On growth and fluctuation of Indian foodgrain production

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We have analysed the variation of all-India foodgrain production over the last four decades to assess the typical magnitude of year-to-year fluctuation. This has shown that the magnitude of the variation between the foodgrain production in 1996 and 1997 is by no means unusual for normal monsoon years and such fluctuations should not have a large impact on GDP if the management of the economy allows for this natural fluctuation. Much larger year-to-year changes are expected for years with large anomalies in monsoon rainfall. The problems of sustaining the growth rate in irrigated areas and enhancing that of rainfed areas are addressed. It is suggested that to attain adequate growth rates for sustaining the per capita availability, a genuinely interdisciplinary approach is required with active participation of the farmers in identifying the optimal strategies.

THERE has been widespread concern about the decrease in foodgrain production from 199.3 million tons in 1996–97 to 194.1 million tons in 1997–98. According to the Indian Economic Survey 1997–98, the sharp fall in the growth rate in agriculture along with deceleration of the growth of industry has led to a significant drop in the Gross Domestic Product (GDP).

In response, huge sops have been provided for the farm sector in the budget for 1998–99 and the government is planning to come out with a National Policy in agriculture at the earliest. It is not clear whether allocation of more resources can bring about favourable changes or whether we need to change our approach as well. The time is thus opportune to take stock of our understanding of the nature of the variation of foodgrain production over time, the underlying mechanisms and attempt predictions (or educated guesses) of how the production will change on shorter as well as decadal time-scales under the business-as-usual scenario. Such an exercise can also suggest whether the approach needs to be changed and how. We address these challenging problems here.

The major questions are the growth rate of foodgrain production and the nature of the fluctuation from year to year. The most striking feature of the variation of the all India foodgrain production over the last fifty years (Figure 1) is the rapid increase in the levels of produc-

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tion from the mid-sixties associated with the green revolution. This phenomenal growth made it possible for the country to move from a food-deficit state to one which is by and large self-sufficient, despite the marked growth in population in this period. The first question that arises is: Can this growth rate be sustained? If so, what are the demands in terms of investments in irrigation, fertilizers, pesticides, etc. required to achieve this?

The foodgrain production varies considerably from one year to the next throughout the period.

The difference between the foodgrain production of successive years, (DP), is also shown in Figure 1 along with the normalized difference, DP%, expressed as a percentage of the average production of the successive years. During the green revolution, these fluctuations occurred around the increasing trend. The important question about the fluctuation is: Is the magnitude of the change in foodgrain production experienced this year unusually large? If so, why? If not, why has the impact on GDP been large? What are the causes for the year-to-year fluctuation in the foodgrain production?

It must be noted that the rapid increase in food production during the green revolution occurred primarily in the well-endowed areas, i.e. areas with irrigation and relatively few soil and climatic constraints on production[1]. In contrast, the progress has been rather slow in the rainfed belt which accounts for about 65% of the area and almost half the total crop production in the country. Thus whereas the foodgrain production increased rapidly enough to ensure a stable per capita availability of foodgrain from the fifties; the production of grain from rainfed crops such as pulses has not increased as rapidly and hence the per capita availability has decreased substantially over this period (Figure 2). The obvious question is: Why has it not been possible to enhance substantially, the production of the rainfed belt?

We address each of these questions in the next section. The challenges ahead and the approach required to meet them are then discussed.

Assessment of growth rates and fluctuation

All India foodgrain production

The rapid increase in production during the green revolution was associated with (i) a large increase in yield

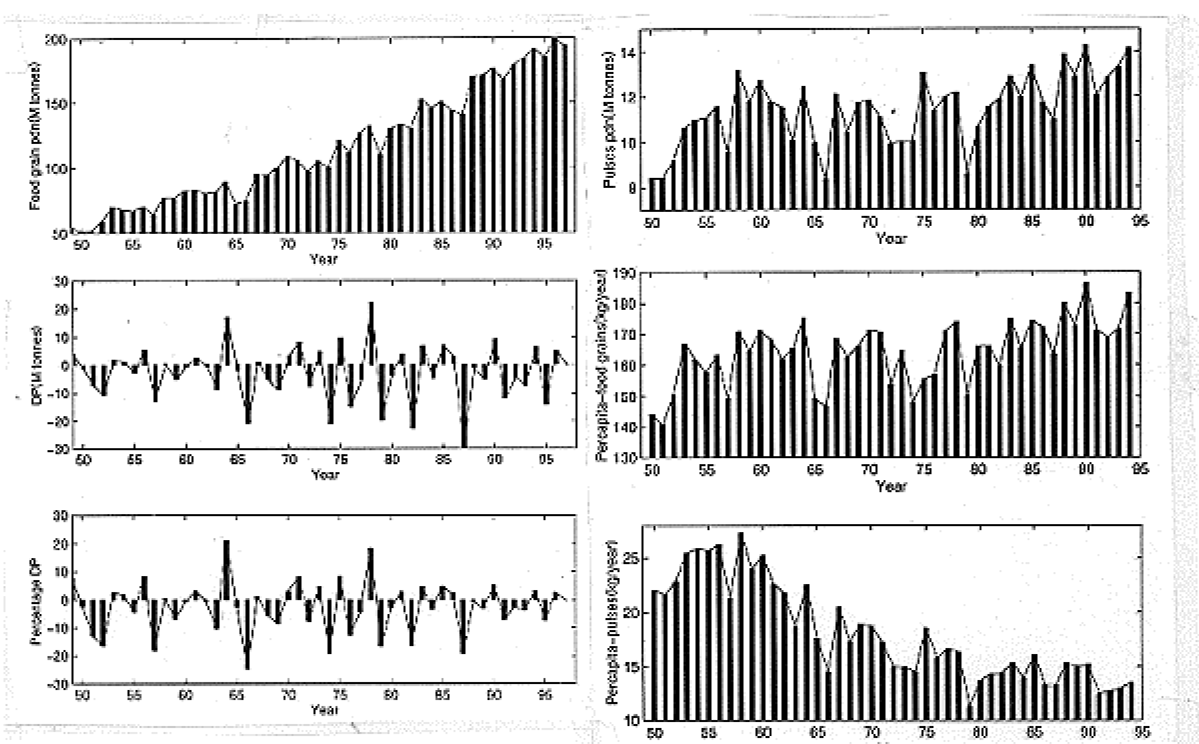

Figure 1. All India foodgrain production, FP, in million tons (top); the difference, DP, between FP of a year and of the next year (middle); the normalized difference, i.e. DP divided by average FP of successive years expressed as a percentage (bottom). Source: *Agricultural Statistics at a Glance*, Directorate of Economics & Statistics, Ministry of Agriculture, Govt of India.

Figure 2. All India production of pulses in million tons (top); per capita availability of foodgrains in kg/year (middle); per capita availability of pulses in kg/year (bottom). Source: Same as Figure 1.

due to the adoption of new dwarf, high-yielding and fertilizer-responsive varieties (of rice and wheat, in particular)[2] and (ii) marked increase in the area under cultivation (Figure 3). This increase in the average yield was made possible by a substantial increase in fertilizer application, irrigation (Figure 4) and pesticide application.

It is seen that the area under cultivation, which increased rapidly in the early stages of the green revolution, is no longer increasing – in fact there is a decrease in the last two decades, which is more marked for the area under the kharif crops (Figure 5). At present, the land under irrigation is increasing more slowly than in the past two or three decades and in future, the rate of irrigated land going out of production (due to salinity, water logging, etc.) may well exceed the rate of new land brought under irrigation[3]. We expect the decrease in area under cultivation contributes towards a decrease in the growth rate of production.

It has been pointed out that the growth rate of foodgrain production has in fact, decreased over the last few years[4]. It was relatively easy to increase the foodgrain production from 100 m tons to 150 m tons, but it has been a slow process to increase it to 198 m tons[4]. This decrease is sharper in the production of the kharif season, which seems to have reached a plateau. It may be pointed out that declining growth rates is not a feature unique to the Indian production; the growth rate of the world foodgrain has also declined rapidly in the last decade (Figure 6) due to the so-called fatigue of the green revolution. A substantial decrease of area under cultivation after the early eighties has contributed to slowing growth rates of production on the global scale[5]. The fatigue of the green revolution in India has been attributed to the steady decrease of the fertility (nutrient availability) of the lands and general decline in soil health in the high potential/well-endowed areas, due to intensive agriculture in the last two or three decades. Since the basic resources have been used in a nonsustainable manner, even to maintain the same levels of production, larger and larger inputs will be required. For example, whereas in the seventies, for an enhancement of production by 15 kg of grain, 1 kg of fertilizer nutrients was adequate; at present 1.5 kg of fertilizer nutrient is required[4]. Furthermore, due to the presence of large irrigated areas under monoculture, the level of

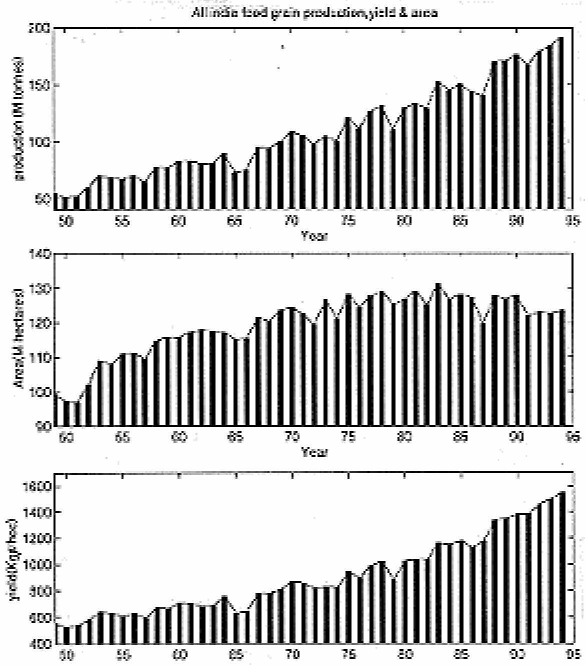

Figure 3. All India foodgrain production in million tons (top); area in million hectares (middle); yield in kg/hectare (bottom). Source: Same as Figure 1.

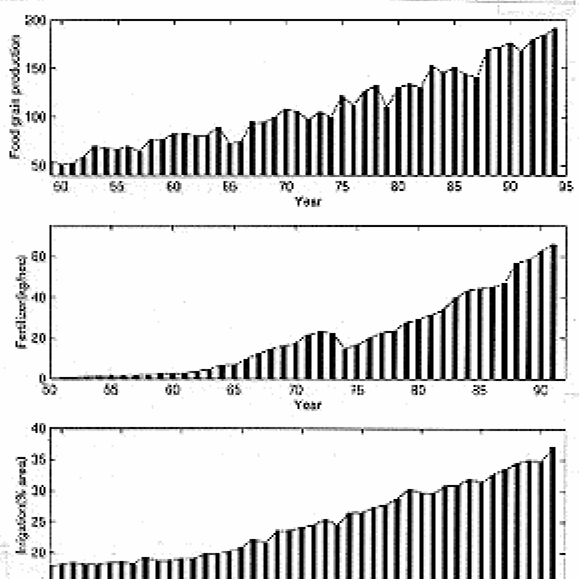

Figure 4. Variation of all India foodgrain production in million tons (top); consumption of fertilizer kg/hectare (middle); per cent area under irrigation (bottom). Source: Same as Figure 1.

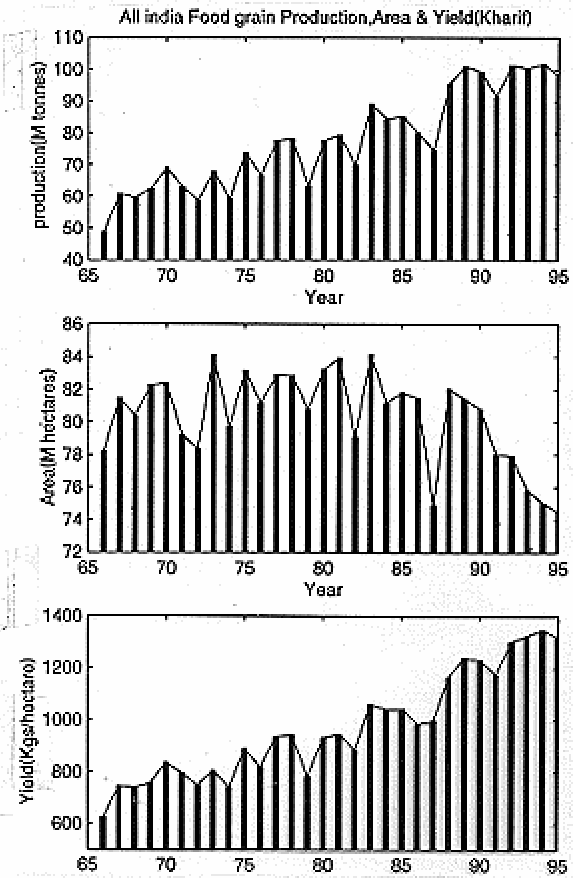

Figure 5. All India foodgrain production in m tons (top); area in million hectares (middle); yield in kg/hectare (bottom) for kharif season. Source: Same as Figure 1.

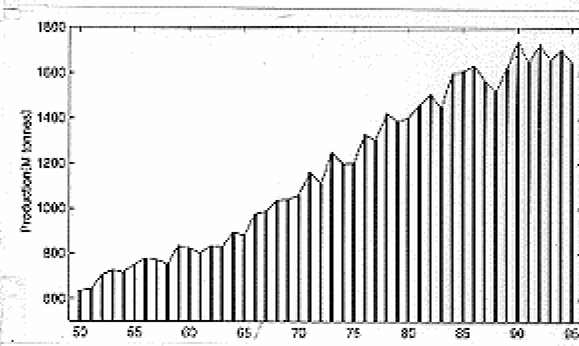

Figure 6. Variation of world foodgrain production (in million tons) during 1950–95 (ref. 5).

incidence/infestation of pests/diseases has increased enormously. The production was maintained at high levels by increasing use of pesticides. The consumption of pesticides increased from about 2000 tons during 1950–51 to 24,000 tons during 1970–71, 45,000 tons during 1980–81 and is now levelling off at about 70,000 tons.

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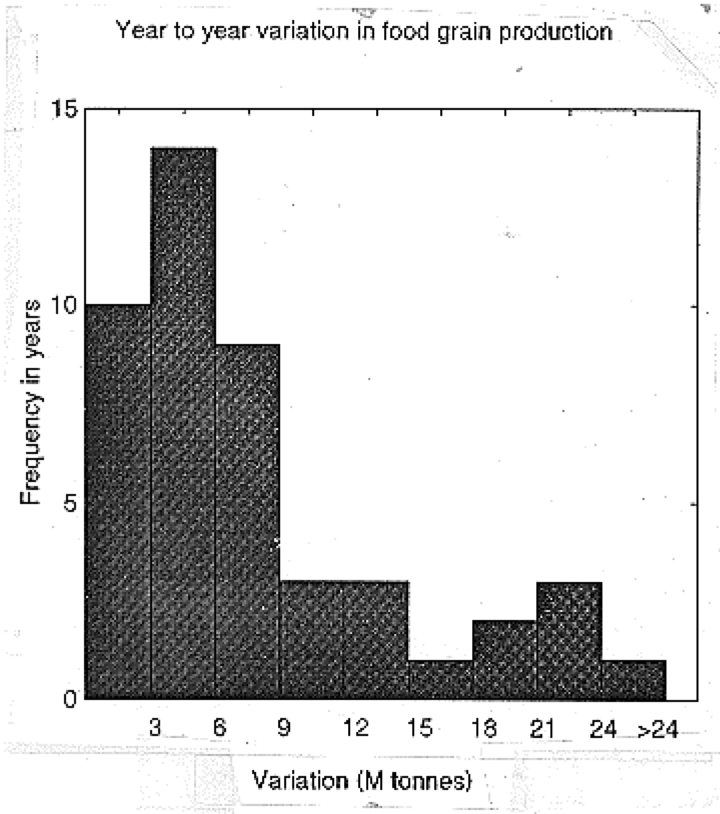

Figure 7. Frequency distribution of the magnitude of the year-to-year variation in the all foodgrain production DP for 1949–97.

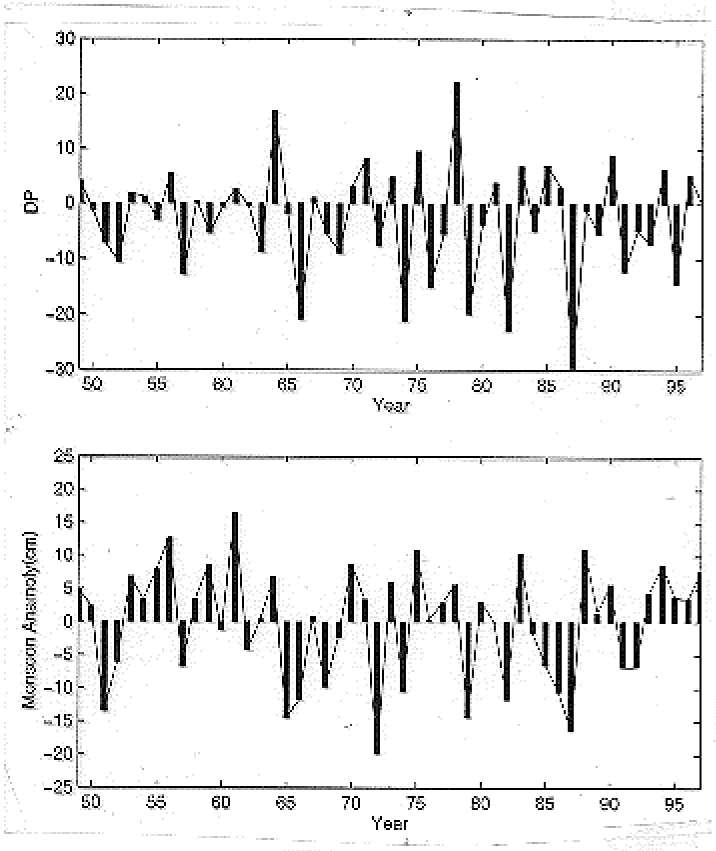

Figure 8. Variation of DP (as in Figure 1) in m tons and the anomaly (departure from average) of the all India summer monsoon rainfall in cm.

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As a result, several pests have developed resistance[6] and plant protection is becoming more difficult.

Thus it appears that under the business-as-usual scenario it may not be possible to maintain the growth rates in foodgrain production of the green revolution era without very large investments in fertilizers, irrigation, etc. which may be beyond what is realizable for our level of economy. Even if such investments are made, the degradation of the soil and adverse effects on the environment will be so large that the growth rates cannot be sustained.

Consider next, the year-to-year fluctuation in the production. The frequency distribution of the magnitude of the year-to-year variation (Figure 7) shows that it is generally less than 9 million tons (in 73% of the years). The mode (30% of the years) is between 3 and 6 million tons. It exceeds 20 million tons in few extreme years. In fact, these years of extreme variation in food production are associated with large variation in the monsoon rainfall (Table 1, Figure 8). Thus, in spite of the rapid increase in the all India foodgrain production brought about by the green revolution, the impact of the vagaries of the monsoon has remained very large throughout the period.

It is clear that the decrease in production in 1997–98 is by no means unusual and a reasonable management of the economy should be able to take a decrease of this magnitude in its stride. If such a decrease has a significant impact on the GDP, then the situation would be very much worse in years of large deficits in monsoon rainfall which are characterized by a decrease of the order of 20 million tons.

It is necessary to investigate in detail, factors that lead to the typical year-to-year fluctuations (3 to 6 million tons). Is this typical variation of the all-India average production a manifestation of relatively large variations over some regions or for some crops? To what extent does the variation of rainfall/weather in space and time contribute to this fluctuation?

In order to modify the large amplitude variation in response to the fluctuations in the monsoon, considerable efforts have been made in developing and propagating soil and water conservation measures. However, as seen in Figure 8, the impact of droughts has remained high throughout. It is necessary to assess the extent to which the potential for crop production is achieved in drought and good monsoon years. Some studies suggest that for crops in the semi-arid region (which are most susceptible to fluctuations in rainfall) the production could be enhanced substantially (to double or more) in good rainfall years with the existing know-how; whereas in drought years the production is close to the potential. This suggests that more emphasis on management of the non-drought years may result in higher overall production. We shall return to this point later.

Table 1. Effects of variation in monsoon on foodgrain production

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Years		Monsoon anomaly (cm)		Foodgrain production (FP) annual in m tons		Change in annual FP in m tons	Kharif FP in m tons		Change in kharif FP in m tons
Y	Y+1	Y	Y+1	Y	Y+1		Y	Y+1	
1966	67	−11	+ 1	74.2	95.05	21	49	60	11
1974	75	−10	+11	99.83	121.03	21	59	74	15
1979	80	−15	+ 3	109.7	129.6	20	63	78	15
1982	83	−9	+10	129.5	152.3	23	70	89	19
1987	88	−16	+11	140.3	169.9	29	74	96	22

Rainfed belt

The next problem is of the productivity of the rainfed belt which, unlike the irrigated area, has not increased substantially over the past three decades. The problem of the rainfed belt cannot be ignored because there is a limit to how much arable area can be brought under irrigation. This limit is estimated to be about 50% (ref. 4). The most important feature of the rainfed regions is of course, the variability of the environment and particularly the rainfall. The agricultural production of these regions is critically dependent on the quantum of rainfall received in a season/year as well as its distribution within the season, i.e. wet and dry spells[7–9]. Thus the production varies a great deal from year to year in response to the vagaries of the monsoon.

The 'green revolution package' of adoption of high-yielding varieties, which resulted in assured high yields in a favourable environment, involves large inputs from the farmers in terms of fertilizers and pesticides and from the farmers/government in irrigation of the lands. On the other hand, in the rainfed belt, there are large fluctuations in yield induced by the variation of the environment and the resources available for inputs are necessarily low.

The problem of finding genotypes with consistently higher yields over years with varying quantum and distribution of rainfall, under low input conditions, appears to be more difficult. It has not been possible, so far to use the detailed knowledge of the nature of the variability of important weather events (such as dry/wet spells) at the different life-history stages of the crops, to tailor the varieties to the nature of the rainfall variability of the region. It is also not clear that selection of varieties which are optimal for the climate variability, will have as large a positive impact in the rainfed belt as in the case of controlled environments. According to some experts, excessive dependence on 'the single strategy of varietal solutions (which worked so well in the well-endowed areas) to the complex and diverse rainfed ecologies is neither wise nor would be relevant in the coming decades'[10]. Management practices which are tailored to the climate variability of the region such as optimal time of sowing, optimal level and timing of pesticides, fertilizers, etc. are bound to play an important role.

In addition to the temporal variation of the environment, there is also a large spatial variation in the rainfed belt. Whereas the high potential areas which contributed to the green revolution comprise large stretches of relatively homogeneous fertile lands, the rainfed belt is rather heterogeneous with large variations in soil–climatic conditions. Thus not only do the strategies need to be tailored to the variability of climate/rainfall in time, they also need to be location-specific. Since there is a constraint on the costs that can be incurred, various management options (including those for soil and water conservation) need to be assessed in terms of the expected benefits.

It is not surprising that in the rainfed belt, with low level of yields which are highly variable, farmers operating under constraints of limited resources (for fertilizers, pesticides and soil and water conservation measures) have been reluctant to adopt the strategies worked out at research stations and the 'lab to land' approach has not been very successful. The need to develop farmer-acceptable strategies is now recognized[4]. Clearly, a new approach is required for addressing the challenging problems of rainfed agriculture.

Challenges ahead

Thus the challenges are (i) to enhance the production of rainfed areas and (ii) to attempt to overcome the fatigue of the green revolution and enhance the growth rates of the bread-basket of the country.

Rainfed areas

The major problems in the rainfed region are: (i) the large fluctuation in production in response to the variability in rainfall and (ii) losses due to incidence/
infestation of pests/diseases. Extensive losses in crops such as cotton and red gram (tur dahl) due to pests/diseases are believed to have led to several suicides by farmers in 1998. The task in the rainfed regions is to identify strategies which can enhance the overall production, with appropriate management of pests/diseases, in the face of climate variability. This has to be achieved under the constraints of low levels of resource availability.

The farming system is complex in which various decisions regarding timing of farming operations (such as sowing) as well as the level and timing of fertilizers, pesticides, etc. have to be taken at different times. To determine the optimum strategy (i.e. the optimum decisions for each action) associated with the goal (such as maximizing overall production), it is essential to assess the benefit of any specific action (such as soil amendments, fertilizer application or spraying of pesticides) in terms of the enhancement in yield. The benefits of various options available can be assessed with a crop model by simulating the yields for different management options. However, a model can be used for this purpose only if it incorporates the important features of the cropping system so that it can realistically simulate the observed fluctuations in production. Most of the existing crop models have been developed for the irrigated regions. A recent intercomparison of the simulation by rice models with observed variation at different agricultural stations over a ten-year period in the Asian monsoon region showed that no model could simulate the observations realistically[11]. Thus for understanding the nature of rainfed production, such as the relatively low yields of rainfed rice in eastern India (viz. 1.8 tons/hectare relative to the national average of 2.7 tons/hectare[12]), the models have to be modified so that they can respond realistically to the variation in rainfall.

For some of the major crops of the semi-arid regions such as groundnut and sorghum, models which incorporate the impact of rainfall variations (particularly moisture stress) have been developed[13,14]. We illustrate what can be learnt from such models by considering the case of rainfed groundnut in the Anantapur region which, we have studied in detail[15,16]. Singh *et al.* [17] have shown that the PNUTGRO model for groundnut can simulate the observed year-to-year fluctuations in yield at the agricultural station Anantapur rather well. Yields as high as 2.5 tons/ha have been achieved at the station under rainfed conditions.

The district average yield of groundnut varies a great deal from year to year, from less than 500 kg/hectare (case of failure of the crop) up to little over one ton per hectare. Thus there is a large yield gap between what can be achieved (potential yield as simulated by the PNUTGRO model) and what is actually obtained in most of the years (Figure 9). One major difference between the practices on the field and the agricultural station is in the management of pests and diseases. At the station, pesticides are used to manage all the pests and diseases for which the know-how exists. The costs of pesticides are high and hence the farmers do not apply

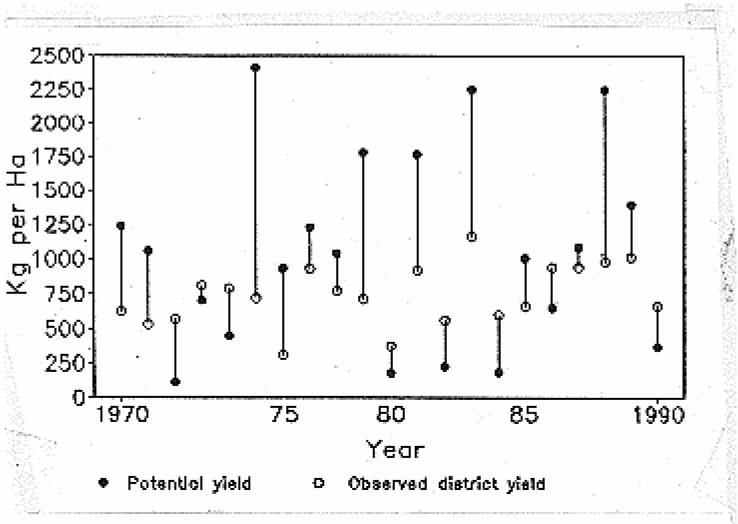

Figure 9. Variation of the simulated yield from PNUTGRO (model without pests and diseases) and the observed yield for Anantapur district during 1970–1990.

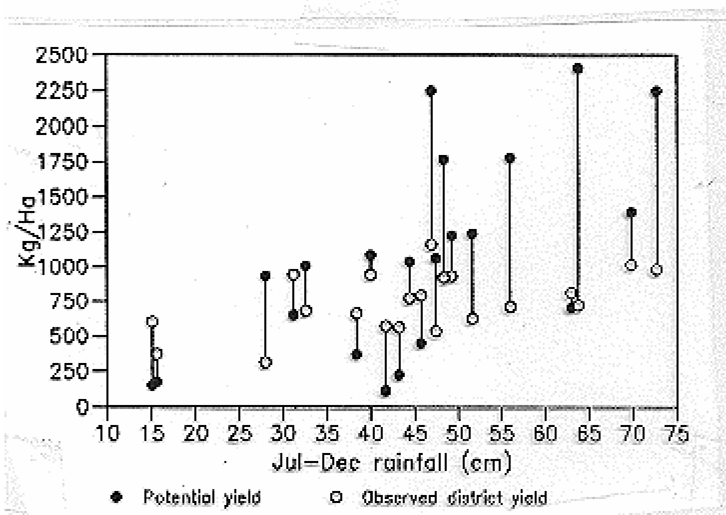

Figure 9. Variation of the simulated yield from PNUTGRO (model without pests and diseases) and the observed yield for Anantapur district during 1970–1990.

Figure 10. Variation of the simulated yield from PNUTGRO (model without pests and diseases) and the observed district yield with July–December rainfall during 1970–1990.

them in case of uncertainty. Thus, farmers do not use pesticides for pests/diseases triggered by weather events (such as wet/dry spells) even though the know-how exists. This is because quantitative assessments of the expected benefits by the control of the pests/diseases are not available.

We consider next the variation of the district and potential yields with the seasonal rainfall (Figure 10). It is seen that the yield gap increases with rainfall. Sivakumar *et al.*[18] found that the difference between the yield at agricultural stations and the fields for maize, sorghum and millet also increased with seasonal rainfall. Thus for rainfed crops in semi-arid regions, when the rainfall is low, the farmers appear to be doing almost as well as possible, but for years with reasonable levels of rainfall, the yields are half (or even less) of what could be achieved. This suggests that, perhaps, in such semi-arid regions, the emphasis should be on effective management of years of normal and good rainfall, rather than on droughts.

We note from Figures 9 and 10 that in some years with low rainfall and low levels of district yields, the PNUTGRO yields are lower than district yields. This was also the case in the comparison between yields at the agricultural station and the PNUTGRO model. This suggests that the PNUTGRO model overestimates the response of groundnut to moisture stress. The model has to be modified to correct this. Optimal management in years with reasonable rainfall can lead to enhancement of yield which more than compensates for the low yields during droughts. To derive such optimal management strategies it is necessary to have a model of the entire system with growth and development of the crop as one component and which incorporates all the important interactions (such as triggering of pests/diseases by climate events, etc.). For development of an integrated model of the farming system, a truly interdisciplinary approach is a must. The first results of such a study are presented in the paper by Gadgil *et al.*[16].

It is clear that what is needed for the development of science, which can lead to further progress in rainfed agriculture is a genuinely interdisciplinary approach, which harnesses the considerable progress made in agricultural and atmospheric sciences in the last two decades as well as the farmers' insight into the complex and diverse rainfed ecologies. The strategies for enhancing production of specific cropping systems have to be worked out for each agroclimatic zone. In order to identify such strategies, it is necessary to understand the rainfed farming system adequately so that realistic models of how production responds to variation in climate, and to different management systems can be developed.

For heterogeneous rainfed areas, rather than a set of recommendations derived in the laboratory or at an agricultural station, decision support systems should be developed, which use detailed information of the variability of soil, climate, etc. in conjunction with an integrated model of the impact of environment on the crop for a set of farming practices. Such systems should also incorporate information/prediction of important weather events as well as spread of pests/diseases. With such a system, a farmer would be able to choose the strategy appropriate for his objective (e.g. maximizing long-term yields even with relatively high risk levels for big farmers, a mini-max strategy for small farmers) for the given farming situation.
This endeavour to develop decision support systems for tailoring to the environmental variability can succeed only with active interaction between scientists and

farmers.

High potential areas

In the high potential areas, the major problems are due to a nonsustainable use of resources. The green revolution era was characterized by large inputs of fertilizers and pesticides which were possible because of the assured high yields of the special varieties introduced in these irrigated areas. However, the consequent prosperity has itself resulted in adverse environmental changes, which in turn have had a negative impact on the growth rates of production. In the pursuit of strategies that maximized the immediate gains in increase in productivity, the long-term implications were not considered before generating recommendations. In fact research that went into the recommendations was often on a single discipline basis. Understanding the interactions, feedbacks characterizing the nonlinear systems involving crops and their ecology requires a multidisciplinary effort with an agro-ecological approach rather than one focussing on crops alone.

The impact of the intensive agriculture, with an efficiency of utilization of irrigated water only about 30–40% (ref. 4) has led to degradation of land, and large areas have become uncultivable due to waterlogging and salinity. Detailed studies of the land degradation of the Indo-Gangetic Plains are available[19]. Salt-affected soils are widespread (about 7 million hectare) in semi-arid and sub-humid (dry) zones of the Indo-Gangetic Plains. Alkali soils dominate (about 2.5 million hectare) in areas with a mean annual rainfall of more than 600 mm, while saline soils are dominant in the arid, semi-arid and coastal regions. According to another estimate, nearly 50 per cent of the canal irrigated area is affected by salinization and/or alkalinization due to inadequate drainage, inefficient use of available water resources and socio-political reasons[20]. Typical examples of salinization caused by rise in groundwater are observed in Uttar Pradesh, Haryana, Rajasthan, Maharashtra and Karnataka.

There has been a significant decline of natural soil fertility. For example, in the Indo-Gangetic Plains in 1950s and 1960s symptoms of plant nutrient deficiencies, with the exception of N and P, were observed rarely when long duration and low-yielding indigenous cultivars were grown. Several studies suggest that factor productivity of fertilizer input in rice–wheat cropping systems has decreased in this region. Single and multiple nutrient deficiencies such as Zn, Fe, Mn and B have become more common and such areas have increased over the years[21]. Net rates of change of nutrient stocks in soils have become negative. Integrated use of organic and chemical fertilizers is not practised due to tractorization of agriculture and burning of crop residues in machine harvested areas. Organic matter content in soils that had initially high levels, has decreased. The biology of the soils has been gradually eroding, resulting in reduced efficiency of applied inputs and has necessitated larger inputs of fertilizers for the same level of production[20]. At the same time excessive use of some fertilizers has led to pollution of groundwater and eutrophication of lakes[4].

It has been noted that the high potential areas comprise large relatively homogeneous regions under monoculture. In the Indo-Gangetic Plains, where the traditional cropping system involved multiple cropping, large fractions of the area are under a single cultivar such as HD 2329 and Jaya or IR 8 in rice. Furthermore, irrigation has made it possible to grow crops round the year. The presence of host plants and habitats which are continuously favourable for growth of pests/diseases over regions of large spatial extent has provided a unique opportunity for the phenomenal growth of pests/diseases and led to attacks of ever-increasing intensity. Since the advent of the high-yielding varieties, there has also been a shift in the spectrum and intensity of pests and pathogens on rice crops across ecologies. While we knew no more than a couple of fungal diseases, blast and brown spot and insect pests (borers and gall midge) prior to high-yield technology, the spectrum has grown so wide today that there are additionally four more fungal, two bacterial and three viral diseases and many new insect pests and their biotypes. There is equally high incidence of variety of diseases and insect species in the native species as well[10]. In wheat, whereas rust diseases were the most serious problem until the mid-seventies, now a minor disease of the past, viz. Karnal bunt has assumed serious proportions[22]. Management in this situation requires pesticides in large quantities which increase the cost of farming and also pollute the environment. The adverse effects of pesticides on soil microflora and hence soil health have been well documented[23]. Excessive use of pesticides is also undesirable if opportunities to export to global markets are to be used.

In rainfed areas also, the cropping patterns have changed from the traditional multiple cropping to monoculture over a large fraction of the area. There are patches of irrigated land in the midst of the rainfed belt, in which crops are grown round the year. Thus conditions favourable for the maintenance and growth of pests/diseases akin to the high potential areas have been created. Hence, management of pests and diseases has become critical for the rainfed regions as well. We return to this point in the next section.

What is needed for the high potential areas is efficient management of natural resources with use of soil, water resources and chemical inputs (fertilizers and pesticides) at the optimal level. Further, for enhancing the fertility of the soil, integrated nutrient management strategies with organic manure and green manuring have to be adopted. The approach will have to involve not only making corrections to imbalance of nutrients but also improvement of nutrient use by adopting new approaches, viz. physiological and molecular ones[24,25]. In order to determine the optimal levels, crop models have to be used. Many of the crop models have been developed in other parts of the world. For determining the optimum dosages, mixes, timing, etc. of fertilizer applications, they will have to be modified to incorporate the considerable expertise generated in the last two decades on relevant facets of plant physiology and advances in areas such as nitrogen fixation, biofertilizers, etc. on the specific varieties grown under Indian conditions[25].

Given the important role of pests/diseases, the problem of breeding cultivars for resistance to pests/diseases also needs to be addressed. The growth of pests and diseases is known to be dependent on the meteorological situation. The state-of-the art models of pests and diseases can predict the growth in the population/intensity and the spread to different regions, if detailed micrometeorological observations near the land surface are available. Appropriate management of pests/diseases requires organizing a system of regular monitoring of the occurrence of the major pests and diseases and a network of special meteorological observatories which can provide necessary inputs to the pest/disease models.

Concluding remarks

We have seen that the growth rates of foodgrain production under the business-as-usual scenario are not adequate to meet the demands in the forthcoming years. Furthermore, even when the year-to-year fluctuation is of magnitude expected for years of normal monsoon, the impact on GDP has been large. It is clear that enhancement of growth rates in foodgrain production over irrigated areas as well as the rainfed belt is the need of the hour.

The green revolution was made possible by advances in agricultural sciences and plant genetics and breeding in particular. However, over the years the response of the system to inputs such as fertilizers has decreased.

We expect research and development to play a major role in the post-green revolution era also. However, in some sense, the problems that remain are far more complex. Precision management systems with soil, water and chemical inputs (e.g. fertilizers, pesticides) at the optimal level have to be adopted in the well-endowed, high potential areas which contributed to the rapid growth rates during the green revolution.

Decision support systems have to be developed for the complex and diverse ecologies of the rainfed belt. These decision support systems have to harness the advances made over the last two decades in understanding the variability of the monsoon and generating predictions over short and medium range with the advances in agricultural sciences. Input from the stake holders–farmers will be critical at all stages of the development of the decision support systems. In fact, to achieve satisfactory results an interdisciplinary approach with active participation of experts in agricultural, atmospheric sciences and farming is essential.

Some overarching problems such as management of pests/diseases have to be tackled with development of models as well as setting up a network of special observatories for input of micro-meteorological data for input to models of pests and diseases. It may also be possible to tailor varieties and management practices for avoidance of some pests and diseases.

Studies of what are the optimal cropping patterns in specific agroclimatic zones are also needed. For example, legumes need to be included in the cropping systems so that the required quantity of nitrogenous fertilizers decreases. Farmers have adopted cropping patterns on the basis of economic pressures/market forces. What needs to be done is matching of the soil and climate variability regime with the requirements of crops and derive an optimal land use system. This again requires active participation of scientists and farmers.

There is considerable expertise in the country in the relevant disciplines as well as a large body of enlightened farmers who are willing to adopt modern tools of proven efficiency. What is needed is concerted efforts by interdisciplinary groups with active participation of farmers to generate the science that can lead to the enhancement of growth rates in foodgrain production.

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