Therefore, the regression equation indicates a benefit from less than normal rainfall and cooler than normal temperature.

This analysis indicates that a cooling trend to the year 2000 would not be detrimental to winter wheat.

Summary

A cooling trend in the world's climate would have serious effects in the monsoon belts depending on whether or not the recent changes in snow and ice cover in the polar regions were responsible for the droughts in Africa and the failure of the monsoons over South Asia. The cooling and shrinking of the atmosphere at the higher latitudes is believed to have brought the subtropical anticyclones nearer to the tropical rainbelt and have caused a shifting of the monsoon belt.

The regions that would be most severely affected by a continuation of the cooling trend to the year 2000 would be the higher latitudes (above 50 degrees) where spring wheat is grown and the warm band below 30 degrees latitude where rice is the principal grain crop.

Weather variability is a much more important consideration in grain production than a cooling trend. Our highest yields are made when weather is near normal or slightly cooler than normal. It is when weather variables deviate greatly from normal that yields are lowest. Even if the weather does trend toward the coolness of a century ago yields will not be reduced significantly unless the weather becomes more variable.

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India: A Perspective on the Food Situation

James D. Gavan and John A. Dixon

In any discussion of the world food situation, India necessarily looms large. One out of every six persons in the world is an Indian, and the population, which is approximately 600 million at present, may well reach 1100 million by the turn of the century. Recent developments have led to renewed fears concerning the ability of the nation to feed her growing millions. Popular accounts present a truly alarming picture of millions of people faced with imminent starvation, at a time when world food reserves are seriously depleted. The current mood of pessimism, following so closely on a period of optimism when it was widely held that the Green Revolution was bringing about dramatic changes and that India was on the way to becoming a net exporter of food grains, clearly calls for a reevaluation of the situation and what it implies for the future of India and, indirectly, for the rest of the world.

In this article we examine the current food situation in India and the recent performance of Indian agriculture, and attempt to ascertain the reasons for the abrupt change in outlook and to arrive at tentative conclusions on the ability of India to feed her growing population in the future.

We conclude that the situation, although serious, is far from calamitous. The Green Revolution has not proved to be the deus ex machina that it was once supposed by many to be. Nevertheless, India has a considerable potential for increasing her agricultural output, and there seems little basis for excessive pessimism concerning the willingness or ability of Indian farmers, given appropriate incentives, to adopt new measures. There are reasonably good prospects that India will be able to feed her growing population in the foreseeable future.

Current Food Situation

The Indian diet is dominated by food grains (cereals and pulses), rice being the preferred grain in most of the country, with wheat taking its place in the northwest. Approximately 74 percent of the average total caloric intake is from food grains, with sugar, vegetable oils, starchy roots, fruits, and vegetables making up most of the remainder (*1*).

Domestic production, imports, and per capita availability of food grains from 1951 to 1974 are given in Table 1 and Fig. 1. From an initial low level of 134 kilograms per year, per capita availability increased to 165 to 170 kg/year, except for the bad years (1958, 1966, and 1967), when it dropped to about 145 kg/year. The mean per capita availability between 1961 and 1974 was 163.9 kg/year, corresponding to roughly 1550 calories per person per day from food grains. The proportion of cereals has increased (from 85 to 91 percent of total food grains by weight), reflecting the poor production record of pulses.

The official estimate of food grain production for the crop year 1973–1974, which essentially represents the supplies available for consumption in 1974, was 103.6 million tons (*2*). Estimates of food grain imports for 1974 range from 5.6 million tons (*3*) to 6.1 million tons (*4*). Estimates of stocks in hand at the end of 1973 varied between 2.7 million and 4 million tons. If we assume that 1 million tons were kept on hand and allow for

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Table 1. Total Indian food grain production, imports, changes in government stocks, and net availability (*38*).

Year	Production ($\times 10^6$ tons)		Net imports ($\times 10^6$ tons)	Stock changes ($\times 10^6$ tons)	Population ($\times 10^6$)	Net availability per capita (kg/year)
	Total	Pulses only				
1950–1951	50.8	8.4	4.80	0.59	363.2	134.0
1955–1956	66.9	11.0	1.44	−0.60	397.3	152.5
1960–1961	82.0	12.7	3.50	−0.17	442.4	170.5
1964–1965	89.4	12.4	7.46	1.06	482.5	175.4
1965–1966	72.3	9.9	10.36	0.14	493.2	145.6
1966–1967	74.2	8.3	8.67	−0.26	504.2	146.5
1967–1968	95.1	12.1	5.70	2.04	515.4	168.6
1968–1969	94.0	10.4	3.87	0.46	527.0	162.5
1969–1970	99.5	11.7	3.63	1.12	538.9	166.2
1970–1971	108.4	11.8	2.05	2.57	550.8	171.3
1971–1972	105.2	11.1	−0.48	−4.69	562.5	172.8
1972–1973	97.0	9.9	4.12	−0.66	576.7	153.1
1973–1974	103.6	9.8	6.10	−1.70	589.7	167.0

feed, seed, and wastage (12.5 percent), the per capita food grain availability for 1974 was in the range 166 to 169 kg (*5–7*). The figures are somewhat surprising. The highest recorded values of per capita availability (see Table 1) are 175.4 and 172.8 kg for 1965 and 1972. Over the entire 23-year period before 1974, per capita availability was apparently at or below 170 kg in 19 of the years. By this standard, even the lower figure for 1974 would appear to be within the normal range.

Requirements can be approximated by using the age- and sex-specific energy requirements and safe levels of protein intake per kilogram of body weight per day published by the Food and Agriculture Organization (FAO) and World Health Organization (WHO) of the United Nations (*8*). Using the body weights determined by the Indian Nutritional Research Laboratory for 1964 (*9*), the average required daily energy intake would be 1780 kilocalories. Some allowance should probably be made for heavier body weights of the younger cohorts in 1974 (*10*). If we suppose that the gap between the body weights of the cohorts under 15 years as determined in 1964 and the heavier FAO "reference" weights diminished by 50 percent in the intervening period as an upper limit, the average energy requirements become 1955 kcal/day. Since protein levels are given in terms of egg or milk protein, a correction factor must be applied to allow for the lower quality of proteins contained in the Indian diet. Using an arbitrary but conservative protein quality "score" of 60 out of a possible 100 for a diet consisting largely of cereals and pulses, and the same range of body weights, we get a range of 39 to 43 grams of protein per day (*11*).

The term "requirements" must be treated with considerable caution. The reference requirements are intake levels for healthy individuals, with adults engaged in occupations involving "moderate" activity (*12*). A case can be made for higher levels of intake as well as for a more balanced and varied diet. Low body weights are themselves in part the outcome of poor diets, and it can be argued that diets should be adequate to allow full genetic potential to be reached. Moreover, productivity and even mental development might be enhanced by improved diets, and the issue of what constitutes an acceptable diet for infants is far from being resolved. The estimates should therefore be regarded as minimal rather than desirable standards.

The White House panel on population and nutrition demands (*9*) pointed out that poorer segments of the population often receive considerably less. They cited a Chilean study which showed that the poorest 25 percent consumed less than 1770 calories and 50 grams of protein per day, and a study in northeast Brazil which showed that the "very poor" averaged 1606 calories per day. They reported that in the city of Vellore, state of Madras, India, during the 1950's, "the poorest communities with household incomes less than 35 rupees per month, obtained an average of 1520 to 1650 calories and 36 and 42 grams of protein per day." Similarly they calculated that "about three-fourths of rural households in South India in the late 1950's had energy supplies of less than 1600 calories per capita per day, and protein supplies of 45 grams per day, or less." The costs in terms of human suffering may be very large if such low levels are maintained over prolonged periods, and may be accompanied by high frequencies of clinical malnutrition and abnormally high mortality rates, particularly among infants. Under very adverse conditions intakes may be reduced, albeit at considerable cost, by voluntary or involuntary lowering of the work load and, for short periods, by drawing on bodily reserves.

How closely did availability match up with requirements? According to U.S. Department of Agriculture (USDA) figures for India, the average contribution of foods other than grains increased slightly through the 1960's, reaching a high point at 566 kcal per capita in 1971 and then declining marginally to 534 kcal per capita in 1974 (*13*). Using the figures given by Watt and Merril (*14*) for calories and protein content per gram of food grain by type, we can calculate total availabilities. Since we are now interested in absolute rather than relative values, the population series must be adjusted for underenumeration. After an adjustment factor of 1.7 percent is applied, the 1971 census population becomes 557 million (*15*). Using a smoothed age distribution procedure, it has been estimated that actual population may have been as high as 585 million in 1971 (*15*). To estimate the 1974 population we applied the 2.52 percent growth rate for 1970 to 1975 implicit in the U.N. medium variant projection, and obtained 601 to 631 million. On the basis of the high population value (631 million), low imports (5.6 million tons), and low stocks (2.7 million tons), we obtain an average availability of 1982 kcal and 59 g of protein per capita. With the low population (601 million), high import (6.1 million tons), and high stock (4 million tons) figures, we obtain 2120 kcal and 63 g of protein (*16*).

The low estimate of available energy and protein for 1974 just exceeds average requirements, and both estimates appear to be well above observed intakes under extremely adverse conditions. Thus food availability in the aggregate seems to have been sufficient to meet minimal requirements and, per se, not to forebode widespread starvation.

Certainly it would be wrong to conclude that there is no food problem in India. Meeting average minimal food requirements is by no means an adequate gauge. Given the distributional inequalities which inevitably arise, a substantial excess margin is required if even minimal requirements are to be met for all segments of the population. Rising living standards must be accompanied by improvements in the quality of the diet, which can only be achieved by rising agricultural output. Failure of the agricultural sector to respond adequately in the face of rising incomes would inevitably lead to rising food prices and hence to severe strains on the economic system, and indeed such a process has been evident in India over the past few years.

The figures on relative availability over time, however, point to problems of distribution as a major factor in the recent crisis. Distributional problems can usefully be considered under three headings: (i) differences associated with socioeconomic status, (ii) rural-urban differences, and (iii) regional maladjustments.

There are marked contrasts in consumption levels between economic groups in both rural and urban areas. According to Indian National Sample Survey (NSS) data (19th round, 1964–1965) the average food grain consumption in rural areas was about 217 kg/year, while the poorest 30 percent averaged 152.4 kg/year, or 30 percent less. In urban areas the poor consumed about 20 percent less than the average of 154 kg/year (*17*). By this standard, the poorest 30 percent of the population averaged 1625 (urban) to 1950 (rural) kcal/day. Furthermore, 1964–1965 was a good year (see Table 1), with per capita food grain availability (175.4 kg) well above average. The NSS data imply an average consumption of 205 kg/year. This discrepancy, which is repeated in other sample rounds, has not been adequately explained. Some observers believe that official production figures are all too low because there are strong incentives for farmers and individual states to underestimate production, while others believe there is overreporting in the surveys. There is no reason to suspect any bias in our longitudinal comparisons.

If the same economic differences in consumption apply to the 1963 to 1974 average per capita availability of 163 kg/year (based on production), the poorest 30 percent received between 1460 to 1670 kcal/day. Both figures are below the nutritional requirement cited earlier. With rising relative food prices and an apparently worsening income distribution, the position of the poor has probably deteriorated since the 1964 NSS, especially in urban areas, with the situation coming to a head in 1974. Still larger percentages below the "nutritional poverty line" have been estimated by Dandekar and Rath (*18*).

Urban areas depend heavily on government ration shops distributing food grains at below market prices. This type of distribution is especially vulnerable since it is traditionally supplied to a large extent from imports, accumulated stocks, and grain surpluses in certain areas of the country. In 1973, while imports amounted to only 4.1 percent of total requirements, they accounted for about 37 percent of the 11.5 million tons distributed through such shops. Throughout the 1960's, imports typically accounted for 60 to 80 percent of the food distributed in this way.

Procurement depends heavily on the more progressive northwestern states. Sixty percent of domestic wheat supplied to India's cities is provided by the Punjab alone (*19*) (Fig. 2). The northwestern areas experienced the most rapid expansion under the Green Revolution, but production has declined there over the last two seasons. By the end of September 1974 less than 5 million tons of food grains had been procured (*20*), and one source estimated issues at only 8.8 million tons for the year (*13*). Thus, the problem in urban areas was acute. No information is available on commercial deliveries, which would have to be added in order to estimate nutritional levels.

Finally, under conditions of rapid inflation and bearish expectation, there is an obvious temptation to hoard rather than deliver to the market. There were frequent references in the press in the second half of 1974 to hoarding by growers and merchants. The situation is aggravated by the policies of the government, which attempts to procure grain at well below open-market prices, and the temptation to hoard is strengthened by the knowledge that there are no longer any massive surpluses on the world market to lower prices in the future. Bhatia (*21*), in a study of famines in India, pointed out the extent to which starvation is a poverty-related phenomenon; the typical pattern is that food prices simply go out of reach of some segments of the population, at the same time that the decreased demand for labor in drought conditions deprives the landless laborers of their means of livelihood.

To compound the problem, food grains are not permitted to move freely between states, and considerable disparities in availability and price result. The situation appears to have been particularly severe in West Bengal, Orissa, Rajasthan, Gujarat, and Madhya Pradesh.

The outlook for 1975 is not good. The 1974 summer (*kharif*) crop was very poor. Although the monsoon began on time, the rains were subsequently very spotty—the rainfall index was only 79 compared to a normal

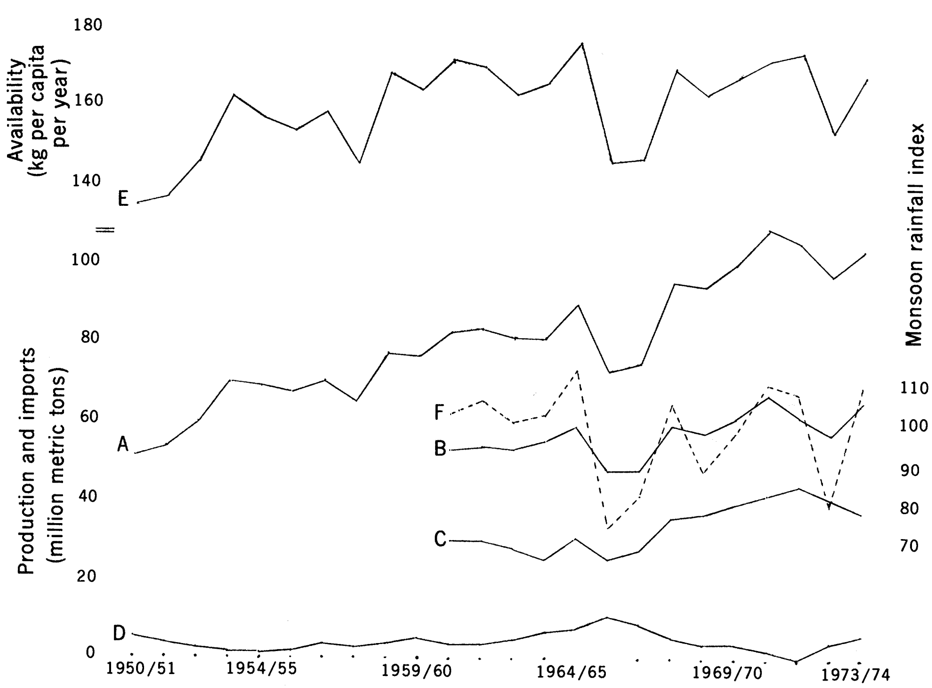

Fig. 1. Indian food grain statistics (*38*) and monsoon rainfall index. Food grains (million metric tons): (A) gross production, (B) summer production, (C) winter production, (D) net imports. (E) Net food grain availability (kilograms per capita per year) (*5*). (F) Monsoon rainfall index (100 = normal) (*24*).

value of 100 (see Fig. 1)—and the drought problem was compounded by severe flooding in Bihar, West Bengal, and Assam. Estimates of production vary from 58 to 59 million tons, some 9 to 10 million tons below the 1973 harvest, which was no higher than the 1970 harvest. A great deal, therefore, depends on the winter (*rabi*) crop, which had not been harvested at the time of this writing. Fortunately, the indications are that it will be good; forecasts range from 38 to 44 million tons, the latter being the record achieved in 1972. Power shortages have hampered tubewell irrigation, but there seems to be no adequate basis for estimating the impact this may have (*22*). Although fertilizer shortages have been reported, the overall supply of approximately 3 million nutrient tons for the agricultural year 1974–1975 is still above total consumption for the record production year 1972. Moreover, the drought conditions probably led to reduced use of fertilizer in the summer season, leaving larger stocks on hand for the winter crop. Finally, although the early winter rains were below normal, the area under well irrigation has expanded considerably since 1972, so the more optimistic forecast does not seem unreasonable.

Even with the more optimistic forecast, however, total output for the year would only reach 103 million tons; with possible imports of 7 million tons, this would give a per capita availability of only 160 kg. With the lower forecast production would be only 96 million tons, and with imports of 8 million tons this would provide an average availability of only 149 kg per capita. Both amounts are distressingly low and fall well below 1974 values. Nevertheless, the lower figure is still marginally higher than that realized in the drought years 1966 and 1967, and the higher figure is 2.4 percent below the average for 1963 to 1973.

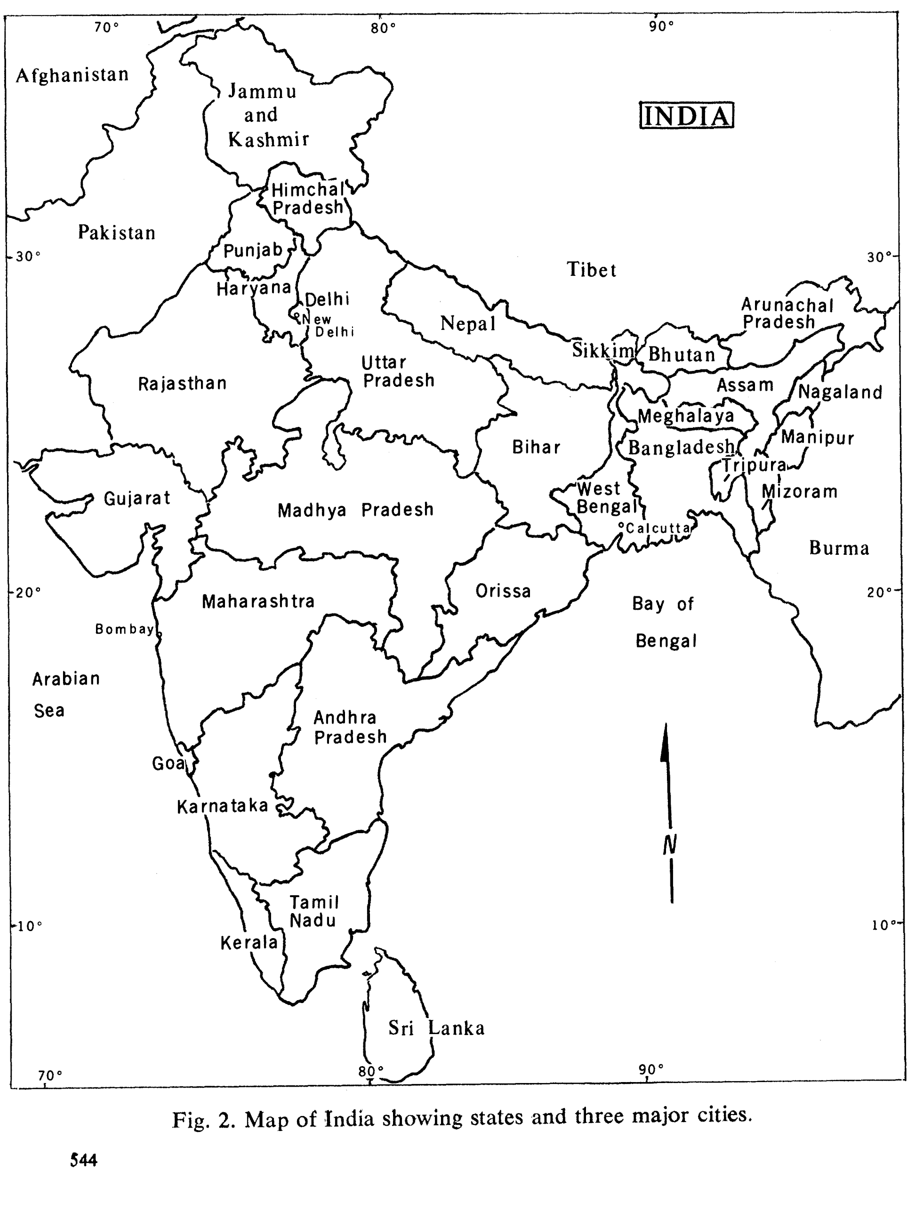

Fig. 2. Map of India showing states and three major cities.

In comparing 1975 with 1974, however, it is important to bear in mind that the nature of the distribution problem will be somewhat changed. Since it is the summer crop that failed, the burden of the shortage should tend to be shifted more toward rural areas. The shortage should therefore be spread more evenly among the whole population, although it seems likely that some rural areas will suffer severe hardships.

Outlook

To what extent can we be sanguine about India's prospects for feeding her rapidly growing population in the future? Is India already in a Malthusian trap, faced with mass starvation or a crushing burden of food imports? In this section we briefly examine demand and then turn our attention to supply.

Birthrates in India are still the subject of considerable dispute. The crude birthrate—births per 1000 persons per year—appears to have diminished from approximately 45 to 41 between 1951–1961 and 1961–1971 (*23*), but neither this nor other evidence establishes that India has entered the declining fertility stage of the demographic transition. The effect of the Green Revolution on fertility under Indian conditions has yet to be established. Although in the long run technological advances, rising incomes, and changing life-styles will probably lower fertility rates in India, as they have elsewhere, this is by no means a foregone conclusion. We cannot exclude the possibility that rising incomes could lead to higher fertility under some circumstances, as when initial income levels are very low and the rate of increase is modest. Moreover, the Green Revolution has only affected a portion of the country to date. It seems prudent therefore to expect a continuation of rapid population growth over the next decades. The U.N. medium variant population projections referred to above assume a significant decline in the general fertility rate—births per 1000 women between 15 and 44 per year—from 180.8 in 1970 to 125.6 in 2000. On this basis the number of mouths to be fed will increase approximately 80 percent over the next 25 years.

Growth of agriculture. Over the entire period represented in Fig. 1, food grain output grew 2.8 percent per year, which was just sufficient to cover population increase and to allow for a small increase in per capita income. The statistics for the period 1967–1968 to 1970–1971 seemed to augur much more dramatic progress, however. Food grain production increased from 95.1 to 108.4 million tons, at a rate of 4.5 percent per annum—sufficient to allow for a significant increase in availability—while imports were reduced by 64 percent to only 2 million tons, which went entirely into increased stocks. In fact, but for the unusual circumstances of the Bangladesh war of independence, India would have had a net surplus for export. The promise was short-lived. The last four harvests have fallen below the level achieved in 1970–1971, while the population has increased by an estimated 54 million.

The overall rates cover up more dramatic underlying changes. Over most of India there are two crop seasons (summer and winter), but in some areas a third (spring) season can be distinguished. Summer is the most abundant rainfall season, the time of the Southwest monsoon, and produces the bulk of the rice, maize, sorghum, and millet crops—60 percent of total food grain production. Wheat, barley, and most of the pulses are grown in the winter season, when rainfall is lighter and more variable. Consequently, the winter crop depends more on irrigation. For the period in Fig. 1, while the summer crop grew at a modest rate, the winter crop showed large gains. If we compare 1964–1965 with the record year 1971–1972, the winter crop increased at 5.5 percent per annum, or a spectacular 8.4 percent if only cereals are considered. Summer production grew by only 2 percent per annum over a comparable period (1964 to 1970).

Overall growth in the agricultural sector was considerably below that of food grains, which suggests some regressive substitution, if not in terms of acreage, then perhaps in terms of quality of inputs. There is some basis, then, for applying the term Green Revolution to the transformation that occurred in the winter crop—largely the wheat crop—but the term needs to be interpreted cautiously since the principal crop seems to have been only marginally affected. The unevenness was also regional. The wheat belt of the cooler and drier northwest showed the most rapid gains; the state of Punjab led with a spectacular growth in food grain production of 10.4 percent per annum over the period 1965 to 1971, followed by Haryana with 9.9 percent, Rajasthan with 8.9 percent, and Gujarat with 7.3 percent. At the other extreme, Andhra Pradesh, Assam, Bihar, Maharashtra, Madhya Pradesh, and Orissa performed poorly.

Table 2. International comparisons (*39*).

Country	Yield (100 kg/ha)		N-P-K fertilizer use (kg/ha)	Area irrigated (%)	Multiple cropping index	Land/man ratio (arable hectares per capita)
	Paddy rice	Wheat				
India	16.2	13.8	16.4	17	119	0.28
Punjab	30.5	24.1	40.3	50	134	0.29
Pakistan	23.3	11.9	13.7	65	111	0.29
Burma	15.6	5.5	1.8	5	111	0.64
China	30.9	12.0	39.6	40	147	0.15
Taiwan	34.2		292.6	58	184	0.06
Japan	58.5	23.1	439.8	55	126	0.05
United States	52.5	22.0	82.0	8	102	0.91

The strong correlation between total food grain output and monsoon rainfall is evident in Fig. 1, although the winter crop does not directly depend on the monsoon (*24*). The poor winter crops in 1973 and 1974 are in line with the below average precipitation that preceded the monsoons in the major wheat-growing areas, but we have no direct information about river flows, the other major component, in the winter months. What is more puzzling is the failure of the summer crop to exceed the 1971 level, despite apparently satisfactory rainfall in 2 of the last 4 years. Although the 1973 summer crop was close to the highest ever, it still appears unsatisfactory, given a normal rate of expansion. In the absence of an alternative explanation, we have to assume that there was a slowdown in the rate of technical advance.

Green Revolution. High-yielding varieties (HYV's) were introduced on a commercial scale in India in 1966–1967. Greatly increased production, especially of wheat, followed. Two years later, 30 percent of the area sown to wheat was in HYV's. By 1972–1973 HYV's accounted for more than 50 percent of the area sown and nearly 75 percent of total production. At the same time the area sown to wheat increased by 6.5 million hectares or 48.5 percent (see Fig. 3).

New rice varieties were also introduced on a commercial scale in 1966–1967 and were also rapidly adopted (although not as rapidly as wheat). After three seasons the proportion of rice HYV's had reached 10 percent, and by 1972–1973 they were sown in 24 percent of the area and formed 36 percent of total production. The rate of adoption of both rice and wheat HYV's then appears to have slackened off, beginning in 1972–1973 for rice and in 1973–1974 for wheat.

Fertilizer use, which had already been increasing, rose sharply after 1966–1967. Total usage increased ninefold, from 300,000 tons in 1960 to an estimated 2.8 million nutrient tons in 1973–1974 (*25*). It showed a tendency to level off in 1971–1972 and 1972–1973.

Expansion of pumpset and tubewell usage tells the same story. According to a 1973 USDA report (*26*), "The number of diesel and electric pumps in India has increased from 979,000 in 1965/66 to 2.7 million units in 1971/72. The number of private tubewells rose from 113,000 in 1965/66 to 550,000 in 1971/72. Government tubewells during this period expanded from 14,000 to 18,000." This development was especially rapid in the wheat-growing areas, led by the Punjab, but no detailed regional breakdown is available.

There are indications that the momentum of the late 1960's and first 2 years of the 1970's may be diminishing. On the output side, it is difficult to unscramble long-term effects from short-term perturbations. We have already noted the tendency toward slower adoption of rice and wheat HYV's in the 1973–1974 season, the leveling off in fertilizer use after 1970–1971, and the failure of the summer crop to surpass 1971 levels. Some of this may be the result of transitory factors, particularly local weather conditions, but there are other warning signals. In the following section we argue that expansion of HYV's may already be reaching a limit.

Despite these warning signals there seems little reason to take a pessimistic view, over the intermediate horizon at least, considering the relatively low starting point and the remaining potential for expansion. Indian agriculture is still relatively extensive in nature compared to parts of east Asia. This is reflected in terms of intensity of fertilizer use, in average yields and, rather surprisingly, in the land-to-man ratio, which is still considerably higher in India than in China, Taiwan, or Japan (Table 2). Fortunately, India possesses some of the most extensive and fertile river basins in the world. Similarly, experiment station results (Table 3) typically show an enormous potential for expansion. The issue does not seem to be technical feasibility, but whether the country can develop the organizational ability to combine its resources effectively.

Fertilizers. One of the main advantages of HYV's is their great responsiveness to fertilizers and their ability to withstand large dosages without lodging. Impressive as the increase of fertilizer use has been, application still falls short of recommended levels. In Table 4 we compare the amounts of nitrogen fertilizer actually used on HYV's and traditional varieties (TV's), assuming that the HYV's received 70 percent of the total, with the amounts recommended by the Indian Department of Agriculture (*27*).

It is not easy to determine whether the shortfall is in demand or supply. Critics charge that the distribution network has not been expanded rapidly enough. Fertilizer scarcities at the farm level were commonly reported even before the present energy crisis, and may have been due in part to failure to budget for importation of adequate quantities as a result of overly optimistic forecasts of domestic production.

Of the 2.78 million tons of fertilizer used in 1973–1974, 52 percent was produced locally. Less than 60 percent of plant capacity has been used in the past 5 years because of a variety of problems including faulty equipment, labor difficulties, internal management problems, lack of technical capabilities, electricity shortages, lack of raw materials, and lack of intermediate feedstocks (*28*). A large-scale expansion program to provide an additional 2.9 million tons is scheduled for completion between 1974 and 1978, and programs for a further 4.7 million tons have been approved or are under consideration (*25*). If plants are fully utilized and new construction is finished on schedule, most of the projected nitrogen and phosphorus requirements for 1978–1979 could be met by local production.

Demand also seems to have fallen short in some cases. Demand for fertilizers is likely to depend on familiarity with their use and on profitability. Profitability is basically a function of output response, relative prices, risk, and credit availability. The responsiveness of HYV's to fertilizers has been established under a wide range of conditions, and that of TV's seems to be far from negligible. Availability of credit on nonusurious terms may be equally important, especially where the risk of crop failure is high; most farmers, especially small ones, still rely heavily on local moneylenders, who charge very high rates. Equally important are the relative prices a farmer faces. India, like many other less developed countries, has tended to maintain terms of trade unfavorable to agriculture in its drive to industrialize. Ward (*29*) calculated that in 1968–1969 the Indian farmer required 5.2 kg of rice to purchase 1 kg of fertilizer, compared to only 1.35 kg for the Japanese farmer and only 1.15 kg for the Pakistani farmer. For wheat the respective figures were 3.7 compared to 1.8 and 1.5 kg. If these figures are representative, it is hardly surprising that fertilizer applications have often fallen far below expectation.

Table 3. Crop yields obtained in the All India Coordinated Research Programmes for Improvement in Crops (AICRIP) (*40*). Dryland trials were for periods with rainfall 20 to 60 percent below normal.

Crop	Yield (kg/ha)		
	Prevailing (maximum for 1961–1972)	Average in AICRIP trials 1970–1971	Range in AICRIP dryland trials 1972
Rice	1150	7900	
Wheat	1375	4800	
Sorghum	550	6000	330–3950
Millet			900–1240
Pulses	530	2300	890–1410
Soybean			540–2980

Table 4. Recommended and optimum rates of nitrogen fertilizer application (*27*). Optimum rates are based on 1968–1970 prices. Abbreviations: HYV, high-yielding variety; TV, traditional variety. For the last column it was assumed that 70 percent was used on HYV's.

Crop	Nitrogen fertilizer application (kg/ha)		
	Recommended	Optimum	Actual 1973–1974
Paddy rice			
HYV	100	142	41.9
TV	40	42	6.0
Wheat			
HYV, irrigated	100	164	31.5
TV, irrigated	48	52	14.0
TV, not irrigated	25	40	14.0

The data indicate a substantial potential for expanded production through greater fertilizer use. The difference between the amounts of fertilizer used and recommended in 1973–1974 was 2.4 million tons for rice and wheat alone (Table 4). Since we are restricting ourselves to recommended rather than optimum dosages, any errors should be on the conservative side. The response ratio (weight of incremental output divided by weight of nutrient input) has been estimated to be as high as 13 to 18 for wheat and 15 to 30 for rice in experimental trials (*30*). At a conservative response ratio of 9, the increment to output from 2.4 million tons of fertilizer would be approximately 22 million tons of food grains, equivalent to the increased consumption due to population growth over a 9-year period (*31*).

It is almost a foregone conclusion that the social benefits of heavier fertilizer use are likely to far outweigh social costs even at today's high prices in the world market, and the increased agricultural output should itself relieve the additional burden on the balance of payments.

Irrigation. Because of the hydrologic regime in India, future agricultural expansion will necessarily be very closely tied to the development of irrigation. The very marked concentration of precipitation in the monsoon season—in Uttar Pradesh, the largest food-producing state, for example, about 88 percent of annual precipitation occurs from June to September (*32*)—means that, despite a seemingly satisfactory annual rainfall, a large part of the country is semiarid for 8 months of the year. Precipitation in the rainy season tends to be peaked, with frequent long dry periods. Supplemental irrigation is often required even during the monsoon period, and in many areas it is needed to secure a satisfactory crop after the monsoons. Flooding is a frequent event, a large part of total precipitation being entirely lost in the heavy summer runoff. Thus, it is not surprising that irrigation has a long tradition in India and that the total area irrigated is the second largest in the world, exceeded only in China.

Some 32 million hectares, out of a net sown area of 141 million hectares, was irrigated in 1973. The quality of irrigation is extremely variable, however. Much of the present system was originally designed to provide famine protection by spreading water over as large an area as possible: canal irrigation in India is sometimes referred to as "supplemental rainfall." In 1968–1969, the irrigation water delivered at canal head averaged approximately 140 cm (*33*). Channel and field losses of approximately 62 percent (under northern Indian conditions) must be deducted. Ten of the 17 systems considered, representing roughly half of the total net irrigated area, provided for a consumptive use of less than 46 cm/year. In many areas deliveries are insufficient to grow a winter crop where irrigation would have to provide almost the entire evapotranspiration demand. Another characteristic of Indian irrigation is that storage plays only a minor role. With the seasonal peaking and high year-to-year variability of rainfall, river low flows in the nonpeak months are rather erratic.

With these characteristics and distribution systems that are often inadequate, supplies tend to be uncertain, particularly in timing, so that investing in greater cash inputs per hectare is risky, if not unprofitable. The problem is compounded by low incomes and credit scarcity, which may combine to preclude improvements even if they offer a higher expected return in the long run. The effect is to diminish the attractiveness of the HYV's, which require relatively large cash outlays on seeds, fertilizers, and pesticides and are particularly sensitive to moisture stress. Reidinger (*34*) wrote that "the present system of canal irrigation was designed on the basis of supplying irrigation for traditional agriculture. In this sense it is a traditional input. The problem is how to change canal irrigation supply to a modern input and make it match the water needs of the new inputs, especially the new HYV which require generally more precise management by the farmers to be a significant improvement over traditional varieties." The grain growers he studied in Haryana obtained the same increase in yield when they changed from canal to tubewell irrigation as they had obtained in going from no irrigation to canal irrigation. Moreover, Reidinger showed that in many cases, with the existing canal irrigation, the HYV's did no better than TV's, and some farmers had reverted back to the latter. The spread of HYV's is therefore likely to be closely tied to the use of private tubewells, which allow more careful

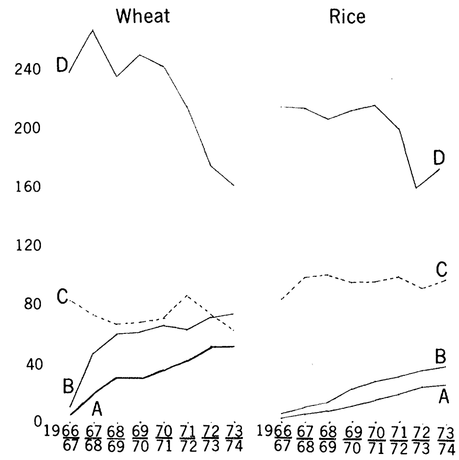

Fig. 3. Production, area covered, and yields of wheat and rice HYV's and TV's (*4*). (A) Percentage of area in HYV's. (B) Percentage of production due to HYV's. (C) Yields of TV's (× 10 kg/ha). (D) Yields of HYV's (× 10 kg/ha).

control of water supplies. Large, state-operated tubewells are often more like canal irrigation, in that they require a large distribution network over which individual farmers have little effective control.

The 10.8 million hectares sown to HYV wheat in 1973–1974 exceeded the total irrigated area for all varieties of wheat (7.8 million hectares) for 1968–1969. The total area served by wells (both tubewells and traditional wells) was estimated as 10.7 million hectares in 1968–1969. Despite a rapid expansion of tubewell irrigation since that time, the orders of magnitude suggest that the acreages sown to HYV's may be pushing the upper limits practicable under present irrigation facilities. The drastic decline in average yields of HYV wheat bears this out, although climatic conditions may also have played a part (see Fig. 3).

While the rate of adoption of HYV rice has been less spectacular than that of wheat, there are also indications that an extensive margin may already have been reached. The 9.5 million hectares sown to HYV rice in 1973–1974 may be compared with a total irrigated rice area of 13.5 million hectares in 1968–1969. The slackening off of the rate of increase over the past 2 years and the declining average yields of HYV rice lend support to this conclusion (Fig. 3).

There is a considerable potential for expanding the irrigated area and for improving the quality of supply on areas presently irrigated through reduction of losses, improved water management, and conjunctive use of ground and surface water. The Fifth Plan (*7*) projects an increase in gross irrigated area of 11.3 million hectares, 40 percent from groundwater and the remainder from surface sources. It also estimates that a gross area of 107 million hectares can ultimately be irrigated, 72 million from surface sources and 35 million from groundwater. Available water supplies will need to be used very carefully if these potentials are to be met. Present plans call for an expansion of some 17 million hectares net and 32 million hectares gross irrigated area by the end of the century (*35*).

It is difficult to generalize about the potential impact of irrigation on yields because of the wide variety of local conditions. Cummings (*36*) uses a basic cereal yield for TV's, without fertilization, of about 500 kg/ha for unirrigated land and 1500 kg/ha for irrigated land. National Sample Survey results show that the yield from TV's is about 50 percent higher with irrigation (*33*). Where water supplies are adequate to permit the use of HYV's, the increment in yields could be closer to 2 tons per cropped hectare. Thus, the potential increase in output from planned irrigation expansion would be some 25 million to 35 million tons at present cropping intensities. The ultimate potential would, of course, be much higher.

So far we have ignored the potential for induced groundwater recharge. Even after the 93 million hectare-meters cited in the Fifth Plan has been fully utilized, another 85.5 million hectare-meters, or almost one-half of the total river flow, would still be lost to the system annually through excess river flows during the monsoon period. A significant portion of this may be captured (i) by using storage sites in Nepal (although part of the water so captured might not be available for use in India) and more importantly (ii) by inducing groundwater recharge through the use of bunding, water spreading, and artificial lowering of the groundwater table in the dry season. The technical and economic feasibility of the latter course of action is under intense scrutiny.

Finally, distribution efficiency can be improved in many existing systems, where as much as 50 percent of the water may be lost by seepage and nonbeneficial evaporation. Effective planning for the optimal utilization of water resources should be a matter of the highest priority.

Multiple cropping. Finally, there is

undoubtedly a large potential for expanding output through increased cropping intensity. Over most of the subcontinent of India, with adequate water supplies, two and even three crops can be grown on the same land. In 1973–1974 the multiple cropping index —total area cropped divided by area available—was 133 on irrigated land and 119 overall. Of the 24.4 million hectares that was double-cropped in 1969 to 1971, only 6.9 million hectares was irrigated. The multiple cropping index was 147 for China and 184 for Taiwan. Experimental results have repeatedly shown that double and triple cropping is feasible, and considerably higher intensities have already been observed under field conditions in some areas: a study in the Punjab found a multiple cropping index of 150 for areas irrigated by wells and 125 for areas irrigated by canals in 1968–1969 (*37*).

In many areas a sound traditional practice has been to maintain soil fertility through fallowing. Increased use of fertilizers, under appropriate credit and pricing policies, could bring much of this fallow into cultivation. In some rice-growing areas, introduction of winter wheat, with its lower water requirements, appears to offer good prospects. An important limitation is the availability of labor and draft power. If multiple cropping is practiced, only a few days are available between harvesting and planting. Here India may well be faced with a dilemma. Increased cropping intensity may require mechanization of field preparation activities, which could release large amounts of rural labor during the rest of the year and add to the already difficult task of providing adequate sources of off-farm employment. Increased multiple cropping also entails increased water use and must be planned along with overall water resource development. The factors that determine the extent of multiple cropping in general, and how it would affect the hydrologic regime, are still little understood and offer a fruitful field for further investigation.

Summary and Conclusions

Four major points emerge from this brief survey of the evidence:

1) The food crisis in 1974 seems to have been largely a result of distributional factors. The per capita availability of food grains from all sources, including imports, although below 1971 and 1972 levels, was probably above the average for 1963 to 1973. Comparison of available food supplies with estimated caloric and protein requirements of the population indicates that, on average, enough food was available to meet minimal requirements, with a small margin to spare. Supplies obtained through the government procurement and distribution program were especially short since the program depends primarily on the winter harvest, which failed badly in 1974. Thus, urban areas and some pockets of rural areas were badly hit. The poorest third of the population, who receive 20 to 30 percent less food than the national average even in normal times, were severely affected by higher prices, and there is little doubt that a sizable fraction of the population received inadequate diets.

2) The food supply for 1975 depends heavily on the winter harvest. If this is good, as it promises to be, widespread starvation, but not hunger, should be averted. Since the main shortfall was in the summer crop, the nature of the distribution problem will be different and shortages may be spread more evenly over the population. Nevertheless, the situation seems to forebode considerable hardship for the poorer segments of the population.

3) Food requirements will continue to grow over the foreseeable future as a result of rising population and incomes. India's agricultural resources are still relatively poorly exploited. In the short run, output can probably be increased substantially by increased fertilizer use on traditional as well as new varieties. In the longer run, increased production can be obtained from more intensive cropping, expansion of surface and groundwater irrigation, improved water management, and improved cultural practices brought about by more active agricultural research and appropriate land and pricing policies. These measures will need buttressing by an expanded food storage program if extreme hardships due to periodic drought are to be avoided.

4) India's farmers have shown considerable willingness to innovate under favorable conditions. The rate of adoption of HYV's in the first few years after their introduction was impressive. The same was true for tubewells and fertilizers. Nevertheless, many of the easy gains may already have been made. Fragmentary information on the quality of irrigation indicates that the acreage sown to wheat and rice HYV's may be approaching an upper limit in many areas because of the requirements of these varieties for a high degree of water control. Further gains will require more aggressive and coordinated policies for agricultural development. A major change in development strategy may be required if scarcities and hardships such as those currently being experienced are to be avoided in the future, and some hard political decisions on land reform and consolidation may have to be made.

It is to be hoped that bold and imaginative agricultural policies will be followed, and that they will be accompanied by greater efforts to reduce population growth to manageable levels.

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5. Total availability for the calendar year is calculated as summer harvest for the previous year plus winter harvest for the current year adjusted by a factor of 0.875 for feed, seed, and wastage, plus net imports and changes in government stocks. In calculating per capita availability in kilograms we used the population figures given in *Bulletin on Food Statistics* (*6*) for years before 1972 and those given in the *Draft Fifth Five Year Plan* (*7*) for subsequent years. These figures slightly underestimate total population in that they are not adjusted for census underenumeration. Although the absolute values are therefore not strictly valid, the longitudinal comparison is consistent.
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11. Figures quoted in (*8*) imply that the protein quality score for adults may be considerably higher. For infants, the situation is complicated by the ability to imbibe sufficient quantities, given the roughage content of the diet. The efficiency of protein utilization may also decline drastically at low levels of energy intake.
12. A number of factors may cause energy requirements to vary from the reference standards under Indian conditions, although we have no information on their relative importance. While the prevalence of intestinal para-

sites would tend to raise requirements because of malabsorption, the higher mean annual temperature of 25°C (compared to the reference standard of 10°C) would tend to work in the opposite direction. Similarly, estimated requirements are based on actual food intakes, which include a proportion of obese individuals who may be using energy inefficiently. Finally, no attempt was made to adjust for heavier work loads since the prevalence of seasonal unemployment in rural areas (which contain about 80 percent of the population) would probably be more than sufficient to counterbalance such effects.
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Agriculture in China

G. F. Sprague

The current ability of the Chinese people to produce enough food for over 800 million people on 11 percent of their total available land is an impressive accomplishment. This has been achieved, in large part, through the expansion and intensification of traditional practices. Water control practice—irrigation, drainage, and land leveling—now include nearly 40 percent of the cultivated area. The intensity of cropping has been greatly increased. China has probably the world's most efficient system for the utilization of human and animal wastes and of crop residues. The development of "backyard" fertilizer plants and the utilization of hybrid corn and kaoliang (sorghum) are new elements contributing to agricultural progress.

Relatively limited data are available either for current agricultural production in the People's Republic of China or for changes in agricultural practices that have developed since the Communist Revolution. The following generalizations are based on observations made by the Plant Studies Delegation on their recent visit, 26 August to 23 September 1974, and on conversations with the many scientists contacted. This trip involved a north-south transect from Canton to Kirin and an east-west transect from Sian to Shanghai (Fig. 1). In all, some 20 research institutes, colleges, or universities and seven communes were visited. Although extensive travel was involved, our view of China remains a very restricted base from which to generalize about agriculture and agricultural developments. It is believed, however, that the observations presented are broadly correct.

The land mass of China is approximately 970 million hectares, exceeding that of the United States (excluding Hawaii and Alaska) by approximately 25 percent. The area of cultivated land in the United States is roughly a third greater than that of China, but area alone provides an inadequate basis for comparison. In the United States a portion of cultivated land remains fallow each year whereas China makes extensive use of multiple cropping. This may involve either a succession of crops grown on the same tract during the growing season, or two or more crops grown in association during a given time period. Neither comparative crop yield nor total production figures are available and, even if they were, interpretation would be difficult because of the difference in production systems. China produces all of the major crops grown within the United States, but the relative importance of individual crops differs widely between the two countries. Furthermore, agri-

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