Soil-Related Constraints for Sustainable Plant Productivity in India

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ABSTRACT

The paper provides an overview of soil-based constraints which are limiting the sustained productivity of agriculture in India. It covers the research activities of the National Agricultural Research network on characterization, genesis and amelioration of soil-related physical, chemical, and biological constraints. Some of the constraints are natural whereas others have arisen due to human interventions. Waterlogging and salinization in irrigation commands of arid and semi-arid regions, overmining of nutrients, and excessive exploitation of underground fresh waters have decreased the productiviy of crops in several region of India. Alternative methods of soil management for improverent of degraded land qualities and maintenance of environment and productivity of the soil resources have been discussed.

Introduction

The Indian economy is predominantly agrarian since 76% of its population is rural-based and commitments for the improvement of the life quality are expected to be fulfilled primarily from agriclture and agro-industrial endeavours. At present India is supporting 16% of the global population on 2.4% of the world geographical area. The present 840 million population of India, with a growth rate of around 2.1% will cross one billion by the end of the century and efforts are being made to stabilize it around 1.5 to 1.7 billion by 2050 A. D. The food requirements are estimated to be 250 and 450 million tons by 2000, and 2050 A. D. respectively. The growth in food grain production during the last 4 decades had averaged around 3.5 mt per year the above projections would demand a quantum jump to 7 mt per year during the nineties which poses a challenge to the planners, administrators, agricultural scientists, and the environmentalists.

Out of 329 million hectares of the total geographical area, about 264 million hectares of land have a biotic potential (Table 1). It is interesting to note that the area under many crops such as food grains, cotton, sugarcane, has stabilized at the level of 125-129, 7.6-8.1 and 2.9 to 3.2 million hectares, respectively, during the last 15 years. The net cultivated area has also stabilized around 141 million hectares, out of which around 20 million hectares suffer from acute site end environmental constraints. Inelasticity of land resources, continuous increase in the number of farm families, competing demands for non-agricultural uses, have decreased per capita land availability from 0.48 ha in 1951 to about 0.20 ha in 1981 which will decline further to 0.14 ha by 2000 A. D. Therefore, the aspirations of nutritional, economic and ecological security will have to be met by increasing productivity per unit area through improved technologies, and the input support systems in India. In the past this has been

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Table 1 Land use pattern in India, 1984-85

(Area-million ha)

Classification		
1	Total geographical area	329.0
2	Biologically potential area	264.0
3	Forests	67.0
4	Not available for cultivation	40.5
5	Other uncultivated land excluding fallow land	31.0
6	Fallow land	24.9
7	Net sown area	140.7
8	Total cropped area	175.9
9	Net irrigated area	41.8
10	Gross irrigated area	54.1

Source : Fertilizer Statistics, 1987-88.

achieved through exploitation of favourably endowed regions which has created problems of socio-economic inequities. Therefore, of late there is a growing concern for a shift in land use pattern which will be continuously sustainable, economically competitive, climatically efficient, environmentally sound and socially equitable.

The status of research on resource inventory and the various land-based constraints are discussed in the following pages.

Resource inventory

Adequate characterization of soil and climatic resources for planning their sustained and ecologically optimized land use is a prerequisite. On the basis of the nature and properties of soils, physiography, and growing period (moisture availability), the country has been divided into 17 agro-ecological regions for the purposes of macro-level planning (NBSS and LUP, 1990). Of course, there are considerable fluctuations within a region and 120 agro-climatic zones have been identified within these broad regions. Scientific management of natural resources in each of these zones has been ensured through establishment of Zonal Research Stations where multi-disciplinary teams are endeavouring to develop site-specific technologies. Further variations at the stage of cultivation units are also being modelled for improving the precision, accuracy and sensitivity of technology testing (Samra *et al.,* 1989 and 1990).

Physical constraints

Inadequate soil moisture relations, high infiltration in sandy soils, poor water transmission in clayey/vertic regions, high bulk density, compaction below plough layer under irrigated rice-wheat rotation (machine-made), occurrence of calcium carbonate nodules/gravels/sesquioxide concretions, clay pans, perched/shallow water table, water/wind erosion, excessive slope, rockiness, swelling/restricted workability of vartisols/vertic subgroups, ingress of sea water in coastal segion, floods, droughts, crusting especially after the irrigasion with sodic waters, are the major limitations observed in different parts of the country. The salient research findings of practical utility for the amelioration of some of the widespread contraints (Table 2) are :

1 An improved raindependent technology involving soil and water conservation by levelling and bunding of fields, safe disposal of surplus rain water, suitable cropping systems/cultivars, balanced use of fertilizers, harvesting of rain water and its recycling at

Table 2 Problems of soil erosion and land degradation in India

(Area in million ha)

1	Rainfed agriculture	100.0
2	Area subject to water and wind erosion	150.0
3	Area degraded through special problems	25.0
	1) Waterlogged	6.0
	2) Alkaline soil	2.5
	3) Saline soil including coastal sandy areas	5.5
	4) Ravines, gullies and torrents	6.7
	5) Area subject to shifting cultivation	4.4
4	Vertisols	73.0
5	Total flood-prone area	40.0

Source : Fertilizer Statistics, 1987-88.

Table 3 Yield of rainfed crops (q/ha) with improved versus farmers practice, Kandi Region, India

Crop	Years of experiment	Mean yield (q/ha)	
		Farmers' practice	Improved practice
Maize	14	16.90(40)	28.0(31)
Wheat	11	19.5 (50)	35.0(26)
Raya	10	7.0 (27)	12.0(29)

Figures in parentheses indicate C. V. (%), results over 14 years.
Source : Prihar *et al*., 1989.

critical stages gave consistently higher yield over farmer's practices (Table 3).

2 An improved vertisol technology consisting of broad-based ridge and furrow system aiming at soil and water conservation has been tested against traditional ways at ICRISAT since 1976. The coventional sorghum cultivation practices gave a yield of 0.59 t/ha (CV 25%) against 3.3 t/ha under the improved technology. Introduction of intercrop pushed the yield further to 4.4. t/ha (CV 17%). Alternatative technology also reduced soil loss to a great extent.

3 Compaction of sandy and loamy sand soils (having less than 6% clay) with four passes of 500 kg roller within 24 hours of irrigation or heavy rainfall produced significantly higher grain and straw yield and compensated more than the cost of compaction (ICAR, 1988).

4 Chiselling of red sandy loam up to 40 cm depth decreased bulk density and increased pod yield of groundnut.

5 Application of farm yard manure @ 30 q/ha after sowing cotton and pearl millet in alluvial sandy loams increased significantly seedling emergence and yield of both the crops.

6 Bye-passing physical root penetration barrier of clay and calcic pan in sodic soils by planting trees in deep auger holes made across the limiting zone, prometed the revegetation programs on wastelands (Gill and Abrol, 1985).

7 Flood-prone and water-logged areas About 40 million ha are subjected to floods, and depending on the physiographic situation these areas continue to be under varying depths of water for periods ranging from two to six months. These lands are locally called *Tal, Chour, Diara,* etc. The ICAR and State Agricultural Universities have been implementing

research programs for suitable exploitation of these water bodies and development of improved crop varieties and cropping systems during flood-free periods.

8 Irrigated lands The country is fortunate to be endowed with a very large irrigation potential and takes pride in developing one of the largest irrigation infrastructure (80

Table 4 Rise in groundwater table due to canal irrigation and subsequent recession after vertical drainage in Punjab and Haryana

Name of the tract	Yearly water table fluctuations (m)	
	Rise	Fall
Punjab		
Upper Bari Doab	0.11(1941-65)*	0.09(1965-70)
Bist Doab	0.17(1941-65)	0.05(1965-70)
Sirhind Ganal (A Zone)	0.11 (1941-65)	0.19(1965-70)
Sirhind Canal (B Zone)	0.36(1941-65)	0.61(1965-70)
Haryana		
Western Yamuna	0.19(1947-52)	—
Canal (Karnal)	0.20(1952-57)	—
		0.14(1957-62)
		0.14(1962-67)
		0.06(1967-72)
		0.30(1972-77)
	0.04(1977-82)	—

* Values in brackets indicate years.

Table 5 Annual rainfall, runoff, and sediment yield from a managed watershed

SI.No.	Year	Rainfall (mm)	Runoff (mm)	(%)	Sediment t/ha
1	June 64-May 65	1254	295	23	40
2	June 65-May 66	718	127	18	28
3	June 66-May 67	1175	178	15	13
4	June 67-May 68	1455	177	12	10
5	June 68-May 69	900	75	8	7
6	June 69-May 70	855	62	7	6
7	June 70-May 71	1123	176	16	7
8	June 71-May 72	1664	180	11	9
9	June 72-May 73	680	28	4	4
10	June 73-May 74	1688	145	9	4
11	June 74-May 75	814	65	8	3
12	June 75-May 76	1197	170	14	3
13	1975-80(Average)	1180	103	9	2
14	1980-85(Average)	1130	78	7	1
15	1983-88(Average)	900	49	5	1
16	1988-89	1732	268	15	1

Bansal, (1990)-Central Soil and Water Conservation Research Center, Sector 27-A, Madhya Marg, Chandigarh-160019, India.

million ha). However, the mismanagement of surface irrigation primarily in medium and major commands has contributed to the problems of high water table (Table 4). Installation of shallow tube-wells as vertical drains lowered the water table after 1965 in the fresh water zones. The over-exploitation of the underground water of good quality in states like Punjab and part of Haryana has posed the problem of declining groundwater.

9 Soil and water erosion According to one estimate at least 58.08 million ha of arable and 6.31 million ha of forest land are yielding more than the permissible limits of 5.0 t/ha of sediments. Loss of soil nutrients alone is of the order of 5.4 to 8.4 million tons. Storage capacity of an artificially created lake on 228.7 ha in Chandigarh (India) was reduced by 68.5% due to sedimentation during the 16 years of its existence. Treatment of a sub-catchment of the lake involving construction of earthen/stone/brushwood check dams, water spreaders, revegetation of catchment with grasses, shrubs and trees reduced runoff and especially sediment yield to very safe limits (Table 5). Encouraged by the success in this endeavour, ICAR established 47 model watersheds representing most of the rainfed regions of the country. The characterization and scientific management of the natural resources and adoption of improved land/crop husbandr practices in the watershed areas over a period of 5 years by the Central Soil and Water Conservation Research and Training Institute, Dehra Dun, and the Central Research Institute for Dryland Agriculture, Hyderabad, helped not only in reversing the processes of degradation but also increased the yield and production of rainfed crops by 100 to 200% during the years when the country witnessed droughts of moderate to severe intensity (1984-1988). On the basis of scientific information generated by these Institutes, the Ministry of Agriculture has launched a National Watershed Development Programme for the predominantly rainfed regions of India.

10 Wind erosion The arid zone accounts for 12% of India's geographical area. Almost 32 million ha of hot deserts are located in Rajasthan (61%), Gujarat (20%), Punjab and Haryana (9%), Andhra Pradesh and Karnataka (10%). In addition, 7 million ha of cold deserts are found in Himachal Pradesh and Jammu and Kashmir States of India. We have just drafted a plan for developing appropriate technologies for cold deserts. However, the Central Arid Zone Research Institute, Jodhpur, has been engaged in research during the past three decades for management of hot deserts where excessive biotic pressures have accentuated the processes of desertification. Their work on combating and monitoring the desertification, sand dune stabilization, cropping practices, improved water management, agroforestry, silvipastoral systems, range land management, arid horticulture and development of sustainable farming enterprises for these areas have won national and international appreciation.

Chemical constraints

1 Poor soil fertility Fertility status of Indian soils is generally low (Ghosh and Hasan, 1980). In most parts of the country even at the current levels of agricultural production we continue to mine from our soils much more plant nutrients than we recycle back as crop residues, organic manures, and chemical fertilizers. This has been responsible for continuous impoverishment of the basic land resources. The soil fertility problems can be broadly described as follows:

1) Continuous decline in soil fertility
2) Nutrient imbalances
3) Environmental pollution

With the introduction of high-yielding varieties and their large scale adoption in the mid-1960s, the fertillizer use has increased from 0.06 mt in 1961-62 to 11.2 mt in 1989-90. During this period the increasing production of high analysis fertilizers and their unbalanced use

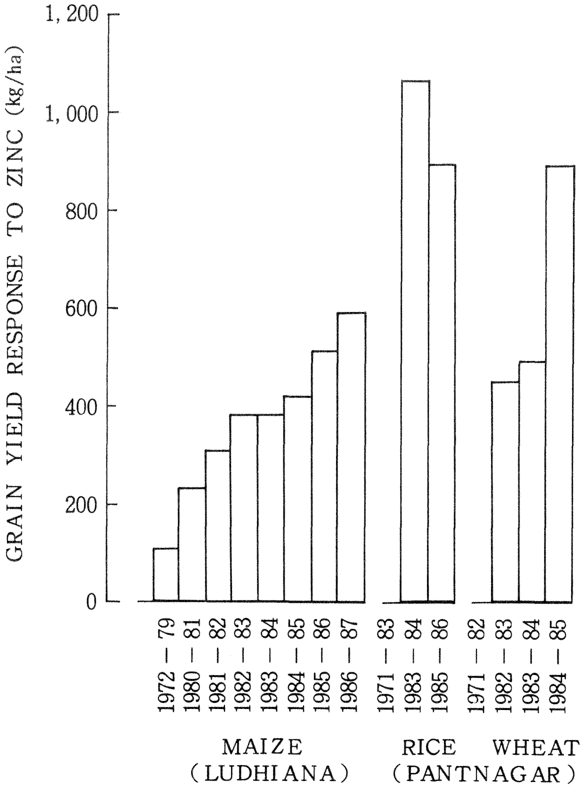

Fig. 1 Response to zing over optimal npk dose in long-term fertilizer experiments over the years (1971-87)
Source : Nambiar and Abron, 1989.

Table 6 Long-term effect of selected fertiliser treatments on the yield of maize grain in maize-wheat rotation on an alfisol (acidic red loam)

Treatment	Average yield (q/ha)			
	1 -12years	13-18years	19-24years	25-28years
NPK	8.3	8.3	5.5	5.3
N	17.0	11.5	0.4	0.0
NP	24.0	28.5	4.0	0.0
NPK	31.7	32.3	8.2	1.2
FYM (=N)	22.7	25.9	27.5	25.9
NPK+Lime	33.7	39.7	37.9	36.7

1 Following years 1-12 of cropping, local maize variety was replaced with a hybrid and the N : P : K dose increased from 40 : 40 : 40 to 100 : 80 : 60.

2 Following years 13-18, N : P : K dose was increased to 110 : 90 : 70.

Source : Lal and Mathur, 1988.

have contributed to the emergence of the deficiencies of P, K, Zn, S, and Mn in the intensively cultivated areas (Fig. 1). The research work under the National Agricultural Research System has indicated that these problems can be overcome by adopting integrated nutrient management systems (Table 6). In order to study the long-term effects of recycling crop residues, green manures, and animal wastes on nutrients substitution and soil fertility maintenance, permanent manurial experiments have been set up in all State Agricultural Universities. With increasing emphasis on the use of renewable source of energy in the urban/rural households, it will permit us to divert the crop/animal wastes for augmenting our nutrient supply resources.

Complementary and supplementary role of blue green algae, bio-fertilizers (rhizobium, actinomycetes, mycorrhiza, etc.) nitrogen-fixing trees through agroforestry programs is also being promoted for ensuring improved supply of nutrients on a long-term basis.

The research programs in the country have been in progress to exploit genetic variability in tailoring plant-types tolerant to different kinds of stresses in our soils. These efforts have been further strengthened through the establishment of advanced centers of biotechnology and genetic engineering.

2 Pollution At the current level of nutrient use of around 60 kg/ha we do not foresee any problem of soil/groundwater pollution arising from the use of chemical fertilizers. Even in a progressive State like Punjab where the nutrient consumption averages arround 165 and 320 kg/ha on gross and net cropped area basis, respectively, a case study did not reveal any serious problem (Table 7). However, some reports about the pollution of groundwater arising from the excessive use of plant nutrients in grape and sugarcane areas have been noticed.

Table 7 Nitrate-N concentration in the ground water in some wheat-rice growing areas of Punjab

Item	1975		1982	
	Before monsoon	After monsoon	Before monsoon	After monsoon
No.of observations	46	33	26	26
Mean (mg NO3-N/L)	0.99	1.02	2.36	3.88
Range (mg NO3-N/L)	0.04 to 6.15	0.05 to 7.90	0.35 to 10.11	0.23 to 15.17
Estimates on probability of occurrence:				
10mg NO3-N/L	NA	NA	—	10%
5 mg NO3-N/L	NA	NA	—	25%

NA: Estimates on probability of occurrence were not available for 1975.
Source: Singh *et al.*, 1987.

3 Pesticides residues There is a considerable evidence that increasing reliance on agricultural chemicals has disturbed the biological equilibrium, thereby affecting crop productivity. The pesticide residues may create a variety of effects on symbiotic (rhizobium), and non-symbiotic (azotobacters and azospirillum) N_2-fixing bacteria; N, S, P, Fe, and Mn-cycling, organic matter turnover, growth of blue green algae, absorption and uptake of nutrients by crops (Sethunathen *et al.*, 1981). Generally organochlorine compounds have been found to be more persistent than organophosphorus compounds under aerobic systems. In anaerobic systems of flooded soils an organochlorine like BHC was relatively less persistent than the carbamates and carbofurans. Application of DDT

beyond 40 ppm concentration was found to be deleterious to the growth, yield, nodulation and N_2-uptake of *Phaseolus aureus*, and *Pisum sativum* inoculated with rhizobium. Use of dicofal (a miticide) at 10 times the normal concentration did not produce any significant effect on the soil microflora associted with N-cycling. Application of commercial formulation of BHC or benomyl to a flooded soil decreased Fe and Mn reduction significantly. This phenomenon can even used for preventing toxicities of nutrients. There are several reports which indicate that BHC, DDT, chlordane, aldrin, helptachlor, himet, sevin, diazinon, chlorophyros, and di-sulfoton increased the level of soluble P whereas carbofuran and disyston had a tendency to reduce P availability.

4 Acid soils About 26 million ha of lands are having a pH below 5.6 and 23 million ha between 5.6 and 6.5 (Mandal, 1976). These are generally found in high rainfall regions and include red, laterite, mixed red and yellow, peat, brown forest and foothills. Acid soils have generally kaolinite, hydrous mica and illitic type of clay minerals with low CEC (3 to 10 meq/100g soil). In some cases exchangeable aluminium whereas in others hydrogen ion activity is the main cause of acidity. The soils are poor in P, Ca, Mo and B. Most of them are well supplied with K, Mn, Zn and Cu. Responses to lime, basic slag and rock phosphates as sources of Ca, P and Mg are common (Goswami, 1982).

5 Acid sulphate soils These are waterlogged soils with low pH, high sulphate salinity, which occupy 0.11 million ha mainly in Kerala and West Bengal. Based on the FAO/UNESCO soil legend, these soils have been named Thionic Gleysols whereas according to USDA soil taxonomy they qualify to be Sulfaquepts. Their pH (1 : 2.5) varies from 3.2 to 3.8 and goes down further on draining. The best land use of these soils is rice cultivation in the standing water. Although their salinity ranges from 4.1 to 15.1 mmhos/cm ample supply of water makes osmotic effects inoperative. Other limitations are toxicity of Al, H_2S and Fe, and deficiency of P and Ca. Salient features of these soils have been reviewed by Goswami (1982).

6 Salt-affected soils Geographical distribution of 7 million ha of salt-affected lands whose productivity has been lost due to high pH (sodium ion activity), and salinity or both have been reported by Singh and Joshi (1990). Sustainability of cana-irrigated lands has been

Table 8 Extent of waterlogging and soil salinity/alkalinity in selected canal commands (000 ha)

Sl.No.	Project	State	Waterlogging	Extent of soil salinity/alkalinity
1	Ram Ganga	U. P.	195(9.7)	352(17.6)
2	Sharda Sahayak	U. P.	260(7.0)	253(6.7)
3	Gandak	Bihar	211(20.1)	400(38.1)
4	Sri Ram Sagar	A. P.	60(47.6)	1(0.8)
5	Nagarjuna Sagar LBC	A. P.	19(5.9)	13(3.9)
6	Nagarjuna Sagar RBC	A. P.	114(24.0)	—
7	Tungbhadra	A. P.	30(10.0)	15(5.0)
8	Ukai-Kakarpur	Gujarat	16(4.3)	8(2.2)
9	Mahi Kadana	Gujarat/ Rajasthan	83(16.8)	38(7.3)
10	Tawa	M. P.	—	7(3.8)
11	Chambal	MP/Rajasthan	98(20.3)	40(8.2)
12	Rajasthan Canal	Rajasthan	43.1(8.0)	29(5.4)

Note : Figures in parenthesis indicate percentage area to the irrigation potential.
Source : Singh and Joshi (1990).

affected adversely by waterlogging and salinity in several command areas (Table 8). From the management point of view, the problem is characterized by the following two distinct groups : -

1) Alkali soils The pH (1 : 2) of these soils may be as high as 10.5 and they are highly dispersed with an exchangeable percentage (ESP) of 80-90%. Reclamation technology consisting of land grading, bunding, soil test-based amendment application, rice as start crop, green manuring, suitable crop varieties, judicious nutrient and water management and agronomic practices proved very effective in the reclamation of these soils (Table 9). Large volumes of data indicate that rice production approached the normal yield within 1-2 years of reclamation whereas for sensitive crops like wheat it took 4-5 years to realize the normal productivity. The sustainability of reclamation is governed both by the

Table 9 Productivity (kg/ha) of paddy and wheat on alkali soil under reclamation vis-a-vis State and district average (kg/ha)

Stat	Category	Paddy		Wheat	
		I	V	I	V
Haryana	Reclaimed soil	3150	4850	1340	2720
	District. Karnal	2052	2783	2153	2671
	Haryana State	2059	2607	1979	2524
Punjab	Reclaimed Soil	3140	5150	1670	2610
	District. Kapurthala	2758	2913	2148	2611
	punjab State	2553	3144 *	2375	3005 *
Uttar Pradesh	Reclaimed Soil	3360	3030	740	1380
	District. Hardoi	1275	NA	1955	NA
	Uttar Pradesh	1361	NA	1934	NA

Note : 1. I and V refer to the first and fifth year of reclamation.
2. (*) refers 2nd year of reclamation.

drainage and chemical regeneration of such lands.

2) Saline soils A high water table has been observed to be often associated with salinity in the semi-arid, and coastal areas of India. The important features are :

a) Some of the outreach programs of the Central Soil Salinity Research Institute, Karnal, revealed that the salt concentration in the top 15 cm layer ranges from 20 to 100 ds/m. Groundwater quality varies from 10 to 40 ds/m. The main drainage objective in India is, therefore, desalinization and not lowering of the water table alone as is the case in humid areas and European countries.

b) The drained water is of poor quality and environmentally undesirable. Disposal of this water is the main issue. Since most of the salt-affected soils are land-locked and several hundred km away from sea, disposal of poor quality drained water has been posing environmental problems. Management of these soils are under investigation along the lines following :

1 Disposal of drainage waters into canals/rivers without creating pollution problems.

2 Elimination of salts from the system through evaporating basin technique (Gupta and Oosterban, 1987).

3 Developing varieties and agronomic practices which permit management of these soils at relatively higher salt concentrations (Misra and Singh, 1988 ; Singh, 1988).

4 Factors like evapotranspiration and variability in drainable pore space have been identified for optimizing drainage designs.

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Discussion

Dev, G, (India) : The possibilities of high yield in India (16 ton/ha/year of rice and wheat) are evident from work by ICRISAT, work by Maximum Yield research conducted by the Potash and Phosphate Institute of Canada and by national demonstrations. Then what are the constraints which limit total food grain production in the county and prevent it from showing the desired results.

Answer : The comparison of crop yields achieved at Agricultural Experiment Stations and the National Demonstrations with those in various States of India and also the National Average reveals that on account of various compulsions/limitations with the farmers representing various levels of the socio-economic strata of our rural society, we are realizing only 10 to 60% of the potential yields of improved varieties with application of the recommended packages of crop production technologies. These constraints can be classified under various sub-systems such as social, economic, cultural, administrative, institutional, legal, legislative and technological. It is only through improvements in the support systems to production agriculture and appropriate agricultural policies that we hope to bridge the above gaps in crop yields.

Khanna, S. S. (India) : It is indeed heartening to hear your lecture. I would like to know how you intend to achieve 250mt and 450mt food grain production by 2000 and 2050AD, as indicated, when the growth rate thus far has been 2.6 on a long-term basis, 2.9 in the 1980s and is projected to be 3.5% per year?

Answer : It is only through gradual improvements in crop productivity that we intend to achieve the projected production targets which in turn are related to the level of management of agricultural production systems unique to various eco-situations in India.