - National Dryland Agriculture Project Experience, J. Venkateswarlu.

2. Field Experience in Increasing Fertilizer Use Efficiency in Rainfed Cultivation in Karnataka, S.R. Chandrasekhariah and C.V. Talur.

SESSION IX INTEGRATED NUTRIENT SUPPLY SYSTEM

1. Integrated Nutrient Supply System - Concept, Scope and Feasibility, D.R. Bhumbla.

2. Integrated Nutrient Supply - A Case Study (Whole Village Adoptive Research Cum Demonstration Project), Ramendra Singh, B.C. Biswas and S.C. Maheshwari.

3. Effect of Application of Zinc, Iron and Manganese on Crop Yield and Uptake of Major Nutrients, G. Ramanathan and S. Subbiah.

4. The System of Supplementing Organic Manures with Chemical Fertilizers in China, Jin Weixu and Zhang Yichun.

SESSION X FERTILIZER USE ECONOMICS

1. Crop Responses to and Economics of Fertilizer Use in India, D.S. Singh and K.S. Krishnan.

2. Constraints to Optimal Use of Fertilizers on Small Farms, A.S. Sirohi, A.K. Ray and B.M. Sharma.

3. Constraints in Optimal Use of Fertilizer in Backward Regions, T.K. Roy.

SESSION XI EXTENSION APPROACHES

1. Bridging the Gaps between Research, Extension and Farmers for Efficient Fertilizer Use, K. Zschernitz.

2. Role of Extension Education in Increasing the Efficiency of Fertilizer Use, G.S. Vidyarthy.

3. Methods and Techniques for Narrowing the Technological Knowledge Gap between Research, Extension and Farmers, K.N. Singh.

4. Profile of Small and Marginal Farmers and Promotion of Fertilizer Use in their Conditions, N.K.S. Mahapatra.

SESSION XII DEVELOPMENTAL STRATEGIES

1. Development Plan for Increasing Fertilizer Use Efficiency - Experience of Tamilnadu, S.A. Subramani and B. Chandrasekaran.

2. Review of Research and Development on Fertilizer Use in West Bengal, B. Mandal.

3. Fertilizer Use Efficiency - The Haryana Experience, A.K. Sinha.

4. Increasing Fertilizer Use Efficiency - Industry's Experience and Viewpoint, V. Kumar and H.S. Subramoney.

5. Fertilizer Quality Control as a Developmental Strategy for Efficient Use of Fertilizers, B.K. Dhar and M.R. Motsara.

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