[Following important policy decisions in the 1960s, India has been able to achieve a significant increase in its food production. This, however, leaves little from for complacency because of the continuing population pressure. The country must control its population growth of unlimited-geometric progression. It must also take bold policy decisions for intensifying agricultural research and for the creation of a more effective management infrastructure for the transfer of new agricultural technology.—Ed.]

SCIENTIFIC TRANSFORMATION OF INDIAN AGRICULTURE—THE SECOND PHASE*

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WHEN we look back to analyse the application of science and technology for the economic and social and development of our people since independence, we find that agriculture is the one field where we have made some of the largest gains. The social relevance of this contribution is obvious from the fact that the majority of our people derive their living from agriculture directly or indirectly. Also, self-sufficiency in food production for a country with a rapidly rising population contributes to the social and political stability. It is impcrtant to recognise retrospectively, that much of this advance has been possible because of the important policy decisions which the Government of India took in the 1960s. Major emphasis was placed in this new policy on the creation of high genetic potentials for crop yields and the expression of these potentials on farmers' fields, with the application of such industrial inputs as chemical fertilizers, pesticides and improved farm tools, in addition to large scale provision of irrigation.

These new options in the last 15 years have resulted in several important developments. Thus, a major reorganisation and strengthening of agricultural research has been undertaken so that India today has one of the world's largest network of federal institutes and state agricultural universities.

Similarly, the Government of India has promoted the growth of a massive chemical fertilizer industry and the country in recent years has become the fourth largest producer and consumer of fertilizer nitrogen in the world. Figure 1 shows India's progress in fertilizer production and consumption since independence; major investments have been made in creating new irrigation potentials and the country today has the second largest area in the world, providing irrigation water. The Government has also taken a decision that in the next 18 years, more than two and a half million hectares of additional land would be brought under irrigation every year, so that by the end of the centuary the country would have a gross irrigation potential of 113 million hectares. The net irrigated area in the country has increased from 22.6 million hectares to 43.0 million hectares since the First Five Year Plan. The gross irrigated area which is based on the intensity of cropping and includes lands growing more than one irrigated crop during the year, is 56.0 million hectares. The total irrigation potential developed during this period of the gross area is 60.0 million hectares. Thus,

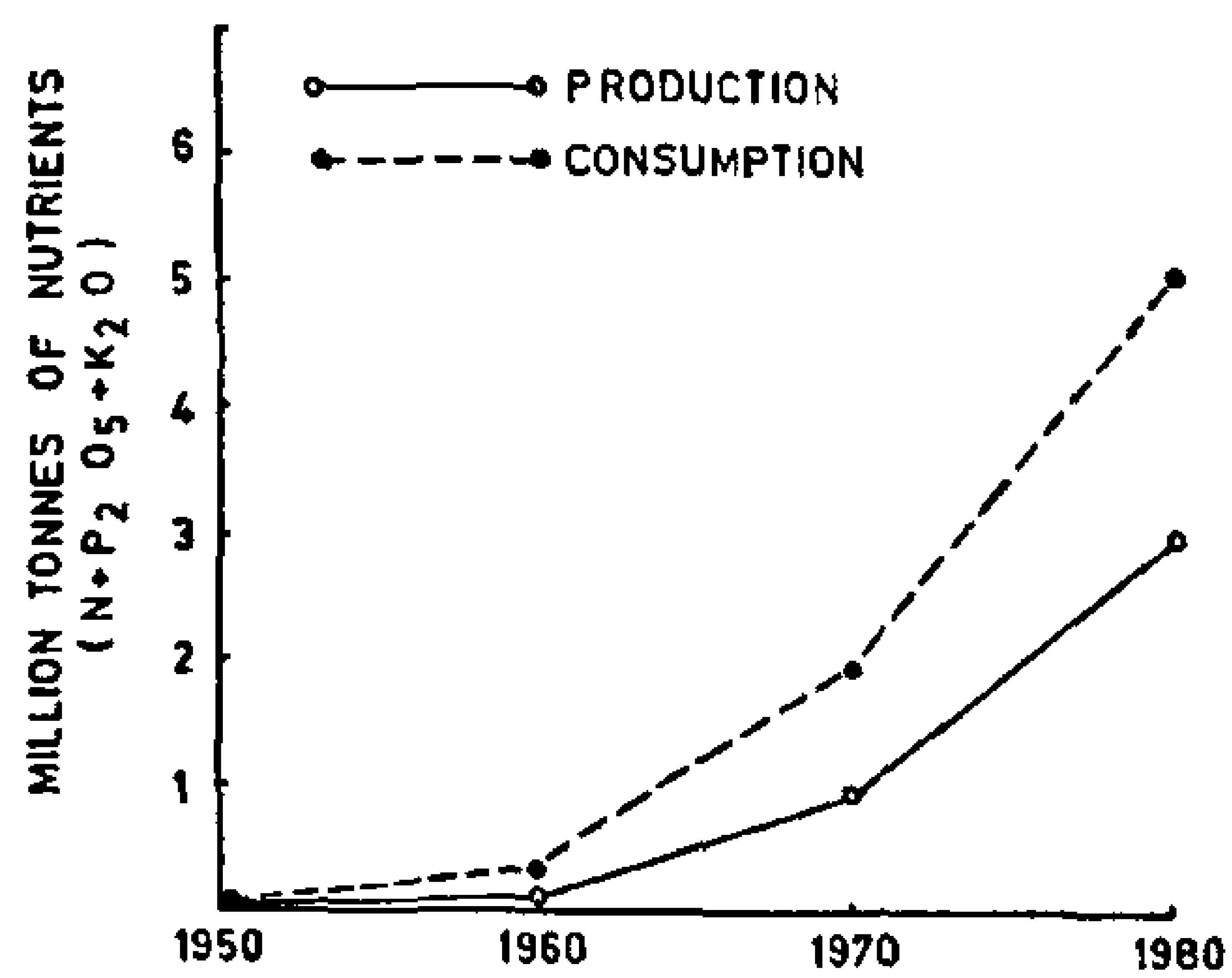

Figure 1. Shows the production and consumption of major plant nutrients provided by chemical fertilizers in Indian agriculture over a period of thirty years since the early 1950s.

*Based on a lecture delivered at the annual meeting of the Indian Academy of Sciences held at Nainital.

about 4.0 million hectares of the gross potential remains unutilised because of lack of suitable infrastructure.

NEW GENETIC POTENTIAL OF CROP YIELDS

These policy decisions have resulted in the organisation of the "High Yielding Varieties Programme" as the main instrument of India's strategy for increasing agricultural production. A major responsibility for providing scientific support of this new kind of agriculture was assigned to plant geneticists working in close collaboration with the agronomists, plant pathologists, entomologists and scientists from other related disciplines. It was clear as these new research priorities were evolved that in the traditional agriculture which Indian farmers have practised for more than 5000 years, human selection had played a very limited role in determining plant type and the genetic potential of our crop yields. The process of natural selection in the traditional agriculture, continued to have an important role in directing the evolution of these plants. This suggested that the selection pressures in the past had been greater for adaptation to stress environments and survival, than for the high grain yields. For this reason it was considered necessary that the existing crop varieties should be reconstructed genetically to fit into the new systems of farming characterized by improved levels of agronomic management. The new selection measures were planned to achieve a better balance between the vegetative and reproductive growth. It was considered important that the vegetative growth should be restricted to the optimum for producing and diverting a large amount of photosynthates into the reproductive parts, resulting in larger grain harvests.

This process of genetic reconstruction has been particularly successful in crops like wheat and rice. The Indian wheat scientists, during the last 15 years, have made extensive use of dwarfing genes first discovered in Japan and successfully exploited by Vogal in U.S.A. and by Borlaug in Mexico. India today has one of the world's largest wheat improvement programmes, which has resulted in the release of a large number of high yielding varieties with a harvest index approaching 35 to 40%.

In the case of rice, the restructuring of the plant became possible with the availability of dwarfing genes first discovered by scientists in Taiwan. One of the first dwarf rice varieties, IR-8 which became very popular in India was introduced in 1966 from the International Rice Research Institute in the Philippines. The Indian Rice Improvement Programme with its coordination centre at Hyderabad has released in recent years over 20 high yielding varieties.

MAIZE, SORGHUM AND MILLET

While rice and wheat constitute the most important foodgrains of India, accounting for nearly 73 per cent of our total production of cereal grains at present, maize, sorghum and millets continue to occupy a large part of our cultivated area—nearly 39 million hectares. Their social relevance can be seen from the fact that they are the main food crops of India's vast drylands. The basic scientific approach for the improvement of these three crops has been heterosis breeding. India's high yielding hybrids of sorghum and pearl millet are considered to be some of the best in the world. In the case of maize, some very short duration composite varieties are also now available for fitting into new cropping patterns. Besides, the *rabi* maize technology developed in more recent years has opened up new possibilities for increasing the production of this cereal crop.

PULSES, OILSEEDS AND COTTON

An important strategy for increasing the production of pulses and oilseeds has been to evolve early maturing varieties with high yields. It has been planned to expand the cultivation of pulses from their traditional habitats in most of the states. Based on the above concept plant breeders in different parts of the country have evolved a large number of new varieties. Thus, the IARI scientists have succeeded in evolving relatively erect varieties of Bengal gram, which allows light penetration and show both increased drymatter production and a high harvest index. A number of new varieties of Bengal gram, with an yield potential of nearly 30 quintals per hectare, have already been released while the average yield of this crop in the country was only 8 quintals per hectare.

A more impressive development is the evolution of early maturing varieties of red gram, which is the second most important pulse crop of India. These new varieties developed at different centres mature in less than 150 days. The wheat-red gram rotation which is now possible has the potential to become one of the most important developments in Indian agriculture. The country can now plan to cover 2 million hectares of land in Punjab, Haryana, Rajasthan and western Uttar Pradesh with this new cropping practice which could lead to a major increase in the production of pulses. Already, the scientists have succeeded in introducing short duration varieties of *mung* in new crop rotations in Uttar Pradesh and Bihar and in the vast rice fallows in southern India.

In the case of oilseeds, improved varieties are now available both in groundnut and rapeseed-mustard which together account for 85% of the total production of oilseeds in the country. Some of the new groundnut varieties have an yield potential of 25–30 quintals per hectare while the national average yield is only 8 quintals. The new groundnut varieties have also opened up possibilities of extending the cultivation of this important oilseed crop during the summer/*rabi* season with the application of irrigation water. Similarly, some of the varieties of rapeseed-mustard have yielded 25 quintals per hectare against the present average yield of 6 quintals per hectare in the country.

In the case of cotton, India is the only country in the world to have successfully released hybrid varieties, using the technique of hand emasculation and pollination. The first of these hybrids—Hybrid-4—was developed in Gujarat by C.T. Patel and his colleagues. Following this important initiative, a number of new hybrids have been evolved in Karnataka, Madhya Pradesh and Maharashtra. Today hybrid varieties cover an area of about one million hectares of our cotton lands in the country and it is this technology which has made India an exporter of cotton fibre, while only ten years back we used to import this material.

IMPACT ON PRODUCTION

The new production technology generated by the scientists in cereals and other crops has contributed to the increased agricultural production. This can be seen from table 1 which gives data on the production and growth rates of some of the important crops of India during the 30 years period from 1949–50 to 1978–79. The overall foodgrain production during this period increased with a compound growth rate of 2.66%. It is important to note that the increased production has been associated in most cases with higher yields per hectare. If we resolve this data into two periods, corresponding to the pre and post-high yielding varieties programmes, we find that the compound growth rate of yield has been higher, for most crops during the second period. This observation brings out clearly the impact of the new production technology.

The development of high yielding and early maturing varieties is now giving rise to new cropping patterns, which could help to make Indian agriculture more intensive. In large parts of the country, where resources of irrigation water are now available, the farmers can plan to take 2–3 crops per year with a potential to produce more than ten tonnes of foodgrains per hectare. In the non-irrigated lands, the major contribution has been in the involvement of a new production technology of crops like sorghum, maize and millet. The new hybrids of these crops give much higher yields than the traditional varieties even in years of drought. A great deal, however, remains to be done for improving the productivity of these lands. Agricultural scientists are now working on the development of new farm technologies with the major objective of stabilising agricultural production of India's non-irrigated lands, which will continue to cover 50% of the total cultivated area in the country even at the end of the present centuary.

TABLE 1
*Agricultural production and growth rates (1949–1979)**

Crop	Production (million tonnes)		Compound growth rates (per cent)		
	1949-50	1978-79	Production	Yield	Area
Rice	23.54	53.77	2.60	1.57	1.01
Jowar	5.87	11.44	1.27	1.37	0.09
Bajra	2.83	5.57	2.42	1.87	0.53
Maize	2.05	6.20	2.98	0.70	2.28
Wheat	6.39	35.5	6.02	3.04	2.89
Cereals	46.75	119.72	3.02	1.73	0.96
Pulses	8.16	12.18	0.31	0.09	0.41
Foodgrains	54.92	131.90	2.66	1.57	0.84
Groundnut	3.43	6.21	2.25	0.46	1.78
Oilseeds	***	9.70	2.16	0.52	1.27
Cotton (Lint)**	2.75	7.95	2.61	1.99	0.59
Jute**	3.11	6.47	1.26	0.42	0.78
Mesta**	-	1.86	2.35	2.26	2.07
Potato	1.54	10.13	5.74	1.56	4.12
Sugarcane	34.20	49.11	3.37	1.10	2.24

*Excludes crop seasons 1965-66 and 1966-67 marked by extreme drought conditions.
**Million bales
***Information not available

Source of primary data: Area and Production of Principal Crops in India 1980 81: Economics and Statistics Directorate, Ministry of Agriculture, New Delhi.

Calculation of compound growth rates.

The growth rates for production, area and yield have been calculated by following the method used by the Directorate of Economics and Statistics, Ministry of Agriculture. The outline of the method is as follows:

The calculations are made on *Index Number* for production, area and yield and not on their absolute values.

Let Y_c be the Index Number for the *Cth* year and *t* the number of years over which the rates have to be calculated. The statistical regression coefficient *b* of $\log_e Y_c$ upon time X_c is calculated by the formula:

$$b = \frac{\sum_{i=1}^{t}(X_c - \bar{X})\log_e Yi}{\sum_{i=1}^{t}(X_c - \bar{X})^2}$$

where $\bar{X}$ is the mean of the t X_c values

The compound rate of growth *r* is then given by the formula:

$r = (\text{antilog}_e\, b - 1) \times 100$

FUTURE TASK

A possible danger in India's agricultural situation today is that the progress made in the past fifteen years may make us complacent, and it may lead to wrong conclusions about the policies and the planning framework, which must now be evolved for the future. In the first place, it is extremely important to recognise that India must improve upon its past performance of fifteen years, impressive though it has been. Unfortunately, the population pressures of the 1960s, which led to the policy decisions to modernise Indian agriculture, have not abated; *indeed, they will become more serious; and towards the close of the century India will have a population of more than one billion!* It has been estimated by the National Commission on Agriculture that India's requirement of food grains at the end of the centuary could be as high as 225 million tonnes, 19% of which will be taken by seeds, feeds, industrial uses and post harvest losses. This estimate made before the 1981 census must be considered a conservative one, as *the population growth will be faster than that anticipated earlier.* Also, India must plan for an export target of 15 20 million tonnes of foodgrains by the end of the centuary for the simple reason that the purchasing power of Indian people may continue to remain low and may not provide adequate incentive to the farmers to adopt more scientific and input intensive techniques of crop production. In the absence of a favourable market economy, *the Indian farmer must be* offered support prices by the Government and this may not be possible unless there are significant export earnings from an expanded programme of food production. Basically, all this leads to the conclusion that the growth rates of yields of major food crops in India in the next 18 years will have to be higher than those achieved in the past 15 years.

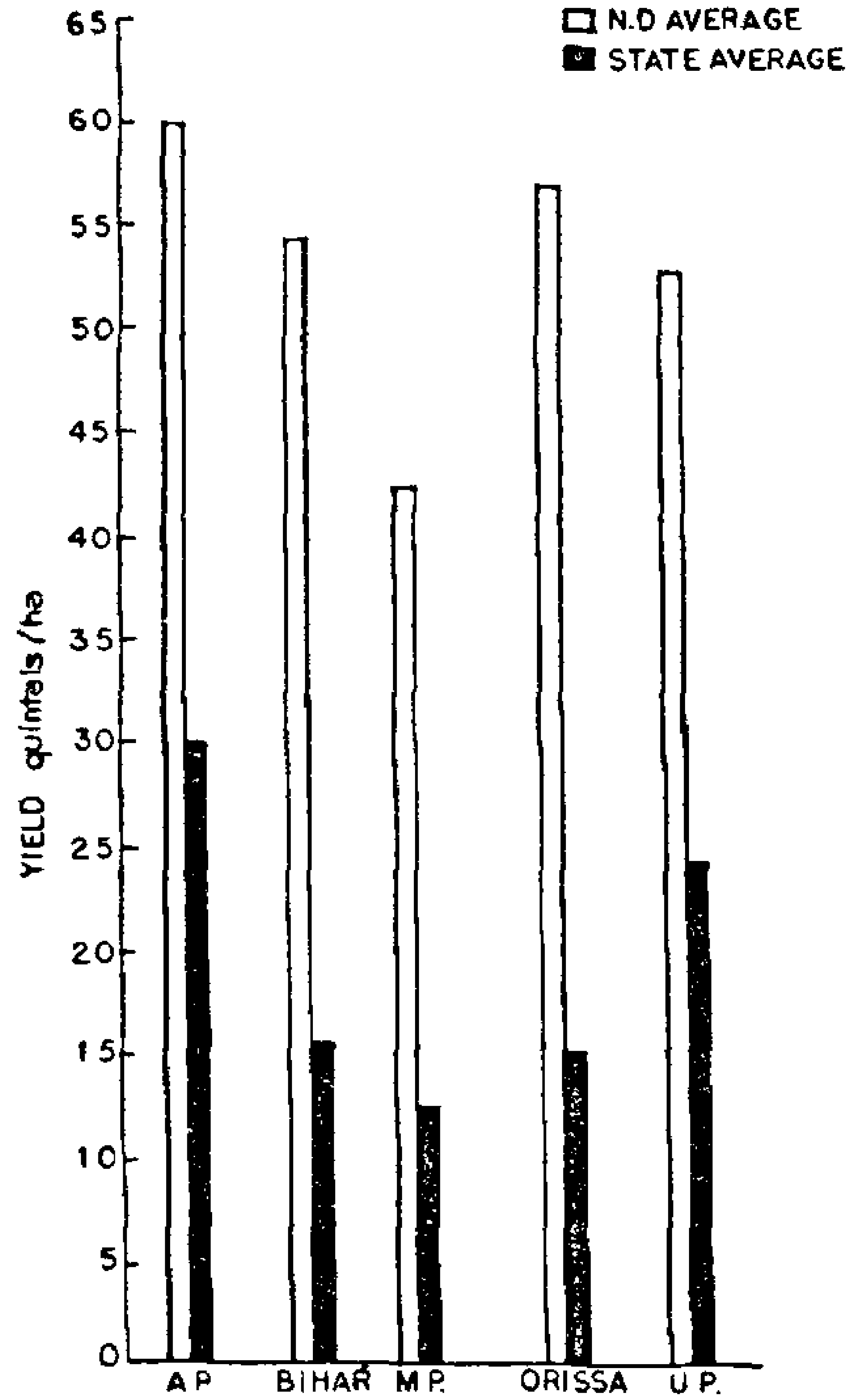

Figure 2. Shows the yield gaps of paddy in some of the states as determined through a programme of "National Demonstrations" carried out on farmers' fields. The blank column shows the average yields obtained in the blank column shows the average yields obtained in the Demonstrations while the solid column shows the average yield of the state. Both yields relate to irrigated conditions. It is clear that in all the states and more particularly in states like Bihar and Orissa there is a great deal of potential for increasing rice yields. (Source: Indian Council of Agricultural Research, New Delhi.)

It is recognised on all sides that there are only limited possibilities for expanding the area under cultivation. During the 15 years period from 1964–65 to 1978–79, the growth rate of net cultivated area dropped to 0.6% from 1.4% achieved in the earlier period of 1949–50 to 1964–65. The fundamental question then is how do we make it possible for the Indian farmer to increase his yields by the exploitation of the newer technological methods. The programme of "National Demonstrations" on farmers' fields has shown that the average yields of many food crops are about one-third to half of those which could be achieved if a larger component of the scientific production technology were adopted by the farmers (figure 2).

MANAGEMENT POLICIES

We must, therefore, evolve new policies which will help the farmers to increase their yields. The reasons for the yield gap, which is far more pronounced in India than in the developed countries are not difficult to understand. Fundamentally, we are concerned here with the problems of management of new technology and providing the necessary incentive to the farmers to produce more. In this context, it should be useful to analyse the evolution of agriculture in the developed countries in the last 40 years—a period associated with major advances in their crop yields. The trend in the western countries has been for agriculture to be increasingly *taken over from small farmers by large agri-businessmen, who function much in the same manner as those engaged in industry*. They use computer systems analysis, market intelligence and all the other approaches of modern management, which contribute to the success of any business enterprise. In the communist countries, the farmer has been reduced to the status of a paid worker. The land belongs to the State and most agriculture is organised in the form of large state farms which are run by professional managers. It is only in the developing countries like India that we have millions of small farmers with meagre resources and with little access to techniques of modern management. It is this group of people which is now being asked to adopt some of the most sophisticated techniques that scientists have evolved in recent years for increasing crop production. Obviously, we are dealing with a completely new situation which calls for new solutions. Above all, we must face the problem of a mismatch between a highly sophisticated scientific production technology and a farming community with very few resources and skills of modern management.

The Government of India, we have seen, took some bold policy decisions in the 1960's to give a new direction to Indian agriculture breaking away with the traditions of past 5000 years. The need for similar policy decisions is equally great today. In the past 15 years, we have been concerned with some of the simple components of improved production technology, such as supply of seeds of improved varieties, use of small doses of chemical fertilizers and provision of irrigation water. The technology which must now be extended to farmers includes many other components. For example, the production of pulses and oilseeds cannot be increased significantly without effective plant protection measures. Farmers must be enabled to use modern equipment and chemicals for the control of insect pests and diseases. Similarly, India's vast resources of irrigation water have to be used more efficiently, and here again, farmers will need a great deal of support for scientific management of soil and water. The improved farm implements including *tractors, threshers and sowing machines must increasingly replace the wooden plough, and this support again must be organised on a service basis.* It is not practical at the present stage to expect most farmers to purchase their own implements including farm machine and dusters and sprayers. The farmers in the non-irrigated lands must be helped to adopt techniques of water harvesting and conservation, which is the most effective solution to problems of low yields in these lands.

MANAGEMENT INFRASTRUCTURE

The country today must create a large management infrastructure to provide a vast network of agro-services to the farmers. In the absence of these services, the Indian farmer's capacity to adopt the more modern techniques of crop production will remain limited. In many ways, agriculture in India at its present stage of evolution must become a joint venture between the government and the farmers, with administration providing the management support, which most farmers, on their own cannot mobilise. The creation of this management and institutional framework could become a key factor in the rapid transformation of Indian agriculture in the next 20 years. We have done well in organising a network of effective extension services. The role of these services has been *to convince the farmers about* the *value of the new technology.* In this, we have been very successful. The Indian farmer has responded to the new message. However, the farmer is now beginning to ask for something more than the mere conviction. He needs services of various kinds, including seeds, fertilizers, pesticides, improved farm implements and techniques of soil and water management. The fundamental question is: can we now take the required policy decisions to create such a management framework for Indian agriculture?

GENETIC UNIFORMITY AND CROP PROTECTION

Perhaps the most important single development in Indian agriculture during the last 15 years has been the induction *of a great deal of genetic uniformity in our crop plants.* Indian farmers have traditionally grown hundreds of genetically diverse varieties and these have provided a natural barrier against the build-up of serious disease and pest epidemics. All this is changing now with the local cultivars being replaced by a few high yielding varieties, often covering very large areas. This makes our crop plants more vulnerable to diseases and pests. The answer obviously lies in the development and release of a large number of varieties, deriving their resistance against pests and pathogens from diverse genetic sources. It is for this reason that agricultural scientists in *India have been working on the concept of a "national multi-*

lineal complex of crop varieties". This alone can help to erect genetic barriers against a build-up of diseases. We need a national policy for release of new varieties so that the interests of the country in agriculture as a whole could be kept in view. The Central Varietal Release Committee should be concerned not only with high crop yields but also with the overall problem of stability of national agriculture. A planned programme of release of genetically diverse varieties for different regions — placing them strategically in time and in space — could go a long way in stabilising our agriculture.

DEVELOPMENT OF RENEWABLE RESOURCES

The new agricultural technology based essentially on the western model, is highly energy-intensive. This kind of technology was first evolved in the developed countries during a period when fossil fuels were cheap, abundant and readily available. There were no compulsions under these circumstances to take into consideration the heavy investments on energy needed for raising good crops. The Western scientists were primarily interested in obtaining high yields and in this they have been remarkably successful. Looking back over the past 15 years, it is clear that this model of agricultural production has served us well. It has helped us to increase agricultural production in India over a relatively short period of time. Basically, however, we should be treating this model as a means to tide over our immediate difficulties. *It is clear that with its high energy costs, it cannot sustain world agriculture on a long term basis, with the diminishing resources of fossil fuels.*

Agricultural scientists in India are now beginning to pay greater attention to the development of renewable resources of energy such as biologically fixed nitrogen. These must become the new research priorities for the agriculture of future. However, it will be a mistake to believe that we can switch from the present energy demanding techniques of crop production quickly. In the next 15 years, India's plans to feed its increasing human population must be based on the technologies which in the recent past have proved successful. The country must organise massive programmes of production of chemical fertilizers and other farm inputs. At the same time, it is important that we begin to enlarge the scientific basis of our agriculture. The development of renewable resources through intensive research in such frontier areas of science, as molecular biology should make this possible. Agriculture of 2000 A.D. could be different—it could not only be highly productive but also highly efficient in terms of the energy input/output ratio.