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ISNAR Reprint Series No. 2

India's Coordinated Crop Improvement Projects: Organisation and Impact

H. K. Jain

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International Service for National Agricultural Research

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India's Coordinated Crop Improvement Projects: Organisation and Impact

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International Service for National Agricultural Research

Foreword

Coordination at the national level is one of the major issues in the organization of agricultural research in most countries. This is even more so in the larger countries which have a network of institutes and experimental stations located in different parts of the country. Also, some countries in more recent years have opted for a decentralized system of research organization, and inter-institutional coordination continues to be one of their major concerns.

We include this article by Dr. H. Krishan Jain in the ISNAR Reprint Series to draw attention to the Indian experience in this field. India, with its federal and state stream of agricultural research has a very large network of institutions whose work it coordinates quite effectively. India's national programs in crop improvement and in other areas of research have received considerable attention. These programs have also had considerable impact on India's agricultural production.

W. K. Gamble
Director General
ISNAR

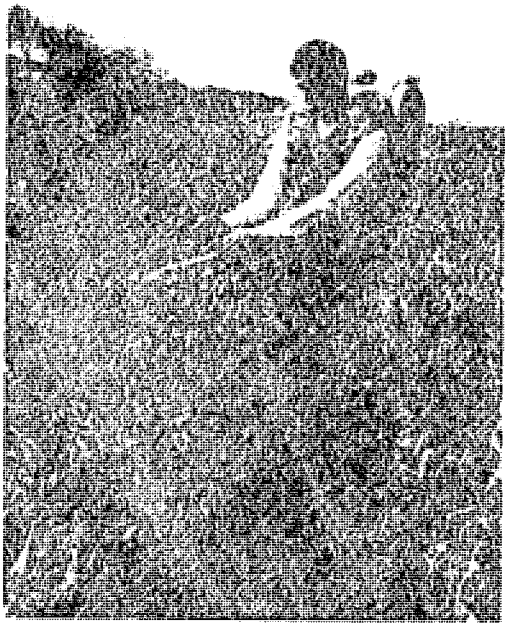


Figure 1. A plant pathologist inoculating the breeding material of wheat with uredo spores of different rust races in order to screen for resistant genotypes.

Despite a ten-thousand-year-old history, agriculture in many parts of the world continues to be of a subsistence kind based on traditional practices. The high-yield agriculture which is now practised in north America, in most parts of Europe, and in countries like Japan and Australia, is a relatively recent development going back nearly fifty years. This can be seen from the fact that large yield increases even in the developed countries have been possible only during the last thirty years or so. Thus, the productivity of some of the important crops like maize and sorghum has seen a remarkable increase in the United States during the twenty-five-year period starting from 1950 (Figure 4). In the United Kingdom, the average yield of wheat has increased more or less linearly over the same period. The progress has been equally spectacular in Japan, which now has one of the world's highest rice yields.

The process of transformation of traditional agriculture leading to these high crop yields has been made possible by two major developments. First, the accelerating pace of industrial revolution in the western world has made it possible for their farmers to use a wide range of farm inputs like chemical fertilisers and sell their produce at incentive prices, following increased consumer demands. Second, important findings in the fields of mineral nutrition of crop plants, Mendelian techniques of crop improvement, plant protection chemicals, and mechanisation have helped to lay down the framework of a more scientific

Figure 2. Newly evolved wheat varieties from the different cooperating centres of the all-India Coordinated Wheat Improvement Project in coordinated trials at the Indian Agricultural Research Institute. The focus in the project is on varietal diversification.

agriculture. Basically, the high productivity of modern agriculture is a function of favourable genotype-environment interactions made possible by our ability to manipulate and assemble genes from diverse sources and use a wide range of inputs derived from fossil fuels and related products, which until recently have been cheap, abundant, and readily available.

Crop Improvement in the Developing Countries

Most developing countries could not take advantage of these developments for giving a new direction to their agriculture. Several factors have contributed to this failure. For one thing, these countries were largely bypassed by the Industrial Revolution, and it is only now that they are making a beginning in this direction. For another, many of them could maintain some balance between low crop yields and relatively small human populations kept in check by disease epidemics. Also, the cultural evolution of these countries had placed greater emphasis on simple living, including the plant-human food chain, rather than the plant-animal-human food chain characteristic of the western countries. This balance, however, was seriously upset in the 1960s when many of these countries on gaining political independence started to organise major programmes of public health. These measures resulted in a sharp decline in the death rate, and the consequent population pressures have forced

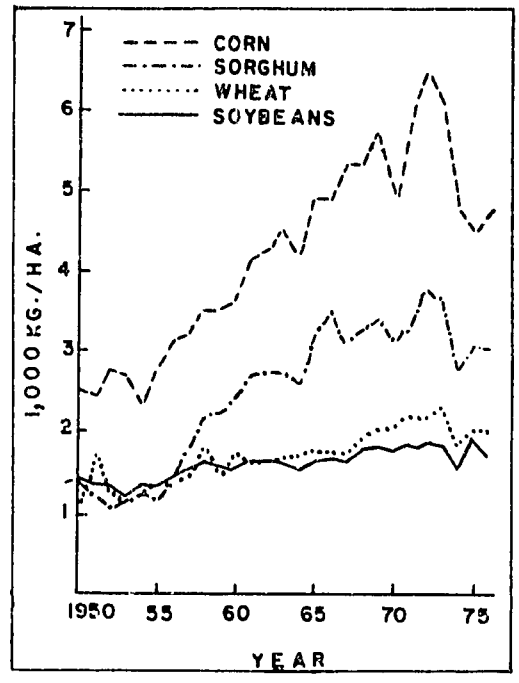


Figure 4. Improvement in crop yields in the United States since 1950. (Adopted from World Food and Nutrition Study, National Academy of Sciences, Washington, 1977.)

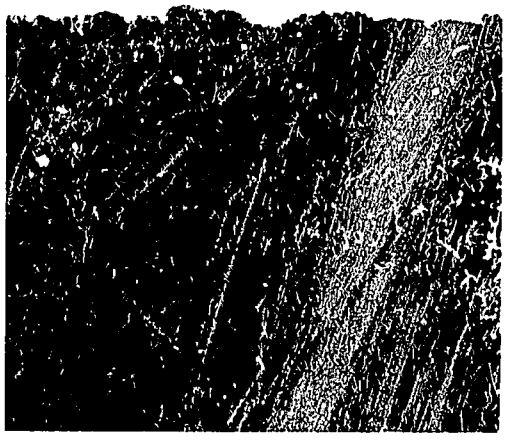


Figure 3. Evolution of short-duration varieties of rice which can be fitted into multiple cropping patterns is a major objective. A newly evolved variety of this kind is shown here in the background of traditional late-maturing, tall cultivars.

many of them to review their programmes of agricultural production. Figure 5 and 6 show the changing pattern of population growth in a number of developing countries in different parts of the world during the fifty-year period starting from 1930. Figure 7 shows the expected food deficits for the developing countries in the year 1990. In a recent report, the International Food Policy Research Institute has projected that the gross deficit of the major food staples of the developing countries will total 120–143 million metric tonnes in this year, depending on the rate of their income growth.

Reorganisation of Agricultural Research

The policy decisions for the modernisation of agriculture in the developing countries have many important implications. One of the most important of these relates to the creation of a new research infrastructure, for it is clear that a more productive kind of agriculture must be spearheaded by a new kind of

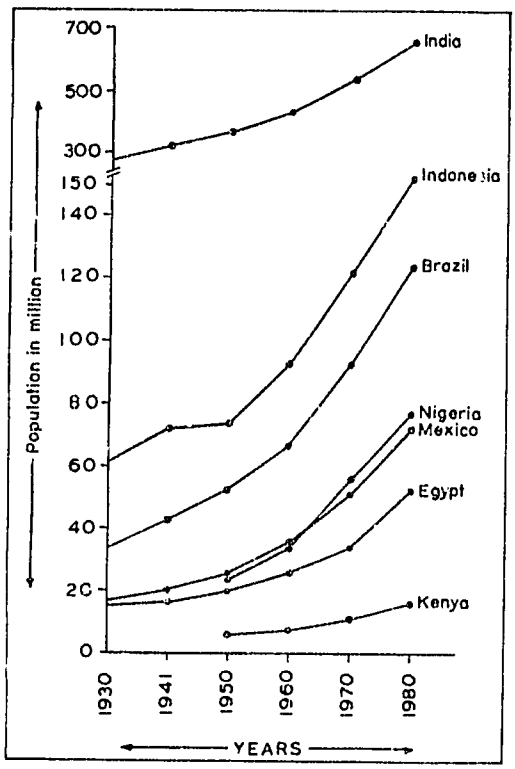


Figure 5. Rapid rise in the human population of developing countries in different parts of the world since the 1950s.

production technology. Looking back over the past 20 years, it seems remarkable that a number of developing countries have succeeded in reorganising their agricultural research services in order to make them more effective for the new tasks. The fundamental change has been in respect of the administrative framework and the organisation within which agricultural experimental stations function in these countries.

In developing countries, institutes of agricultural research have mostly formed an integral part of the Departments of Agriculture, with policy making and administrative control resting with the civil servants. Also, the personnel management policies and the operational procedures for the functioning of these institutes have been similar to those evolved for the secretariat-based staff. The Indian experience in changing this old pattern is particularly relevant. In India, a major reorganisation of research services has been brought about in the last 20 years by transferring the federal (central) research institutes from the administrative control of the Ministry of Agriculture to that of the Indian Council of Agricultural Research (ICAR). The Council, organised and funded by the Indian Government, is headed by a senior scientist and enjoys considerable autonomy in its management of research in the country. It is the Director-General of the Council, assisted by a team of other scientists from different disciplines with considerable experience in management of science, who administers the programmes of agricultural research in the country. Also, it is these scientists working in close consultation with the scientists of the central institutes and the agricultural universities, who decide on priority areas of research and the infrastructure needed to support them. The Council funds a network of 43 central institutes located in different parts of the country. The Director-General reports to the Minister of Agriculture, who acts as the President of the Council.

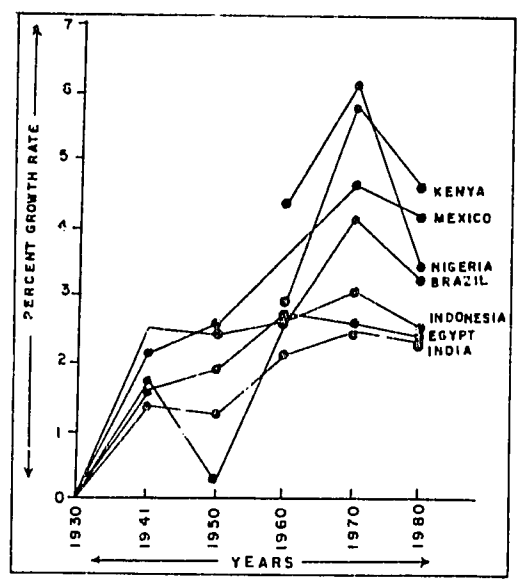


Figure 6. Population growth rates in developing countries. It will be seen that there has been a sharp rise in growth rate since the 1950s, with evidence of small decline in the 1970s. Simple growth rates have been estimated from the observed population increases during successive decades, taking 1930, 1941, 1950, 1960, and 1970 as the base year.

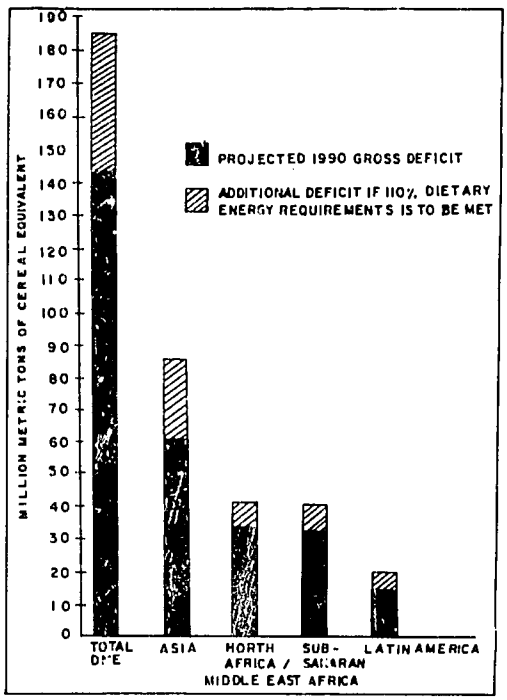


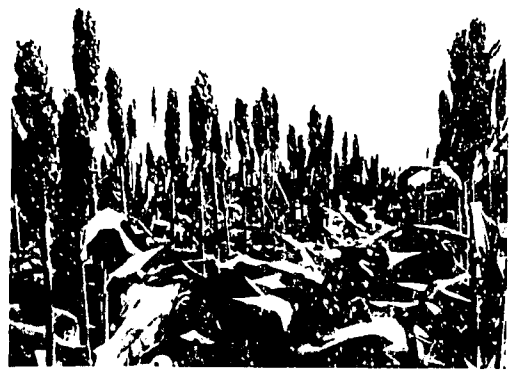
Figure 7. Projected gross food deficits in the year 1990 for the developing countries (Developing Market Economies.) The solid part of the column shows the projected deficits on the assumption of a high income growth. The deficit would be less if the expected income growth fails to materialise. On the other hand, the deficit would be much greater if the developing countries plan to meet the recommended dietary energy requirements of their people. (Based on International Food Policy Research Institute Report 3, 1977.)

A reorganisation of agricultural research has also been brought about during this period in the states. In these, responsibility for research and teaching has been transferred to the newly set up agricultural universities. There are 23 of them now functioning in different states – leaving the Departments of Agriculture free to organise programmes of transfer of technology through their extension services. The agricultural universities in India function on the pattern of the Land Grant Colleges in the United States. They maintain close links with the staff of the Department of Agriculture and the extension service. It should be noted that even though the agricultural universities derive their statutory powers from the University Grants Commission of the Ministry of Education, it is the Indian Council of Agricultural Research and the concerned state governments which monitor their progress in the field of teaching and research. The funding support for the agricultural universities comes from the respective state governments and from the Council.

Research Coordination

The developing countries already face a serious challenge in increasing their food production, and the situation is expected to worsen in the closing years of the century. Nothing is going to be more important for the continued political and social stability of these countries than their ability to meet their growing food needs. Agricultural research systems in the developing world must be able to respond to these needs in the face of increasing population pressures. The Coordinated Crop Improvement Projects organised by the Indian Council of Agricultural Reseach provide one example of the mechanisms which are now being evolved from this purpose. These projects, involving the participation of scientists from a large number of central institutes and state agricultural universities, have been conceived as an instrument to mobilise the country's available scientific resources for focussing attention on the various problems of agricultural production and finding effective solutions to them in the shortest possible time. The projects help to generate inter-institutional and inter-disciplinary interactions, ensure complementarity in the research programmes of different experimental stations, provide a mechanism for joint evaluation of the new technologies evolved by their scientists, and arrive at collective recommendation for the release of these technologies to farmers. The emphasis is on defining the objectives and goals clearly, laying down priorities, and identifying the most relevant experimental approaches. A high degree of accountability based on continued monitoring is built into the system. The Coordinated Crop Improvement Projects may not quite correspond to the 'customer-contractor' model proposed by Lord Rothschild to the British Government for organising research activity with a practical application in view. The customer in this model is the Head of the Government Department who needs a new or improved technology, while the contractor is the Chief Executive of the research and development organisation. In the case of the Coordinated Crop Improvement Projects, the customers are the Secretaries of the Departments of Agriculture, while the contractor is the Director-General of the Indian Council of Agricultural Research, with his network of the central institutes and the agricultural universities.

Figure 8. New plant types in grain sorghum have brought about a major improvement in the productivity of this rainfed crop. A sorghum hybrid with a high harvest index is seen here.



Organisational Structure

The Council has organised research projects on different crops or groups of crops, including rice, wheat, maize, sorghum, millets, pulses, oilseeds, cotton, sugarcane, plantation crops, fruits, vegetables, and fodder crops. These and all the other all-India Coordinated Projects, including those in the field of livestock production, account for nearly 25 percent of the research budget of the Council. Typically, a Coordinated Crop Improvement Project consists of a National Coordinating Centre and a number of Cooperating Centres located in the different agricultural universities and the central institutes, depending on the distribution of the particular crop in the country. The Coordinating Centre headed by a Project Coordinator and assisted by a small group of scientists from different disciplines, is located in one of the central institutes or agricultural universities, more commonly the former. The Project Coordinator is appointed on the basis of his recognised position of scientific leadership in his field, as his personality contributes significantly to the success of the project. The Coordinator exercises little direct control over the Cooperating Centres which, for all practical purposes, are an integral part of the institutions in which they are located. He must maintain close contacts with the Directors of the central institutes and Vice-Chancellors and Directors of Research in the agricultural universities to ensure that their scientists implement the research programmes assigned to them.

The main components of the priority areas of research are identified in the 'All-India Workshop' of the scientists from the different Cooperating Centres. The Workshop is held at least once in a year when a review of the results obtained at the different centres during the previous season is presented by the Coordinator in a consolidated form. Also, the Workshop provides the opportunity to plan the programme of work for the next year on an all-India basis. The impression one carries of these Workshops is of strong inter-disciplinary, inter-institutional interactions in the formulation and execution of research programmes. There is also an element of healthy competition between the different centres on a project.

The identification of the Cooperating Centres in the project begins with a delineation of the different agro-ecological regions in the country over which a particular crop is distributed. Thus, the All-India

Figure 9. Release of a new variety is always a big event for the farmers. Here they are seen talking with the scientists about the performance of a newly released wheat variety.

Coordinated Rice Improvement Project recognises eight different zones of rice production in the country, which together cover a wide range of agro-climatic conditions, including the irrigated and rainfed rice lands, the latter spread over different situations such as the uplands characterised by considerable moisture stress and the lowlands, where waterlogging is a serious problem following heavy rains. Also, rice is grown under very deep water conditions in lands which are visited by floods in most years. Table 1 describes the different zones of the All-India Coordinated Rice Improvment Project. Normally, each zone would be having a number of Cooperating Centres depending on its size. Each Cooperating Centre is provided with a team of scientists drawn from different disciplines like plant breeding, agronomy, plant pathology, entomology, soil chemistry, and crop physiology. The Council makes separate allocation of funds for the Cooperating Centre over and above the regular budget of the institutions in which they are located. The team of scientists provided in the different centres helps to strengthen the research programmes on a particular crop. It should be explained that in addition to these scientists, a regular complement of scientific staff is already available at each of the centres as part of the normal research activity of these institutions. The two groups of scientists are expected to be integrated into a single functional unit for the purpose of coordination; unfortunately this does not always happen.

The Project Coordinator not only monitors the work of the different Cooperating Centres; he, with the help of his team of scientists, also organises a research programme of his own. This is designed to have a service role. The Coordinator is not expected to compete with his own Cooperating Centres. He strengthens them with a flow of new genetic materials introduced from different parts of the world and developed by his own scientists. He also acts as a link between the Cooperating Centres of the project and international crop research institutes, like CIMMYT and IRRI, established by the Consultative Group on International Agricultural Research for exchange of genetic material.

A good example of the type of contribution which the Coordinator makes to the research programmes of the Cooperating Centre is provided by some of the recent developments in the rice project. The rice crop in India, as well as in most other countries of south and southeast Asia in the last ten years had to face repeated outbreaks of the brown planthopper. The appearance of this pest in an epidemic form is widely attributed to the large-scale cultivation of short-statured and fertiliser-responsive, heavy-tillering varieties. The development of these high-yielding varieties became possible following the discovery of the Dee-geo-woo-gen dwarfing source in indica rice in Taiwan. These dwarfing genes have been widely used in breeding programmes at the International Rice Research Institute in the Philippines and in countries like India.

The scientists of the Coordinating Centre of the rice Project at Hyderabad, working in collaboration with the IRRI entomologists, responded to this situation by developing techniques of mass rearing of brown plant-hopper and by perfecting a mass screen methodology under controlled greenhouse conditions. Using a quantified score of injury, the scientists at Hyderabad have evaluated more than 15,000 varieties and breeding lines for their reaction to the brown planthopper. One of their important findings is that some of the traditional Indian rice varieties from the Pattambi collection in Kerala possess a high degree of resistance to this pest. These varieties in recent years have been extensively used by rice breeders both in India and abroad. Figure 11 summarises the results of the mass screening tests carried out by the entomologists of the Coordinated Rice Improvement Project.

New Research Priorities and Scientific Research

As Indian farmers begin to adopt some of the more modern techniques of crop production, new problems are being encountered calling for a review of research priorities. Thus, when India decided to replace its traditional varieties of wheat with the dwarf genotypes developed by Borlaug and his colleagues in Mexico, the foremost task was to organise an intensive hybridisation programme crossing the new introductions with the adapted local cultivars. These efforts have resulted in the evolution and release in the last ten years of a large number of high-yielding varieties combining such desirable characters as improved grain quality and stability of performance under a wide range of agronomic conditions. However, the very success of these new varieties has been responsible for a more serious disease problem. The dwarf varieties, in contrast to the earlier tall types are grown with the application of large doses of chemical fertilisers and irrigation water, with the result that new micro environments are being created on the farmers' fields. The rust fungi often find these environments more favourable for their growth. Also, of course, the large-scale replacement of the traditional varieties characterised by considerable genetic diversity by a few high-yielding cultivars is giving rise to new selection pressures for the pathogens. The wheat scientists in the Coordinated Project have responded to this situation by organising a strong programme of breeding for disease resistance. There have been no serious epidemics of wheat rusts in the country since the first introduction of the dwarf varieties in the 1960s.

In the case of rice, India's most important cereal crop, a similar redefining of research priorities is now under way. Twenty years ago the foremost need was the

creation of high genetic potentials for grain yield. This became possible with the development of dwarf varieties at the International Rice Research Institute in the Philippines, and in more recent years at the different centres of the Coordinated Rice Project. The additional production of wheat and rice amounting to 42.4 million tonnes in the 15-year period from 1963-64 to 1978-79 is now focussing attention on the more difficult problem of evolving a suitable production technology for the drylands and lands affected by waterlogging and floods, which together constitute about 70 percent of the total rice area in India. If rice production in India has not advanced as rapidly as that of wheat, the reason is that rice is grown under a very wide range of agro-climatic conditions, including areas where water management is extremely difficult. Soil and water management are now becoming priority areas of research for the scientists of many of the coordinated crop improvement projects. It is now being recognised that a purely genetic approach will not solve all the problems of agricultural production – a message which is not very popular.

Another good example of the scientific capacity created by the Coordinated Crop Improvement Projects to respond to rapidly changing situations is provided by the recent history of the pearl millet crop in India. The country in the 1960s and early 1970s released a number of F_1 hybrids of this crop which contributed to a spectacular increase in production – a near doubling of the harvest over a period of ten years. All the five hybrids, however, began to be attacked by the downy mildew disease in the 1970s, leading to a serious epidemic and a sharp decline in production. The hybrids had been evolved using a common source of cytoplasm contributing a male sterility in the female parent. The scientists of the Coordinated Project on Millets were quick to diagnose the problem, tracing the disease to the cytoplasm. They succeeded in developing new male-sterile lines in the next five years, and the country today has a series of new hybrids which are relatively resistant to the downy mildew disease. These are now beginning to gain wide popularity with the farmers, and pearl millet production in the country is again beginning to rise to the high levels achieved earlier.

As the country's production of cereal grains increases, leading to a significant improvement in the availability of calories in the Indian diet, the scientists of the Coordinated Projects are beginning to pay greater attention to crops like pulses and oilseeds. They recognise that pulses offer the most practical means of eradicating protein malnutrition in countries like India. The pulse crops, however, have been traditionally grown in those parts of the country which have very limited water for irrigation. The scientists have argued that for a major advance in the production of pulses in the short term, these crops must be moved in time and in space so that they could be brought under improved

Figure 10. A short duration variety of pigeonpea which can be fitted in rotation with the wheat crop. The late-maturing and highly photosensitive traditional varieties of pigeonpea can be seen in the background.

levels of agronomic management in the highly fertile and irrigated lands of the Indo-Gangetic plains. Responding to this requirement, the pulse scientists have developed a large number of short duration varieties which can be fitted in multiple and inter-cropping patterns. They are now recommending that farmers in states like Punjab, Haryana, Western Uttar

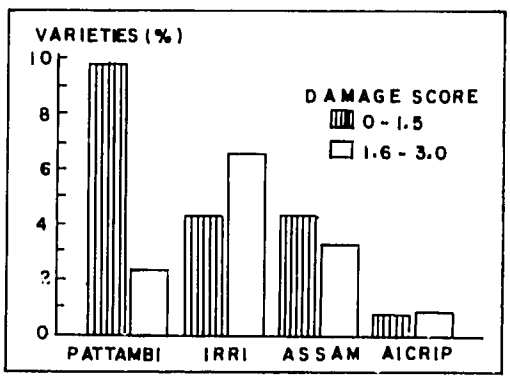


Figure 11. Reaction of different rice germplasm collections against the brown planthopper. It will be noted that the Pattambi collection of Kerala in India shows the least damage score. (Based on M. B. Kalode and T. S. Krishna, All-India Coordinated Rice Improvement Project, Hyderabad, India.)

Pradesh, and parts of Bihar should be adopting more intensive cropping systems, with pulses finding an important place in them. A good example of these new varieties is provided by pigeonpea. The traditional varieties of this pulse crop take nearly ten months to mature. For the first time now, a wheat-pigeonpea rotation is possible in the northwestern states of India, with the availability of new varieties which take only five months from sowing to harvest.

Interinstitutional and Interdisciplinary Collaboration

Nothing adds more to the effectiveness of the Coordinated Crop Improvement Projects than the interdisciplinary collaboration which they have helped to foster. Also, the projects are helping to promote close inter-institutional linkages in finding solutions to specific problems. A good example of the multi-disciplinary approach is provided by the successful teamwork of the breeders and pathologists in countering the threat of disease epidemics in the wheat crop. The wheat scientists have been very conscious of the fact that even a moderate rust epidemic causing a ten percent crop loss could reduce wheat production by as much as three and a half million tonnes. The loss 15 years ago would have been a little more than one million tonnes. The plant pathologists have made a significant contribution in meeting this challenge. First, they have developed in the last 15 years simple techniques for the production of disease inoculum in large quantities so that artificial epiphytotic conditions could be created in the field for the breeders to select resistant genotypes in their segregating populations (Figure 12). With the availability of these new techniques, it has been possible to multiply sufficient quantities of rust spores in a small alkathene house for inoculating 50 acres of breeding material. Second, the plant pathologists have been organising PPSN (Plant Pathologists' Screening Nursery) with the object of testing the newly evolved varieties for their diesase resistance in different parts of the country, including those which are known to be the hot-spots of rust pathogens. Also, the plant pathologists test the new varieties under glasshouse conditions for seedling resistance to different races of rust. The combined information from the field and laboratory tests provides a sound basis for identifying varieties with a more durable kind of disease resistance.

Last but not the least, the pathologists keep monitoring the distribution of rust races in different parts of the country, and in this way they are able to trace the movement of rust spores from one part of the country to the other and warn the breeders in advance of an expected shift in race composition. To take one example, 'Kalyanosona', the most widely grown wheat variety in India, covering an area of nearly 5 million hectares, was beginning to be attacked in 1971 by three new biotypes of the stripe rust fungus in the north Indian hills. The pathologists believed that these biotypes would soon migrate to the main wheat belt in the Indo-Gangetic plains with a potential to create serious disease conditions. The breeders were ready to replace 'Kalyansona' with new varieties when the new biotypes did threaten the wheat crop in the plains a few years later.

Another good example of interdisciplinary collaboration is provided by the breeders and pathologists of the Coordinated Maize Improvement Project. The maize crop in India is attacked by a large number of diseases, including the different stalk rots, leaf and sheath blights, downy mildew, and the common rust. While genes for resistance to each of these diseases are available in the world maize germplasm, they are so highly dispersed that a hybridisation programme becomes extremely complex. The maize scientists at the Indian Agricultural Research Institute have worked in the last ten years to synthesise sources of multiple resistance. The process started with the pooling of a large number of diverse resistant lines and the elite material into a recombination block. The genes in this block were allowed to reshuffle mostly through the mechanism of natural cross pollination for two reproductive cycles. This was followed by sib-mating of selected plants showing resistance to different diseases or groups of diseases. In this way, a number of full-sib families showing resistance to different groups of diseases were generated. Following repeated cycles of fall sib-mating of plants from these different families, it has been possible to evolve genetic stocks combining resistance to as many as ten diseases. Figure 13 shows the reaction of families against each of the ten different diseases. It will be seen that nearly 24 percent of the families show resistance to all ten diseases. Also, a large proportion of them (more than 70 percent) show resistance to all the diseases, with the exception of bacterial stalk rot and the downy mildew disease. The next step in this study will be the incorporation of multiple resistance to both diseases and pests. The plant pathologists, the entomologists, and the breeders have planned a further programme of population improvement to evolve genetic stocks which will combine resistance against all ten diseases, and insects like stem borer and pink borer.

The agronomists have provided support of a different kind which is particularly important for countries like India, where the farming community is largely made up of millions of small and marginal farmers. In these countries it is extremely important that only those improved varieties are recommended which show a high degree of stability in their yield performance under varying levels of agronomic managment. Ideally, these varieties should be able to take full advantage of chemical fertilisers and other inputs used by the more progressive groups of farmers. At the

same time, they should not show a steep decline in their yield in the fields of those farmers who are able to provide only limited inputs. The agronomists help in the identification of such varieties by conducting trials under different regimes of management practices in respect of fertiliser, irrigation, and other inputs. The results of their analysis often show that the variety which gives the highest yield in breeders' trials may not be the most suitable for farmers in view of its poor stability of performance. A variety of this kind can be more readily recommended to farmers in the developed countries, most of whom practise a high level of crop management.

The inter-institutional collaboration of a more active kind begins with the identification of a specific objective. The maize scientists were called upon ten years ago to develop new varieties characterised by a short maturity duration of no more than 75-80 days. The new varieties were needed for a specific agroecological situation in the states of Bihar and Uttar Pradesh, marked by flooding of land in the months of August-September following heavy monsoon rains. The maize varieties in these lands planted in the month of May must be harvested before the end of July to escape flood damage. Six cooperating centres of the Maize Project in the states of Uttar Pradesh, Bihar, and Gujarat were asked to collaborate with the Delhi Centre in evolving such varieties. As a first step the Delhi Centre developed 250 full-sib families from the early-maturing Diara composite. These families were distributed to the six Cooperating Centres and their scientists were asked to select the ones which gave best performance under their conditions. The families which did well at all the six centres were combined into a new population at each one of these Centres for continued selection. Further full-sib families selections were made at the different participating stations for yield and maturity, and finally, two varieties were evolved which are now undergoing extensive tests in pre-release trials on farmers' fields.

Figure 12. Mass rearing techniques of insect pests have helped to accelerate resistance breeding programmes. Here Chilo partellus, the stem borer of maize, is being mass produced on a synthetic medium.

National Network of Coordinated Trials

An important task of the scientists meeting in their annual workshop is to identify new varieties and other technologies for testing in the 'All-India Coordinated Trials.' A well-defined testing procedure has been evolved for this purpose. It is best illustrated with reference to the rice project.

The rice breeders in the different Cooperating Centres identify every year a large number of promising cultures in their breeding material and pool them in a "National Screening Nursery." As many as 300-400 such cultures entering the pool are evaluated at more than 30 locations covering all the different rice-growing regions of the country. The selection pressures at this first stage of testing relate mainly to disease and insect pest resistance, acceptable maturity durations and a reasonably good performance in terms of yield and other characters. The more promising cultures following this first screening are now entered into 'Preliminary Varietal Trials' (PVT). These are designed to sort out strains of different maturity durations for the plains and the hills, for normal and difficult water conditions, for a high degree of resistance to diseases and pests in regions where these are endemic, and finally, those showing fine grain quality characteristics similar to those of India's traditional basmati rices. For this purpose, the Preliminary Varietal Trials are conducted in several different sets spread over different zones of the Coordinated Project. These trials help to reduce the number of cultures to the more promising 10-15, which are subsequently tested for two consecutive years in the 'Uniform Varietal Trials' (UVT). These latter trials, like the PVT, get diversified into different

sets based on different requirements of adaptation, disease and pest resistance, and quality characteristics. Two years of testing in these leads to the identification of a few varieties whose overall performance in respect of yield, adaptability to specific situations, disease and pest resistance, and acceptable maturity duration for different cropping systems may justify their release. These selected varieties are given to farmers in the form of 'Minikits' containing seeds and other inputs like chemical fertiliser and pesticides. The idea is to expose the new varieties to farmers' own conditions and ask them to give their independent evaluation. If the farmers' reactions are generally favourable, a variety at this stage may be recommended for cultivation in some parts of the country by the Central Varietal Release Committee of the Government of India. Some of the varieties at this stage of testing may also be picked up by the different State Varietal Release Committees for recommendation to their farmers.

It should be explained that as the selected varieties reach the stage of Uniform Varietal Trials, they are simultaneously evaluated under different levels of agronomic management, including high and moderate doses of fertilisers. The entire procedure starting with the National Screening Nursery takes five years of intensive testing before a variety can be recommended for release. Figure 16 describes various stages of the coordinated testing in the rice project. Table 2 lists the different sets of Preliminary Varietal Trials, each designed to identify suitable rice varieties for a particular set of ecological and agronomic conditions or for specific needs.

Table 1. DIFFERENT ZONES OF THE ALL-INDIA COORDINATED RICE IMPROVEMENT PROJECT

Zone	States	Specific Objectives
Southern peninsula	Kerala, Karnataka, Tamil Nadu, Pondicherry, Andhra Pradesh	Field tolerance to major diseases and pests
Far-eastern plains	Orissa, West Bengal	Adaptation to waterlogged conditions, resistance to diseases and pests
North-eastern and valleys	Assam, north-eastern hilly states	Adaptation to waterlogged flooded conditions, moderate cold tolerance
Central India	Madhya Pradesh	Adaption to waterlogged conditions/direct seeding
North-eastern plains	Bihar, eastern Uttar Pradesh	Early to medium maturity, resistance to diseases and pests
North-western plains	Punjab, Haryana, Rajasthan, Delhi, Western Uttar Pradesh	Very high yields with excellent water management
Western plains	Maharashtra, Gujarat	Resistance to diseases and pests, tolerance to cold/drought
North-western hills	Jammu and Kashmir, Himachal Pradesh, Hills of Uttar Pradesh	Cold tolerance and blast resistance

Genetic Vulnerability and Varietal Diversification

An important development which can be expected to have serious implications for future agriculture in most parts of the world is the replacement during the last 15 years of hundreds of traditional varieties by a handful of high-yielding cultivars. Many countries of Asia have initiated this process which is expected to gather momentum in the coming years. Thus, it has been estimated that the Indian farmers may have been growing in their traditional systems of farming as many as 30 thousand different varieties of rice. Most of these are now being replaced so that by the end of the century no more than 200 varieties may be grown, and of these, 20 or so may be saturating large parts of the rice lands in the country. Introduction of genetic uniformity on this massive scale greatly enhances possibilities of serious disease and pest epidemics. These have been kept in check in the past by the genetic barriers which the locally adapted and genetically diverse varieties have helped to erect. Already, there have been several examples of large crop losses resulting from genetic vulnerability of this kind. The widespread outbreak of the leaf blight disease of maize in the United States and of the downy mildew disease of pearl millet in India provide two such examples in the last 10 years. The developing countries traditionally have been the most important centres of genetic resources of crop plants and also the areas of considerable genetic diversity in their crop cultivars. While these countries have no option but to modernise their agriculture, they must plan for a high degree of varietal diversification to contain the threat of disease and pest outbreaks.

The Coordinated Crop Improvement Projects in India are helping to achieve this objective. The release of a large number of varieties from these projects responding to specific agro-ecological requirements is

TABLE 2. DIFFERENT SETS OF PRELIMINARY VARIETAL TRIALS OF THE RICE PROJECT

Title	No. of testing locations (main season)	Varietal features	Adaptive requirements
Hills	7	Cold tolerant, blast resistant, early maturing	High altitude area in J&K, U.P., H.P., Meghalaya, Arunachal Pradesh
Plains (< 100 days)	28		
a. Direct seeded, rainfed		Tolerance to moisture stress	Up and medium lands, non-irrigated
b. Direct seeded, irrigated		Monocropped, high-intensity rice production systems	Medium and uplands of traditional rice states of southern and eastern India
c. Transplanted		Intensive cropping systems	Medium lands of assured irrigation
Plains (100-120 days)	30	Adapted to double cropping	Medium lands, assured irrigation-assured rainfall
Plains (120-135 days)	21	Management responsive, very high yield potential	Medium lands of high fertility and controlled irrigation North-western states and areas of low pest incidence
Plains 130-150 days)	21	Weakly to strongly photo-sensitive, adapted to prolonged and heavy monsoons	Traditional rice-growing states of riverine and delta regions and areas of high rainfall (15 to 70 cm water depth)
Deep water (> 150 days)	4	Strongly photosensitive, adapted to prolonged deep-water conditions	Riverine and delta regions of Assam, W.B., Orissa, and Bihar (> 100 cm depth)
Saline and alkaline	10	Tolerant to abnormal soil conditions	Coastal parts of W.B., A.P., Maharashtra, Orissa, T.N., Karnataka, Haryana, U.P., Punjab, and Gujarat
Tungro virus	8	Medium and late duration, high degree of resistance	T.N., A.P., W.B.
Gall-midge	28	Medium duration, high degree of resistance	Endemic areas in A.P., Orissa, M.P., T.N., Karnataka
Brown planthopper	7	Medium and medium-early with resistance to prevailing biotypes	Endemic areas all over India
Aromatic slender grains	29	Medium and medium early, high yields and basmati quality	Punjab, Haryana, U.P., Rajasthan, J&K and A.P.

J&K = Jammu and Kashmir, A.P. = Andhra Pradesh, M.P. = Madhya Pradesh, U.P. = Uttar Pradesh, H.P. = Himachal Pradesh, W.B. = West Bengal, T.N. = Tamil Nadu

effectively countering the problem of increasing genetic uniformity, which began with the first introduction of dwarf varieties of wheat and rice in the mid 1960s. The Coordinated Projects are also providing an answer to recent developments in the field of patenting of seeds through legislation of plant breeders' rights. One consequence of this legislation is that large commercial organisations would like to evolve varieties whose seeds could be marketed in different countries. The developing as well as the developed countries must respond to this new situation through the creation of a network of breeding centres

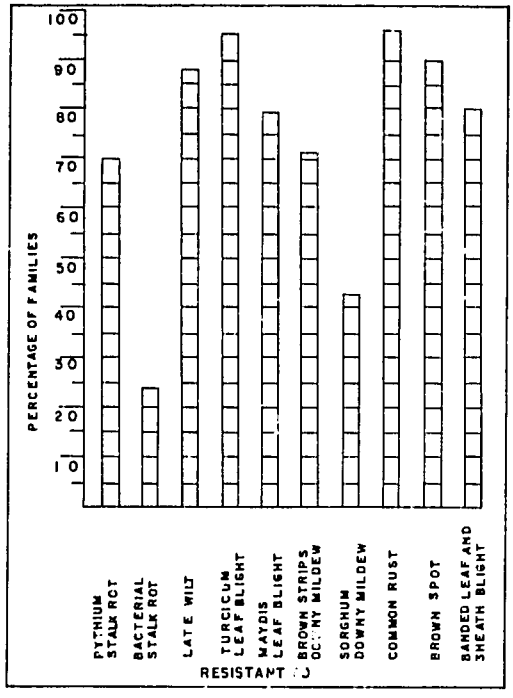


Figure 13. Testing of full-sib families of maize and their reaction to ten different diseases. It will be noted that nearly 24 percent of the families are resistant to all ten diseases, while 70 percent are resistant to as many as eight different diseases.

so that a large number of varieties can be distributed in space and in time. A complex of such diverse varieties would be expected to have the same effect in reducing the build-up of populations of pests and pathogens in a region as a multiline variety would have on a farmer's field. Scientists of the Coordinated Projects have been identifying a large number of genes for disease resistance in crops like wheat so that these could be deployed in their hyoridisation programme. Table 3 lists some of the genes conferrring resistance to leaf rust studied by the Indian wheat geneticists, which would help in the process of varietal diversification.

Transformation through Accelerated Genetic Improvement

The Coordinated Crop Improvement Projects in India are helping to create higher genetic potentials of yields of the kind achived in the western countries over a much longer period. Crop plants in most developing countries, despite a long history of domestication, have continued to retain some of their wild and weedy characteristics. This is not surprising when we consider the fact that agriculture in these countries has derived little support from modern farm inputs like chemical fertilisers. In the absence of this kind of management support, selection pressures have been more for an aggresive growth habit to survive in stress environments rather than for high seed yields.

In the western countries the process of transformation of traditional crop plants leading to changes in their architecture associated with a more efficient partitioning of the dry matter between seeds and straw started about fifty years ago, although it has gathered momentum only in the last twenty years. The Coordinated Crop Improvement Projects in India in the last twenty years have provided an effective instrument to bring about rapid transformation of this kind. The dwarf wheat and the dwarf rice varieties provide the most outstanding examples of this change. Wheat and rice, however, are not the only crops which are now beginning to be restructured. The new hybrid varieties of sorghum provide an equally good example. The traditional varieties of grain sorghum grown over an area of 16 million hectares in India are highly photosensitive and take about five months to mature. In the last 15 years it has been possible to evolve hybrid strains which are dwarf and relatively insensitive to day

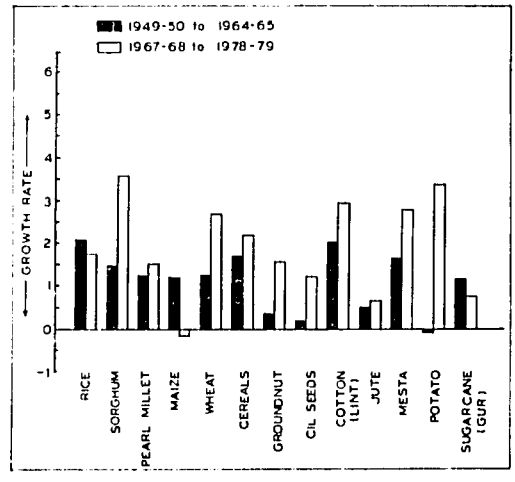


Figure 14. Compound growth rates of yield of some of the major crops of India following the advent of high-yielding varieties programmes in the 1960s and during an earlier period. (After Daljit Singh, Indian Agricultural Research Institute, New Delhi.)

TABLE 3. GENES FOR FIELD AND SEEDLING RESISTANCE FOUND EFFECTIVE AGAINST THE INDIAN LEAF RUST PATHOGEN

Genes/Stocks	Mean coefficient of infection of four years from five locations*	Races against which effective in seedling stage
Tc-Lr9	0.55	10, 11, 12, 12A, 17, 20, 63, 77, 77A, 104, 104A, 106, 107, 108, 162, 162A. (All available races in the country)
Tc-Lr14ab-W3531	23.35	10, 11, 12, 17, 20, 63, 104, 106, 108, 162, 162A.
Tc-Lr17	23.70	12, 12A, 12B, 20, 63, 77, 77A-1, 106, 107, 162.
Tc-Lr19	0.05	All available races in the country
Tc-Lr21	7.65	63
Tc-Lr22	16.80	None
Lr24	0.40	** 10, 11, 12, 12A, 20, 77, 77A, 104, 104A, 107, 108, 162A.
Lr25	15.65	** 12, 12A, 20, 77, 77A, 104, 104A, 107, 162, 162A.
Lr26'Kavkaz'	0.90	** 12, 12A, 20, 77, 77A, 104, 104A, 107, 162, 162A.
Lr27'Gatsher'	9.9	12, 12A, 20, 77, 104, 104A, 107
Thatcher (Check)	72.50	—

* Provides a measure of field resistance.

** These include the most virulent and widely prevalent races of leaf rust in India.

(Based on R.N. Shawney, Indian Agricultural Research Institute, New Delhi).

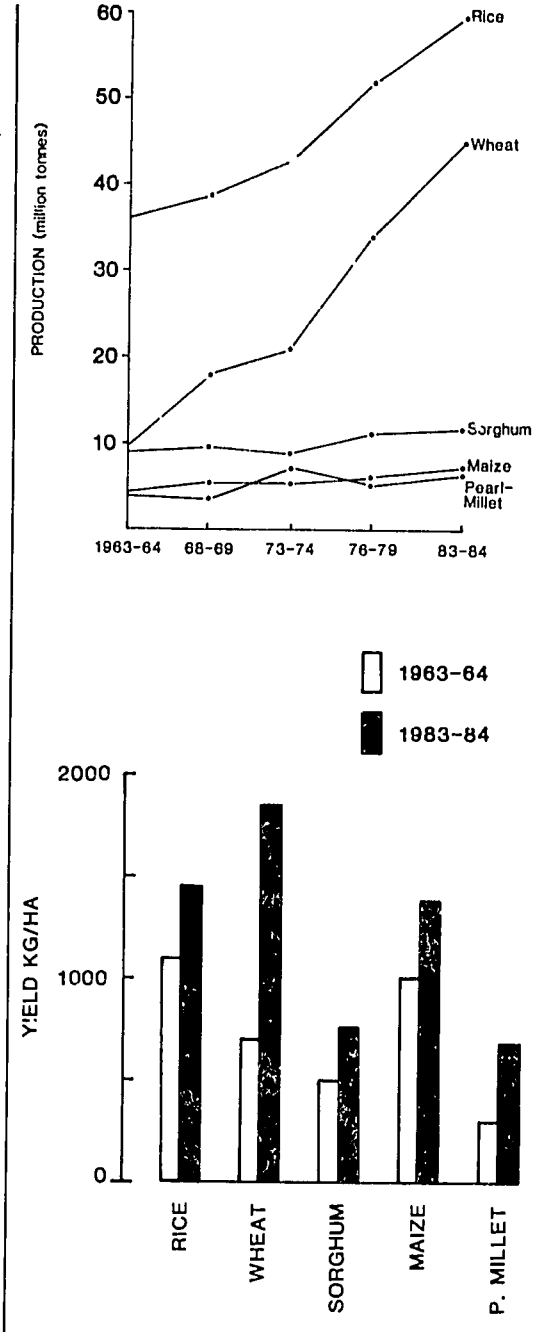
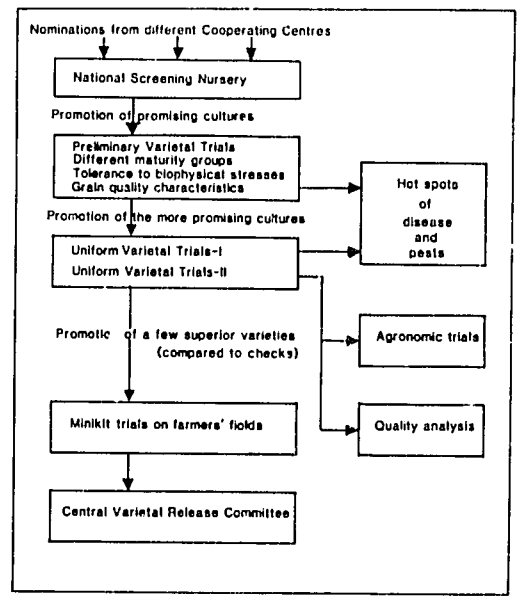


Figure 15. Production and productivity increase of rice, wheat, sorghum, maize, and pearl millet in India during the period 1963-64 to 1978-79.

Figure 16. Different stages of testing of rice varieties in the all-India coordinated trials.



length so that they can be harvested in 100–110 days. The result is that for the first time in the 2000-year history of sorghum cultivation in India, the production of this crop is beginning to see a high level of stability and a trend for increasing yields.

The accelerated pace of improvement is reflected in the fact that in some of the major cereal crops, Indian scientists now face the same problem of emerging yield ceilings as their counterparts do in the western countries. The selection pressures in the last 15 years have been mostly for a higher harvest index. There are indications that major yield improvements in future may depend to a considerable extent on our ability to select for higher rates of photosynthesis.

Impact on Production

India's production of foodgrains, which amounted to 50.8 million tonnes in 1950–51, increased to 131.9 million tonnes in 1978–79. A major part of this increase has been achieved with the advent of the high-yielding varieties in the 1960s. Wheat production, which was 9.8 million tonnes in 1963–64, increased to 35.5 million tonnes in 1978–79. Rice production during the same period saw an increase of nearly 17 million tonnes. Production of coarse cereal grains like sorghum, maize, and pearl millet, which are grown mostly in non-irrigated lands, has increased only to a limited extent. For the first time, however, their production and productivity is beginning to see a high degree of stability (Figure 15).

Increased production of foodgrains, as well as of other agricultural commodities since the advent of the Coordinated Projects, has been associated both with expansion in area and increase in yields. The compound growth rate of yield for many of the crops has been higher during this period, compared to the preceding years (Figure 14).

The impact of the Coordinated Crop Improvement Projects can be seen more clearly if we analyse the problems which Indian agriculture faces today. In the 1960s the most important need was the evolution of high-yield technology. As Indian agriculture enters the 1980s, the problems are perceived to be of a different kind. The most important task today is one of a more effective transfer of technology to the farmers. In the past 15 years Indian farmers have adopted only the simpler components of the new techniques of crop production. The more complex components of the technology package such as efficient soil and water management, chemical control of diseases, pests and weeds, and use of improved farm implements have yet to reach the bulk of the Indian farming community. It is now becoming clear that small and marginal farmers in countries like India must receive support in the form of the wide range of agro-services for a greater flow of improved technology to their fields. In the western countries, agriculture has been increasingly taken over in the last 30 years by agri-businessmen. In countries like India, millions of small and marginal farmers with very limited capacity for investment and limited skills are now being asked to adopt scientific techniques, which are not very different from those in use in the developed countries. The success of the Coordinated Crop Improvement Projects is giving rise to suggestions that farming in developing countries must become a joint venture between farmers and the government, the latter taking the responsibility for providing a wide range of services and inputs.