Nature Farming in India: Constraints and Prospects

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Abstract
Nature has given us enough to fulfill our needs but not our greeds. In the present materialistic age, our needs include intensive farming for producing more and more to meet our demands for food, fiber, fuel, fruits, and industrial goods. Densely populated countries of the world are being forced to produce more than the sustaining capacity per unit of land permits. India, the land of Ashoka the Great Lord Buddha, was one of the most prosperous countries in the world in the ancient past. However, due to the increase in population and exploitation of resources in the past few hundred years, India has experienced a set back. Again, during the last three decades, India has emerged as a strong developing country by increasing more than threefold its food grain production from about 51 million .Mg in 1950-51 to over 171 million Mg in 1988-89. Increases in the production of other essential commodities like cotton and surgarcane also have been two and threefold, respectively, during the postindependence period. No doubt we have been able to make ourselves sufficient in food grains and in other essential items but the proportionate increase in fertilizer consumption per hectare has been about a hundredfold (0.55 to 53.2 kg ha^{-1}) and twenty fold in pesticides (4,000 to 80,000 Mg) during the same period. Gross irrigated area in 1951-52 was only 23 million ha and has increased to about 55 million ha in recent years. In this race for increasing agricultural production, we have learned positive and negative lessons. The problems of rising water tables in irrigated areas and increasing nutritional imbalances are evident. Perhaps the time has come when we have to stop exploitive types of farming and develop techniques for conservation/nature farming in order to sustain agricultural production and meet our demands without further degradation of our land, water, and environment. This paper reflects on the progress made by India in agriculture, with increasing use of modern technology including agrichemicals, and on the constraints and prospects of nature farming in the future.

Introduction
India is a vast country of 329 million ha and large variations in agroclimatic conditions, including the cold arid region of Ladakh with only 100 mm annual precipitation; the temperate climate of the Kashmir Valley; the subtropical alluvial plains of the northwestern region; and the tropical regions of the southern States. Rainfall varies from as low as 100 mm per annum in the Thar Desert to more than 2000 mm in certain eastern States like Assam and West Bengal. India has made tremendous progress in the last three decades, achieving a threefold growth in food grain production and almost doubling the output of other agricultural commodities. However, the need for increased agricultural production has resulted in extensive degradation of our agricultural lands, our water resources, and our environment. The purpose of this paper is to provide background information on the past and present status of agriculture in India. The concept of natural farming and its constraints and prospects for sustaining agricultural production without deteriorating natural resources are also discussed.

Past and Present Status of Agriculture in India
During the past four decades, Indian agriculture has experienced major changes. Research and development efforts have been mainly directed towards improving the production potential of individual crops and crop cultivars. With the increase in our irrigated area and introduction of high yielding varieties (HYV) during the 1960s, the production and productivity of various field crops have shown spectacular increases.

Area
As shown in Table 1, there has been a progressive increase in the total (gross) cropped area from 1951-52 to 1981-82. Increases lagged during the drought but cultivated area is expected to be more

than 177 Mha during 1988-89. The major part of the total cropped area during all these periods was occupied by food grains which increased from 96.9 Mha in 195l-52 to 126.1 Mha during 1986-87. Cereals have remained the major food crop and occupy about 80 percent of the total area under cultivation. Among the cereal crops, rice grown during the kharif season (monsoon or rainy period) and wheat during the rabi season (post-monsoon or winter period) have been the major crops cultivated on about one-third and one-fourth the area under cereal crops, respectively.

Table 1. All India Cultivated Area (Fertilizer Statistics, 1987-88)**.**

Year	Area Sown			Cropping Intensity
	Gross	Net	More Than Once	
		Mha		%
1951-52	133	119	13.8	112
1961-62	156	135	20.8	115
1971-72	165	140	25.1	117
1981-82	177	142	35.0	125

The data in Table 2 further reveal a trend of change in area under different crops during the past 35 years. The area under rice increased 50 percent from 29.8 Mha in 1951 to 40.7 Mha in 198-87, while the wheat area more than doubled from about 9.5 Mha in 1951-52 to 22.8 Mha in 1986-87. The total area under cereals also increased during this time, as shown in Table 2.

Table 2. Gross Area Under Important Crops in India (Fertilizer Statistics, 1 987-88)**.**

Year	Rice	Wheat	Total Cereals	Total Pulses	Total Food Grains	Total Oil Seeds	Cotton	Sugarcane
					Mha			
1951-52	29.8	9.5	78.2	18.8	96.9	11.6	6.5	1.9
1961-62	34.7	13.5	93	24.2	117	14.8	7.9	2.4
1971-72	37.7	19.1	100	22.1	122	17.2	7.8	2.4
1981-82	40.7	22.1	105	23.8	129	18.9	8.1	3.2
1986-87	40.7	22.8	103	23.1	126	18.7	7.1	3.1

On the other hand, the area under pulses registered only a small increase from 18.8 Mha in 1951-52 to 24.2 Mha in 1961-62, and decreased to 23.1 Mha in 1986-87. The area under oilseeds increased more rapidly up to 1971-72 but remained almost constant during later years. Although cotton has been an important crop since the preindependence days, the area under this crop did not increase significantly. The area planted to cotton increased from 6.5 Mha in 1951-52 to about 8.1 Mha in 1981-82, but had decreased by 1986-87. The area planted to sugarcane increased 50 percent from 1950-51 to 1986-87.

Productivity and Production of Important Crops

Looking to the average yield figures given in Table 3, it is highly satisfying to note that there has been definite growth in the yields of almost all the crops. This is mainly attributable to increases in irrigated area and fertilizer consumption, the use of high yielding varieties (HYV), better production technology, more efficient management practices, the identification of suitable crops for dryland areas, and conservation of rainfall in these areas. The largest increases in productivity were achieved with rice, wheat and other cereal crops. Total cereal production doubled during this overall period.

Cereals and millets are responsive to irrigation and high levels of inputs and management. Data in Table 4 indicate an increase in India's irrigated area from 17 percent of the overall cropped area to more than 30 percent from 1951 through 1987. During this same period, the use of fertilizers (Table 5), in terms of NPK, increased about 100 times from 0.55 kg ha^{-1} to about 53.2 kg ha^{-1}. These inputs went largely to the cultivation of rice, wheat, sugarcane, cotton, and to some extent to high yielding varieties of maize, pearl millet, and sorghum grown under irrigated conditions. Total production of cereal crops has also shown an upward trend due to increases in area planted and productivity of crops (Table 6). Rice production increased by about threefold, from in 1951-52 to 1986-87. A more dramatic increase occurred in wheat production. The total output of wheat in India increased from only 6.1 million Mg in 1951-52 to 45.5 million Mg in 1986-87. The increase in total output of cereal crops more than doubled during this period.

Table 3. Productivity of Important Crops in India (Fertilizer Statistics, 1987-88).

Year	Rice	Wheat	Total Cereals	Total Pulses	Total Food Grains	Total Oil Seeds	Cotton	Sugarcane (cane)
					kg ha^{-1}			
1951-52	714	653	557	448	536	430	85	31,800
1961-62	1,030	890	763	485	705	493	100	42,300
1971-72	1,140	1,380	936	501	858	526	151	47,500
1981-82	1,310	1,690	1,160	483	1,030	639	166	53,800
1986-87	1,483	1,998	1,284	508	1,140	613	167	59,700

Table 4. All India Irrigated Area (Fertilizer Statistics, 1987-88).

Year	Irrigated Area		Percent of Total Cropped Area
	Gross	Net	
	Mha		*%*
1951-52	23.2	21.0	17.4
1961-62	28.4	24.8	18.2
1971-72	38.4	31.5	23.3
1981-82	51.5	39.9	29.1
1984-85	54.1	41.8	30.7

Table 5. All India Consumption of Plant Nutrients Per Unit of Gross Cropped Area (Fertilizer Statistics, 1987-88).

Year	Gross Cropped Area	Consumption			Total Consumption
		N	P_2O_5	K_2O	
	Mha		*kg ha^{-1}*		*Mg X 10^{6}*
1951-52	133	0.44	0.05	0.06	0.06
1961-62	156	1.60	0.39	0.18	0.34
1971-72	165	10.4	3.38	1.88	2.65
1981-82	177	23.0	7.47	3.82	6.06
1987-88	176	36.1	12.3	4.80	9.01

Productivity of pulses, oilseeds and cotton did not show encouraging trends even though these crops have received considerable production emphasis by researchers, government departments, and other development agencies. Average yield of pulses (Table 3) increased slightly. In the case of oilseed crops, the average yield increased from 430 kg ha^{-1} in 1951-52 to over 600 kg ha^{-1} at present. Similarly, the production of pulse crops (Table 6) tripled during the 1950s but then remained stagnant.

The initial productivity level of cotton, as seen in Table 3, was very low but has improved. The total production of this crop in India doubled during this period, from 3.3 million bales in 1951-52 to 7.0 million bales in 1986-87.

Productivity of sugarcane has also increased twofold during the last three decades, from 32 Mg cane ha^{-1} to about 60 Mg ha^{-1}. Total production of sugarcane has increased threefold during this period (Table 6).

Table 6. Total Production of Important Crops in India (Fertilizer Statistics, 1987-88).

Year	Rice	Wheat	Total Cereals	Total Pulses	Total Food Grains	Total Oil Seeds	Sugarcane	Cotton Bales
	Mg X 10^6							
1951-52	21.3	6.1	48.6	3.4	51.9	5.0	61.6	3.3
1961-62	35.6	12.1	70.9	11.7	82.7	7.3	104	4.8
1971-72	43.1	26.9	94.1	11.1	105	9.1	114	6.9
1981-82	53.2	37.4	122	11.5	133	12.1	186	7.9
1986-87	60.4	45.5	132	11.7	144	11.4	182	7.0

Cropping Intensity and Area Under Cereals and Pulses

There has been a shift in the type of crops, crop rotations, and cropping intensity in different regions of India during the past 35 years. It is absolutely necessary that we increase our productivity and production on existing lands since there is little additional land that is either available or suitable for cultivation. Irrigation has allowed cropping intensity to increase, and there is now considerable potential to grow more than two crops in a year on the same piece of land. Similarly, under dryland conditions, new technologies have made it possible to grow at least one short duration crop even under very limited soil moisture. All these factors resulted in higher cropping intensity, from about 111 percent in 1951-52 to 125 percent in the 1980s (Table 1).

Fertilizer Use

At the time of independence, the level of fertilizer consumption in India was almost negligible and during 1951-52 only about 60,000 Mg of NPK fertilizers were used (Table 5). The growth in fertilizer use has been phenomenal during the past 35 years. Fertilizer consumption has increased from 0.34 million Mg in the early 1960s to 9.01 million Mg in 1987-88.

Consumption per hectare increased a hundredfold from 0.55 kg ha^{-1} in 1951-52 to 53.2 kg ha^{-1} in 1987-88.

Pesticides

Control of weeds, insects, pests, and diseases is essential for attaining an optimum level of productivity and production, particularly with HYV of field, vegetable, and fruit crops. Although the level of pesticide application in India during the last three decades has been lower than that of the developed countries, the use of these chemicals has increased by 20 times, from a level of 4000 Mg in 1954-55 to 80,000 Mg in 1986-87. Insecticides have comprised about 75 percent of total pesticides used in the country. However, during the last two decades with changes in crop rotations and associated weed problems, the use of herbicides has increased rapidly.

Irrigation

After independence, the main efforts of the Government of India and the various State Governments have been aimed at bringing land under irrigation. Thus, there has been a rapid increase in the gross as well as the net irrigated area in the country during the last 35 years (Table 4). The gross irrigated area increased from 23.2 Mha in 1951-52 to 54.1 Mha in 1984-85 and the proportion of irrigated area to total cropped area increased from 17.4 percent in 1951-52 to more than 30 percent in 1984-85.

Constraints and Problems

As discussed earlier, there has been a substantial increase in the irrigated area, which has resulted in increased crop production through the use of high yielding varieties, fertilizers, and agricultural chemicals. In many cases, double- and triple-cropping have been possible with appropriate inputs. While crop production and productivity have increased from these agrichemical inputs, the potential for environmental pollution has also increased. As pollutants, these chemicals can lead to the degradation of soil health and soil productivity by adversely affecting the physical, chemical, and biological properties of soil. The excessive use of agrichemicals can also impair both surface and ground water quality and cause possibly adverse effects on human and animal health.

Soil Degradation

The increased productivity of field crops during the last three decades, particularly wheat and rice, has been due largely to the increase in irrigation and fertilizer use. However, increased cropping intensity has often resulted in soil degradation through erosion and nutrient depletion. Indian soils were once only deficient in N, but now most of our soils are also deficient in P and K. Moreover, soils utilized for cereal-based crop rotations are becoming deficient in micronutrients as well. The best example may be for the rice-wheat crop rotation in northwest India. In this entire belt, zinc was not a limiting factor for plant growth up to 1970. But with the use of HYVS of rice and wheat in the same crop rotation with increased N and P fertilizers, soils have become deficient in zinc. Consequently, there is now a blanket recommendation for the application of 25 kg $ZnSO_4$ ha^{-1} to these soils. In some other areas, sulphur, iron, and other elements are limiting plant growth and yield because of intensive cultivation of high yielding crops and varieties under irrigated conditions.

Soil Sickness

Continuous use of high levels of fertilizers and adoption of exploitive agricultural practices associated with cereal-based rotations, have resulted in a decline in crop yield and crop quality. The exact reason for this is not known. However, soil sickness is becoming a major cause of concern in these intensively cultivated, irrigated lands.

Table 7. Problems of Soil Erosion and Land Degradation in India (Fertilizer Statistics, 1987-88).

Soil Problem	Area
	Mha
1. Total geographical area	329
2. Area subject to water and wind erosion	150
3. Area degraded through special problems	25.0
a) Water logged	6.00
b) Alkaline soil	2.50
c) Saline soil including coastal sandy areas	5.50
d) Ravines and gullies	3.90
e) Area subject to shifting cultivation	4.36
f) Riverine and torrents	2.73
	Mha
4. Total problem area	175
5. Annual average loss of nutrients from degraded land	5.37 to 8.40 Mg X 10^6
6. Average loss of production for not developing ravines	3 Mg
7, Average annual rate of encroachment of table lands by ravines	8000 ha
	Mha
8. Total flood prone area	40
a) Average area affected by floods	9
b) Average cropped area affected by floods	3.8
9. Total drought prone area	260
	Mha
10. Additional land needed in 2000 A.D	60
a) For crop production	10
b) For production of fuel wood	40
c) For production of fodder	10

Table 7 shows that out of a total geographical area of 329 Mha, about 150 Mha has been subject to wind and water erosion. About 25 Mha has undergone severe degradation due to an exploitive type of agriculture. Excessive and improper irrigation have created both low and high water table problems. In areas having good quality water in northwest India, tubewells are the major source of

irrigation, and the lowering of the water table has become a very serious problem.
On the other hand, in areas having brackish water along with canal irrigation, water tables have been rising at a rate of about 50 to 60 cm per year and have caused increased salinization and loss of soil productivity.
The irrigated belt of semiarid northwest India is facing this problem on a large scale.
Table 7 reveals the extent of such problems as salinity, alkalinity, Waterlogging, ravines, and gullies which have led to the removal of these lands from agricultural production. Although there have been many efforts to reclaim these lands, the input costs for the rehabilitation and restoration of productivity are economically prohibitive in most cases.

Soil Nutrients and Organic Matter

The end result of intensive and exploitive agriculture during the last three decades has been accelerated soil erosion, loss of soil fertility, and depletion of soil organic matter. The data for 1987-88 (Table 7) indicate that the average loss of nutrients due to soil degradation and erosion was between 5.37 to 8.40 million Mg per year. Similarly, the average annual requirement for major plant nutrients (NPK) at the present level of food production is about 7.5 million Mg for cereal crops, while the addition of chemical fertilizers to all crops is less than 3.0 million Mg (based on 37, 14 and 44 percent use efficiency of added N, P and K, respectively). These figures are alarming since they indicate such wide differences between the depletion and addition of these nutrients in Indian soils. Another important damaging effect of intensive cropping has been on the organic matter content of the soil. The results of a long fertility trial conducted at Haryana Agricultural University, Hisar, indicate that the organic carbon content in unfertilized soil has declined to about half of the initial level. Similarly, N added through chemical fertilizers did not result in an increase of organic carbon; however, when farmyard manure was used, the soil organic carbon content increased to about twice the initial level.

Soil Pollution

Little is known of the effects of pesticides on the soil microflora which include some of the most important nontarget organisms threatened by man’s mismanagement of the ecosystem. These organisms produce antibiotics and other metabolites; control organic matter transformations; decompose organic wastes and add nitrogen to the soil; decompose pesticides; transform rocks and other inorganic matter to provide nutrients and increase soil tilth; act as growth factors for plants and animals; keep the soil microecosystem in balance; and help to integrate living and nonliving factors of the environment.
A study by Malkomes (1976) on the effects of applied herbicides on the soil microflora and fauna indicate that the application of methabenzthiazuron stimulated the population of actinomycetes and algae but did not affect other microorganisms, and had little effect on straw decomposition (Table 8).
Dichlorprop, another herbicide, increased soil dehydrogenase activity during the entire growing season. This herbicide stimulates bacterial and algal populations but reduces the numbers of fungi and actinomycetes (Malkomes, 1976).
Sarawad (1985) reported that thimet (phorate), bavistin (carbendazim) and diuron at 10 to 100 ppm inhibited nitrification, but soil dehydrogenase activity was stimulated by all pesticides. While some stimulatory responses by soil microorganisms can occur at relatively low concentrations of pesticides, the response to higher concentrations, and particularly at increased time of exposure, is almost inhibitory.
A major source of soil pollution is from the use of polluted water, such as municipal sewage and industrial effluents, for growing vegetable and fodder crops. Irrigation with such polluted water sources can result in the accumulation of heavy metals that can cause phytotoxicity in crops and endanger the human food chain. Continued use of such wastewaters can adversely affect the physico-chemical properties of agricultural soils and decrease their productivity (Narwal et al., 1988).

Table 8. Microbial Populations as Affected by Herbicides Malkomes, 1976).*

Microorganism	Control	Dichlorprop	Methabenzthiazuron
Bacteria	100	381	103
Actinomycetes	100	71	150
Fungus	100	38	138
Algae	100	182	212

*Population estimates were made four days after treatment.

Nature Farming for Conserving Soil and Protecting the Environment

In the postindependence period, with the increasing use of agrichemicals and supplemental irrigation, we have increased our wheat production sevenfold. Wheat is mainly an irrigated crop and a major food grain grown in India. However, the problems of lowering water tables in areas having good quality ground water, and the rising water tables that have caused serious soil salinity problems in areas having brackisri ground water, have posed a major threat to sustainable agricultural production. Similarly, widespread soil deficiencies of phosphorus, zinc, and more recently sulphur and iron have been detected in areas of intensive irrigated farming. In these areas the use of high analysis nitrogenous fertilizers is posing a problem of unbalanced nutrition in crops and of malnutrition of farm animals. Although we have not yet reached a high consumption level of pesticides, the hazards of pesticide pollution is now being reported in certain areas. With this in mind, and in view of our future need for increased agricultural production, we must adopt the principle of nature farming to sustain our needs for food and fiber, to conserve our natural resource base, and to protect the environment. The development of integrated farming systems that are stable, productive, economically-viable, and environmentally sound over the long-term will be absolutely essential to ensure our future health and prosperity.

Although there may be several components to achieve this goal, some of the important ones are:

1) Recycling of farm residues/by-products/organic waste;
2) Crop rotations;
3) Green manuring
4) Use of soil amendments;
5) Biological/mechanical control of weeds, insects and diseases;
6) Energy conservation; and
7) Integrated farming systems.

Recycling of Farm Residues, By-Products and Organic Wastes

The projected demand for food grains in India for the year 2000 A. D. has been estimated at 225 million Mg (Randhawa and Abrol, 1990). Such a high level of production can be attained only through improved management of different inputs including fertilizers. However, this requires careful study of certain technological and economic considerations, such as the nutrient requirement of crops; fertilizer use on crop production; economics of using large quantities of fertilizers; and their overall effect on environmental pollution. Quantification of crop response to fertilizers in various countries of the world has shown that there is a significant relationship between fertilizer use and the yield of most crops. The NPK fertilizer consumption in India in 1985-86 was only 50.3 kg ha^{-1} per year compared with 346 kg ha^{-1} in the Netherlands, 380 kg ha^{-1} in Japan, and 378 kg ha^{-1} in the Republic of Korea. The corresponding yield figures for major cereals were 1560, 6160, 5850 and 5650 kg ha^{-1} in India, the Netherlands, Japan, and the Republic of Korea, respectively (Fertilizer Statistics , 1986-87) . Indian scientists have established that, with balanced fertilization, yields of 4000 to 5000 kg ha^{-1} of wheat and rice can be obtained even on farmer's fields. At the macro-level, to obtain 5000 kg of wheat from one hectare, the average uptake of N. P_2O_5, and K_2O is about 125, 40, and 105 kg ha^{-1}, and for 50,000 kg of rice yield, the uptake will be about 106, 39, and 112 kg ha^{-1} N, P_2O_5, and K_2O, respectively (Singh et al., 1988).

It has been estimated that about 50 percent of the nutrient requirement to grow a crop of wheat or rice can be met by soil reserves. Moreover, in view of the percent use efficiency of applied fertilizers (i.e.. 37, 14, and 44 percent of applied N, P, and K, respectively) the fertilizer requirement for pulses , fibre, oilseeds , other major crops , and vegetables will further increase the required quantities of fertilizer nutrients. Taking the above facts on cereal-based food grains production and fertilizer use efficiency in India into consideration, the quantity of N, P_2O_5, and K_2O required to meet our target of 225 million Mg of food grain production by the year 2000 will be about 6.0, 6.0, and 5.5 million Mg, respectively (Singh et al., 1988). The present total N, P_2O_5, and K_2O consumption is 9.0 million Mg. Fertilizers will also be required for the production of other nonfood grain crops.

It is virtually impossible to meet these calculated fertilizer requirements because of energy costs, lack of production capacity, and lack of foreign exchange. Thus, to maintain even the present level of soil fertility and to keep pace with food production for a rapidly growing population, we must focus on integrated nutrient management involving: (1) the collection, treatment, and utilization of urban wastes for crop production and environmental conservation; (2) increasing biological N fixation through inclusion of legumes in cropping systems and cultivation of shrubs and trees along the bunds; and (3) increasing the efficiency of applied fertilizers through better management practices.

Crop Rotations

Emphasis in the past has been on developing cropping systems (both intercrop and sequential) to ensure stable/optimal yields and maximum profits. At the same time, full exploitation of the agroclimatic resources should be the main objective. The superiority of crop rotations over monocropping has been thoroughly documented throughout the country. Research results have shown that the inclusion of leguminous crops can provide 40 to 50 kg N ha^{-1} for cereal crops such as wheat, rice, pearl millet, and sorghum. With the adoption of a rice-wheat rotation in northwest India, the problem of grassy weeds has posed a serious constraint to stabilizing crop yields without chemical weed control. However, the inclusion of other crops in the rotation such as sugarcane, potato, and mustard has facilitated nonchemical weed control, and the net return from these crops was actually higher than from cereal crops.

Intercropping and mixed cropping has been practiced in India for many years, but because of increased food needs such practices were abandoned in favor of monocropping. However, research has shown that even with HYVS this practice, especially under dryland or rainfed conditions, was more profitable and more conserving of soil fertility than monocropping. Inclusion of crops like pigeonpea with sorghum and pearl millet, and soybean with maize can yield about 90 percent of a sole sorghum or maize crop and about 50 percent of sole pigeonpea or soybean.

Green Manuring

Rice-wheat has emerged as an important rotation in the irrigated areas of northwest India. This is a highly productive but very exhaustive rotation. Experiments conducted in Haryana and Punjab have shown that inclusion of cowpea or sesbania as a green manure crop after harvesting wheat in April, and before transplanting rice at the end of June, resulted in rice yields of 40 to 50 kg ha^{-1}, and also helped to maintain good soil tilth. Because of increased pressure on the land for food production, we cannot afford to replace any main season crop with a green manure crop; however, a green manure crop could be included in the interval between two main crop seasons. This practice needs further assessment.

Soil Amendments

According to recent reports, the availability of plant nutrients from urban wastes alone accounts for 30,000 Mg of N, 21,000 Mg of P_2O_5, and 30,000 Mg of K_2O. The corresponding values from rural wastes account for 1.23 million Mg of N, 0.67 Mg of K_2O, respectively. Little attention, however, has been given to collection and treatment of sewage from towns and cities, and its utilization for agricultural purposes. Research at various agricultural institutes in the country have shown that both rural and urban organic wastes are highly valuable commodities for restoring and maintaining the tilth, fertility, and productivity of agricultural lands.

Under the subtropical and semiarid conditions in India, it has been shown that over a span of 20 years the organic carbon content of agricultural soils was reduced to 50 percent of its original value where no farm yard manure (FYM) was added in the cereal-based cropping system, The addition of 15 Mg of FYM ha^{-1} could increase the organic carbon content from 0.47 percent to 0.56 percent, or by 19 percent, whereas addition of 45 Mg of FYM ha^{-1} increased the organic carbon content by more than 50 percent of its original value. It is noteworthy that the addition of FYM in conjunction with chemical fertilizer has not only increased the soil organic carbon content, but has also resulted in significantly higher yields than from either treatment applied alone.

The introduction of irrigation in areas having brackish underground water has created problems of rising water tables and soil salinity/alkalinity. To overcome soil alkalinity due to brackish water, regular additions of gypsum must be made to maintain crop yields and soil productivity.

Biological and Mechanical Control of Weeds, Insects, and Diseases

Aquatic, terrestrial, and parasitic weeds cause enormous direct and indirect losses to the ecosystem as a whole. Losses caused by various types of weeds in different agricultural crops can, however, be minimized by timely and careful application of herbicides. At the same time, their continuous and indiscriminate use can pollute our land, water, and atmosphere. For example, in some locations where intensive vegetable production and rice farming is being practiced, there is some evidence of environmental pollution by pesticides. Suppression of weeds through biotic agents, mechanical cultivation, and proper crop rotation should be an important component of our crop production plan. Biological control of Prickly pear (*Oputina* spp.) was first achieved in India when *Dactycopins ceylonicus* was introduced from Brazil in 1795. More work in this area could be usefully undertaken.

Grassy weeds such as wild canary grass can be controlled by following a sugarcane-based, three-year crop rotation. Similarly, by using special planting techniques and row crop orientation, broad-leaved weeds can be controlled more readily. Biological methods for control of *Pyrilla* in sugarcane have almost eliminated the use of pesticides for control of this pest in many parts of India. Research is underway to develop effective biological control methods for serious pests like pinkboll worm in cotton and aphids in mustard.

Water and Energy Conservation

Water is essential for crop production and its proper use must be ensured. With total development of our water resources we could bring about 32 percent of our cultivated area under irrigation. At the same time, intensification of land use through irrigation can be self defeating, because it is exploitive and often results in the degradation of our soil and water resources. Thus, management strategies are urgently needed that will effectively conserve and utilize natural rainfall and maintain soil productivity. In rainfed agriculture the only source of available water is the rainfall on a given area. Runoff, erosion, and drainage pose serious problems for most semiarid areas in India. It is not unusual to experience excessive rainfall and serious drought during the same growing season. Methods and strategies for the collection and conservation of runoff water and its utilization for rainfed agriculture have been developed under the All India Coordinated Research Project on Watershed Management. A watershed approach to the harvesting and utilization of water is currently being followed in many of the dryland areas. Similarly, in areas with brackish ground water, we have to practice saline agriculture. Instead of introducing canal water to these problematic areas we have to survive with saline agriculture so that the natural hydrology is not disturbed.

Agriculture is a great consumer of energy and is in competition with industry. Presently, agriculture is one of the largest consumers of solar energy. We in India are fortunate to have such a geographical location where abundant solar radiation is available throughout the year. Research in many advanced countries, and India as well, have shown that solar energy can be conserved, stored, and utilized for commercial purposes. Increased use of biogas not only provides a major source of fuel for agriculture, but also facilitates the recycling of a large quantity of plant nutrients. Wind is another alternative energy source in semiarid parts of the country and efforts to utilize wind energy are already underway. While directing our efforts towards the search for alternative energy sources, our motto in energy consumption, either in agriculture or industry, should be “energy conserved is

energy saved.”
Integrated Farming Approach Conceptually, integrated farming involves a mix of crops, animals, poultry, fish, and agroforestry. It follows the concept of conservation and recycling of energy and nutrients in the soil-water-plant-atmosphere continuum- Animal feeding trials and metabolic studies conducted at Haryana Agricultural University, Hisar, India and elsewhere have conclusively shown that only 25 percent of the nutrients and energy fed to ruminant animals is retained in their bodies while 75 percent is recycled in the continuum. Thus, it is essential that animal wastes be recycled efficiently and effectively for the greatest agricultural benefit, and to ensure that they do not become environmental pollutants. In view of the increased population pressure on land, and the increased demand for food and fiber, India must increase its agricultural production and productivity per unit of land, but with utmost concern for conserving the natural resource base and protecting the environment. The development of a more sustainable agriculture, can best be achieved through an integrated farming approach.

Research Needs and Priorities

To produce more food, our efforts to date have been directed toward the development of high yielding and high input responsive crop cultivars, particularly cereals. Recently there has been a growing consensus that India should shift toward a cropping systems or farming systems approach. To maintain good soil quality and a pollution-free environment, we need to begin solving the problems of soil fertility, crop nutrition, plant diseases, insect and weed control, renewable energy sources, and efficient utilization of natural precipitation.
To produce enough food to feed the Indian population by the year 2000, and to avoid further depletion of our soil fertility status, the projected plant nutrient requirement will be about 18 million Mg compared with the current consumption level of about 9 million Mg. Therefore, it is essential that research be directed toward the development of efficient strains of nitrogen-fixing bacteria for food legumes and green manure crops. Programs for collecting, treating, and processing urban and industrial organic wastes for beneficial use on agricultural land should be a high priority for state and local governments. Such materials as lawn clippings, slaughterhouse wastes, sewage, nightsoil, wood processing wastes, and street refuse could be composted into valuable organic amendments and biofertilizers. Thus, it is necessary that we shift from an individualistic approach to crop nutrition toward a system of integrated nutrient supply and management in which crop rotations, organic recycling, biological nitrogen fixation, and biofertilizers are supplemented and balanced with chemical fertilizers to achieve long-term, sustainable agricultural production.
Some African and Asian countries are now facing a serious problem of protein malnutrition known as kwashiorkor. Research is needed to improve the nutritive value and digestibility of soybean and groundnut flour for human consumption. Thus, it is not only important to increase agricultural production but also to enhance the nutritional value of agricultural commodities through improved processing methods.
Efforts to control insect pests and weeds, particularly in developing countries, have been on an individualistic basis and no serious efforts have been made toward integrated pest management. A suitable mix of crop rotations, and cultural, mechanical, and biological control of pests should reduce the need for pesticides, minimize environmental risks, and lower farm production costs.

Conclusions

India has made unparalleled progress in agriculture during its postindependence period by increasing food grain production from about 51 million Mg to 171 million Mg, doubling the production of cotton, and increasing sugar production threefold. However, there are certain problems which must be dealt with to ensure our future prosperity. Nature farming, with its increased emphasis on conservation of natural resources and protection of the environment, seems to hold considerable promise for achieving desirable and feasible solutions to these problems. High priorities for research and technology transfer include the following:

1) Efficient use of water with increased emphasis on rain water harvesting.
2) Control rising water tables in canal irrigated areas of arid and semiarid regions having brackish ground water.
3) Develop salt-, drought-, and pest-tolerant varieties of field, vegetable and fruit crops.
4) Integrated nutrient management.
5) Integrated pest management.
6) Identification of efficient crop zones and adoption of efficient cropping systems.
7) Develop information on integrated farming systems for different agroecological situations.
8) Develop suitable marketing and processing infrastructure for preserving/processing of surplus produce.
9) Improve the nutritional value of agricultural by-products with particular reference to protein nutrition.
10) Strengthen research-extension linkages to ensure rapid adoption of conservation farming practices.

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