Roles of Agriculture (ROA)

India Environment National Assessment

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Environmental Roles of Agriculture in India

The environmental impacts generated by agricultural activity could be global or regional or national or local. However, they are site-specific and tend to vary with farming systems, technologies used and other response/choices of the individual producers. These environmental roles could be positive or negative. With the ROA project focusing more on the positive externalities of agriculture on the environment, an attempt is made to identify and assess the mitigation of negative impacts of agriculture in addition to other issues.

This module has two major parts :

Part I - National Assessment

Assessment of the environmental roles of agriculture at the national level disaggregated into major farming systems and agro-ecological zones, based on secondary data and existing studies.

Part II – Field Study

Measuring and valuing specific environmental externalities associated with representative farming systems by adopting on-site studies and questionnaire surveys.

The following methodologies and approaches would be adopted in realizing the above.

1. Part I - National Assessment -

In this part of the study, the linkages between agriculture and environment would be built on the strength of existing studies and secondary data at the national level. Both negative and positive environmental roles of agriculture would be identified disaggregated by major farming system based on dominant farming practices and agro-ecological zones.

Careful attention is given to connections between agricultural growth and environmental externalities, by dominant farming systems (two or three), small holder cultivation, macro and sectoral policies. A multi-dimensional matrix is being prepared for the compact presentation of agriculture-environment linkages. A wide range of farming systems viz. rice-wheat, rice-rice etc., are considered in this part of study. The national assessment has taken into account both negative and positive externalities.

2. Part II – Field Study

Selection of Farming System

The farming system most dominant in the Indo-gangetic plains (IGP) of India was selected for study. IGP is the most fertile region of India and has contributed to its food security. This Rice Wheat system (RW) contributes about 1/3 of the total cereal production. Therefore, RW system was chosen to carry out the identification and assessment of various environmental impacts of agriculture.

Selection of Sites

Two sites have been selected for the chosen farming system to capture a wide range of environmental roles of agriculture. We have selected the role of improve technologies to capture the environmental impacts. The impact of zero tillage technology in reducing the negative environmental impacts was studied. Further, the farmers' perception towards this technology was also recorded so as to see the possibility of its expansion in other areas and cropping systems. A primary survey was conducted for the proposed objective. The sites were selected from two states, one at a very advanced stage of agricultural mechanization and intensification and another at a lower level of agricultural development. These states were Haryana, which harnessed the early benefits of green revolution, to represent the developed and irrigated agriculture and the other state was Bihar, where the spill over effects of the green revolution is still percolating down, to represent the lower level of agricultural advancement. One district each from Haryana and Bihar were selected. From the selected districts equal numbers of both adopters and non-adopters of zero tillage technology were selected.

3. Selection of Environmental Externalities

The first stage of part I includes an overview of all possible categories of environmental externalities including both positive and negative, viz. soil quality, water quality(water retention, flood protection, water recharge and pollution etc.), biodiversity (conservation of wildlife), air quality (reduction of GHG, carbon sequestration) and rural amenities. The second stage includes the selection of few externalities based on the farming systems selected and also on the national commitments at international platforms. A detailed analysis is carried out on the selected list of externalities.

4. Assessment and Quantification of Environmental Impacts

Valuation of environmental role of agriculture involves two steps. Initially the physical/biological linkages between agriculture and the environment is established. In the second step physical valuation of the impacts are carried out. Since environmental effects are long lasting, second hand information are also used to the extent possible.

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Executive Summary

Agriculture draws from and impacts the environment in multiple domains –soil, water, air and biodiversity. The present work tries to identify the possible linkages (both positive and negative) of various agricultural production activities with the environment. We also document the extent of impact in terms of changes in soil quantity and quality, changes in water quantity and quality, the impacts on air and biodiversity.

An assessment is made at the national level of the various impacts on the above four domains by classifying Indian agriculture into five agro eco systems (AES) – rainfed, irrigated, arid, hill and mountain and coastal. It's only by understanding regionally the existing natural endowments and constrains and also the socio-economic characteristics that the environmental impacts can be placed in a meaningful perspective. Thus, poverty and rainwater management can have important implications for rainfed AES, salinity and waterlogging induced by large irrigation projects are important in arid and rainfed AES, water depletion and soil deterioration is important in the irrigated AES, wind erosion due to mechanization is important in the arid AES, soil erosion due to shifting cultivation is important for hill and mountain AES and water pollution due to aquaculture is an important issue in coastal AES.

Documentation is made of the available estimates of degradation in particular AES at the macro level and where such estimates are not possible indicative estimates from experimental plot level studies have been stated. Then we survey the practices and systems that have been developed to combat the above negative impacts of agriculture. Such practices include soil and water conservation measures, integrated watershed management, alternative land uses, integrated pest and nutrient management. Their benefits in terms of reduction in resource degradation are stated.

The last section of this report presents a review of policies and discussion on their possible implications for various domains of the environment. Finally, the policy and environmental interaction is presented as an indicative matrix of policies and their implications for the environment.

Section A: Environmental Impacts of Indian Agriculture

1. Introduction

This report consists of two parts – national assessment and a case study. The present work is a national assessment of the impacts of Indian agriculture on environment due to various farming practices. It presents an overview of Indian agriculture in terms of different agro eco systems and ensuing impacts within each system due to human intervention. It also presents a brief note of the emerging initiatives for conservation. This report begins with a brief review on of various classifications in Indian agriculture that would allow a systems perspective. It further looks at various environmental impacts arising from agriculture in the domains of soil, water, air and biodiversity with the specificities occurring in each agro eco system. Later section of the report presents different policy initiatives undertaken with regard to agriculture and their possible impact on the environment. Finally, the possible impacts of various policies on environment are presented in the form of a matrix.

The national assessment provides the necessary information for the selection of an appropriate Agro eco system (AES) for the quantification of environmental impacts. We choose the irrigated AES, which is a dominant contributor in terms of agricultural production, as a case study for the quantification of environmental impacts. This is also a region where major technological interventions have taken place in terms of the green revolution. Environmental impacts due to the changes in agricultural practice in this AES are well documented. In the recent past there has been a concern about the fall in agricultural productivity in this region, which could be possibly attributed to environmental degradation. This has important implications for food security and also the sustainability of the production base. Thus, the irrigated AES where the Rice-Wheat (R-W) cropping system is predominant was chosen for the case study to measure and document the environmental impacts (both negative and positive) of agriculture.

1.1 Why a system perspective

Agriculture varies widely depending on the natural and socio-economic endowments of every region. Policy making in agriculture at an aggregate level without giving due consideration to the specific constraints and requirements of each region can and has lead to an array of environmental and social problems. Thus, a systems perspective allows in understanding each system according to its broad homogenous features in a particular region. Moreover, since environmental impacts are primarily dependent on resource utilization patterns, we need to look beyond an agro-climatic approach and look for a classification that enables us to characterize agriculture according to the various production patterns in each zone.

1.2 Systems Classification in Indian Agriculture

Various attempts have been made at characterizing Indian agriculture in terms of agro-climatic and agro-ecological zones with respect to soils, climate, physiography and natural vegetation for macro-level planning on a scientific basis. Some of the important attempts made in this line –

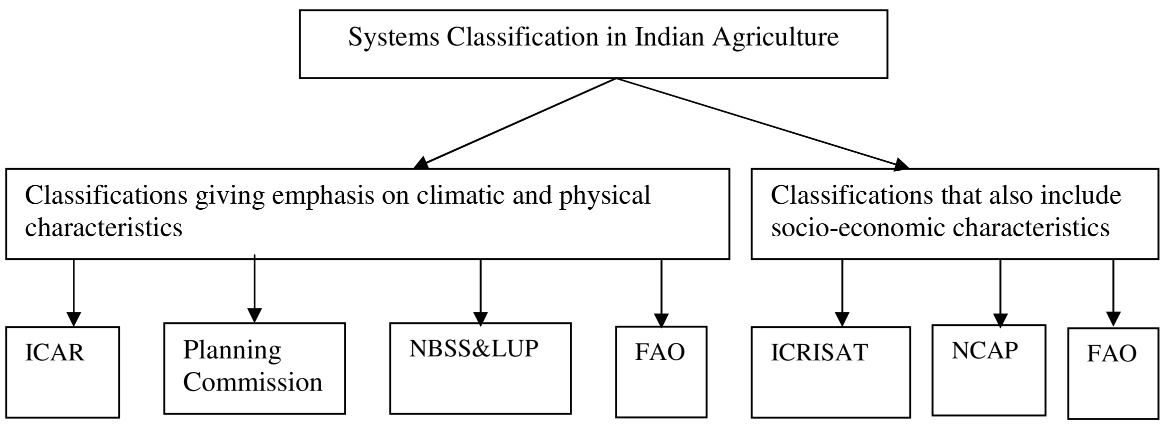

Figure 1: Systems classification in Indian agriculture

Various classifications given by Indian Council of Agricultural Research (2000), Planning Commission (1989), National Bureau of Soil Survey & Land Use Planning (1992) and Food and Agriculture Organization etc. have attempted at agro-climatic or agro ecological zoning. All of them have laid emphasis to the physiography, soils, climate, and length of growing period, available soil moisture and other biophysical indicators. However, farmer's choices on cropping sequences are conditioned by his own socioeconomic considerations just as much as agro-ecological factors - a fact ignored by agricultural classifications based solely on the latter criterion. Thus, classifications of both International Crop Research Institute for Semi-Arid Tropics (ICRISAT, 1999) and National Centre for Agricultural Economics and Policy Research (NCAP, 2001) have tried to move towards a classification driven by agricultural activity. Further, both have delineated production systems. FAO (2001) has identified eleven farming systems[1] in south Asia on

[1] Farming system is defined as a population of individual farm systems that have broadly similar resource bases, enterprise patterns, household livelihoods and constraints, and for which similar development strategies and interventions would be appropriate.

the basis of the available natural resource base, the dominant pattern of farm activities and household livelihoods, including relationship to markets, and the intensity of production activities.

1.3 Agro Eco Systems and Production System Classification of NCAP

This typology was developed for the National Agricultural Technology Project (NATP) and tried to incorporate key elements of all the past approaches using district level data. According to NCAP an agro-eco region or agro-ecosystem (AES) is a homogenous geographical area where the production environment of the region in terms of agro-climate, resource endowments and socio-economic conditions is homogenous and majority of farmers has similar production constraints and research needs. Accordingly, the entire country has been divided into 5 broad agro-ecosystems namely Arid, Coastal, Hill and Mountain, Irrigated and Rainfed. A sub classification of 14 production systems has been made based on the most important crops identified in each region. Figure 1 and 2 presents the maps of agro-ecosystems and respective production systems.

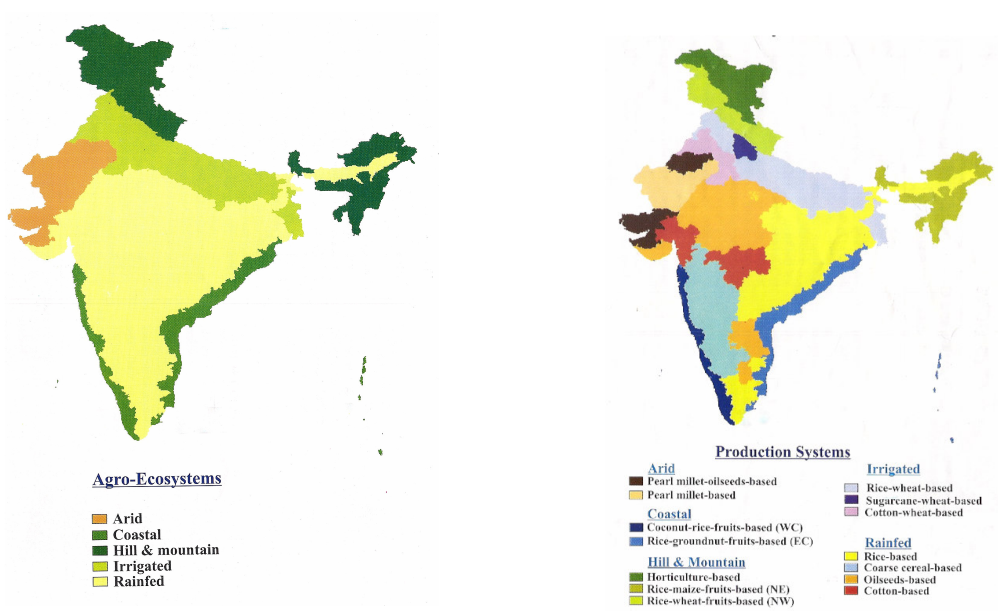

Figure 2: NCAP classification of Indian agriculture (a) Agro Eco Zone (b) Production systems

1.4 Agro-Eco Systems and their Characteristics

Population, area and density of population according to the census 2001, and the total cropped area (1997-98) under each AES have been calculated and tabulated in Table 1, which also gives a characterization of the agro eco systems in terms of certain relevant parameters.

The arid and coastal ecosystems occupy the smallest areas. However the arid ecosystem supports about 30 million population where as the coastal eco-system supports about 139 million. The coastal and the irrigated systems have high population densities but the rainfed system covers about 54% of the land area and also cropped area and supports about 44 % of the population. Hence, the rainfed system is the most important system in India followed by the irrigated system, which support 35% of the population and spread over 15% of the total land area.

The hill and mountain system has comparatively the least area under crop production and the net cropped area at 18% while the irrigated areas have the most area under crop production at 68% while the rainfed areas have about 52% of the land under crop production. Share of the rainfed AES to the national NCA is highest at 60%. The hill regions also have the highest area under forests at 32% followed by coastal regions. After the irrigated ecosystem, which has irrigation intensity of 64%, the irrigation intensity is high for coastal regions at 47%. Livestock contributes significantly to agricultural output in all the production systems though it is highest for arid regions at 49%. Irrigated and Coastal ecosystems are high input use and high productivity regions while Rainfed and Arid ecosystems are low input use and low productivity regions. Pearl-millet and horticulture based production systems of Arid and Hill-agro ecosystems, respectively having low productivity and high incidence of rural illiteracy. Coastal regions enjoy much better infrastructure in terms of higher road density (km road length per square kilometer of area) closely followed by Irrigated and Rainfed regions. Rural illiteracy is high in all regions with arid regions leading the list with 73% illiteracy. The value of agricultural output per capita works out to be the greatest for irrigated areas, followed by coastal and rainfed regions.

Table 1: Characterization of agro-ecosystems and production systems (Number of districts, population and area for year 2001 and the other characteristics relate to the triennium average ending 1994-95)

Agro-ecosystem/ Production system	Number of Districts	Area (ha)	Population		TCA (ha) (1998-99)	NCA as % of GA*	Forest area as a % of GA	Irrigation intensity (GIA as % of GCA)	Rainfall (mm)	NPK use (kg/ha)	Road density+	Rural illiteracy (%)	Major pulse crop	Value of agricultural output		Share of livestock in total value of output	Major Livestock Activities
			In Million	Density Per Sq.Km.										Rs/ha	Rs/ capita		
Arid	**16**	**28072**	**30.32**	**108**	**14699**	**44(8)**	**4**	**18**	**518**	**22**	**17**	**73**	**Greengram**	**907**	**454**	**49**	**Sheep+Goats**
Pearl millet based	9	14914	16.45	110		46(4)	3	19	472	9	16	77	Greengram	591	315	55	Sheep
Pearl millet-oilseeds based	7	13158	13.88	105		42(4)	5	17	585	35	17	67	Chickpea	1327	659	43	Sheep
Coastal	**67**	**27638**	**139.34**	**504**	**14284**	**41(6)**	**24**	**47**	**1589**	**101**	**83**	**57**	**Greengram**	**5775**	**879**	**17**	**Buffalo+Cattle+Sheep**
Rice-groundnut-fruits based	41	18267	75.32	412		45(5)	21	51	1068	107	86	59	Greengram	6022	970	15	Buffalo+Sheep
Coconut-rice-fruits based	26	9371	64.02	683		25(1)	33	15	2827	54	73	45	Blackgram	4392	531	25	Cattle+Buffalo
Hill & Mountain	**98**	**42355**	**50.98**	**120**	**5879**	**18(3)**	**32**	**19**	**1825**	**40**	**15**	**61**	**Blackgram**	**4027**	**706**	**36**	**Sheep+Goats+Cattle**
Horticulture based	4	7938	0.35	4		22(<1)	<1	41	<150	19	3	78	Nil	3696	457	25	Sheep
Rice-maize-fruits based	60	21537	25.52	118		13(2)	20	9	4008	31	4	65	Blackgram	4853	814	23	Sheep
Rice-wheat-fruits based	34	12880	25.12	195		14(1)	51	19	>1500	52	16	55	Blackgram	3357	619	51	Cattle+Buffalo
Irrigated	**158**	**48585**	**358.39**	**738**	**53160**	**68(23)**	**7**	**64**	**725**	**104**	**57**	**69**	**Chickpea**	**4941**	**924**	**34**	**Buffalo+Goats**
Rice-wheat based	129	37398	305.63	817		66(17)	8	62	752	108	62	69	Chickpea	4915	828	34	Buffalo+Goats
Cotton-wheat based	19	8365	28.10	336		76(4)	3	63	430	74	39	66	Chickpea	4470	1733	39	Buffalo+Sheep
Sugarcane-wheat based	10	2822	24.65	873		74(2)	7	85	1080	142	34	70	Blackgram	6488	1194	29	Buffalo
Rainfed	**254**	**169978**	**447.99**	**264**	**104598**	**52(60)**	**18**	**26**	**1027**	**51**	**55**	**65**	**Chickpea**	**2724**	**776**	**28**	**Cattle+Sheep+Goats**
Rice based	121	72112	196.44	272		44(22)	23	28	1140	43	65	69	Greengram	2709	679	27	Cattle+Sheep+Goats
Coarse cereal based	38	31925	89.77			62(14)	12	21	949	65	70	59	Pigeonpea	2873	984	28	Sheep+Goats+Cattle
Oilseed based	68	47984	104.06	217		53(16)	15	28	846	46	31	70	Chickpea	2809	783	31	Buffalo+Cattle+Sheep
Cotton based	27	17957	57.71	321		65(8)	15	20	1124	64	46	55	Pigeonpea	2353	733	26	Buffalo+Goats

Source: NCAP, 2001

TCA: Total Cropped Area; NCA: Net cropped area; GA: Geographical area; GIA: Gross irrigated area; GCA: Gross Cropped Area; EC: East Coast; WC: West Coast; NE: North East; NW: North West.

Figures in parentheses are percentage shares of agro-ecosystem/production system to the national NCA; + Km/100 sq km of GA

Figures related to triennium average ending 1994-95 have been taken from NCAP, 2001.

2. Linkage between Agriculture and the Environment

Environmental impacts are the result of intensification of agriculture which signifies unsustainable resource use and use of modern inputs like chemicals and machinery. Water, soil, air and biodiversity are the common domains for all agricultural practices and any environmental impacts resulting from agriculture would reflect in these domains. Thus environmental impacts arising from agriculture are presented under these domains of impact (Air, Bio-diversity, Soil and Water).

Subsequent to the green revolution (GR), Indian agriculture has undergone many changes impacting the environment and natural resources. These changes, which acts as drivers for environmental impacts are AES specific and even production system specific in some cases. Therefore, presentation of environmental impacts under the respective domains is further segregated into agro-ecosystems. Following are the indicative list of drivers under each AES and most of the environmental implications presented in this report are resulting from these drivers in the respective Agro-Eco systems.

Arid System (AES)
Large Irrigation Projects
Grazing and common lands being put under crops
Cropping pattern towards water intensive crops
Growth in livestock
Mechanization of agriculture

Coastal System (AES)
Conversion of forestland to agricultural land/ -aquaculture
Growth of modern/intensive aquaculture
Low level of fertilizer use
Coir production

Hill & Mountainous System (AES)
Shifting cultivation
Conversion of forest land to agricultural land
Mono cropping
Overgrazing

Irrigated System (AES)
Predominance of rice-wheat sequence
Expansion of irrigation
Use of chemical fertilizers and pesticides
Burning of rice-wheat straw

Rainfed System (AES)
Spread of agriculture into marginal lands
Inability to invest in adequate inputs/technologies
Spread of irrigation
Rainy season fallow
Changes in mixed systems
Limited scientific progress & infrastructure

In the following paragraphs impacts under each domain of impact are presented covering all the AES under each of them. Policy interventions are also potential drivers. Such policy and environmental interactions are presented in a separate section.

2.1 Soil related externalities arising from Indian agriculture

Land degradation implies temporary and permanent regression from a higher to lower status of productivity through deterioration of physical, chemical and biological aspects. The physical processes that constitute land degradation are mainly water and wind erosion, compaction, crusting and waterlogging. The chemical processes include salinization, alkalization, acidification, pollution and nutrient depletion. The biological processes on the other hand are related to the reduction of organic matter content in the soil, denudation of vegetation and impairment of activities of microorganisms and fauna. Table 2 presents the details of human induced soil degradation in India.

Table 2: Extent of soil degradation (human induced) under different degradation types

Degradation type	**Degree of degradation (million ha)**					**Area affected**
	Slight	***Moderate***	***Strong***	***Extreme***	***Total***	**%**
Water erosion	27.3	111.6	5.4	4.6	148.9	45.3
a. Loss of topsoil (Wt)	27.3	99.8	5.4	-	132.5	40.3
b. Terrain (Wd) deterioration	-	11.8	-	4.6	16.4	5
Wind erosion	0.3	10.1	3.1	-	13.5	4.1
a. Loss of topsoil (Wt)	0.3	5.5	0.4	-	6.2	1.9
b. Loss of topsoil / terrain deterioration (Et/Ed)	-	4.6	-	-	4.6	1.4
c. Terrain deformation /over blowing (Ed/Co)	-	-	2.7	-	2.7	0.8
Chemical deterioration	6.5	7.3	-	-	13.8	4.2
a. Loss of nutrient (Cn)	3.7	-	-	-	3.7	1.1
b. Salinization (Cs)	2.8	7.3	-	-	10.1	3.1
Physical deterioration					16.6	3.5
a. Waterlogging (w)	6.4	5.2	-	-	11.6	3.5
Total (affected area)	36.8	137.9	8.5	4.6	187.8	57.1
Land not fit for agriculture					18.2	5.5
Soils with little/no degradation problem					90.5	27.5
Stable terrain - Under natural condition (Sn)					31.2	9.8
Total geographical area of India					328.7	100

Source: Sehgal and Abrol (1994)

As can be seen from the table above, *water erosion* is by far the most important soil degradation problem in India. 45% of the area is affected by it. *Water erosion* is distributed through out the country; its most severe form is found in parts of Uttar Pradesh, Madhya Pradesh, Rajasthan and Gujarat. *Wind erosion* is confined to desert regions of Rajasthan and Gujarat. *Salinity* is a severe problem affecting mainly irrigated areas. Lands with *nutrient losses* are small in spite of the fact that large areas of rainfed soils are naturally deficient in nutrients and also receive only a small application of fertilizer and organic matter (Kerr, 1996).

In economic terms the country looses a phenomenal amount of Rs. 285.51 billion annually at the current level of total *land degradation* and at current prices. At constant (1979-82) prices the annual economic loss is Rs. 89.38 billion. In per hectare terms, the economic loss due to *land degradation* is Rs. 1521 at current prices and Rs. 476 at constant prices annually. State wise the magnitude of loss is high in AP, Gujarat, Karnataka, Maharashtra, MP, Rajasthan, TN and WB. These states together account for nearly 73% of the total loss in the country. Among the 17 major states of the country *land degradation* in physical terms, the highest is in MP (26.2 million ha) and the lowest in Punjab (0.9 million ha). The estimated economic losses resulting from various sources of land degradation in Madhya Pradesh account for Rs. 33.37 billion at (1995-97 prices) and losses in Punjab work out to around Rs. 4.84 billion at current prices annually (Singh et al, 2003).

2.1.1 Soil Erosion

Of all the human induced land degradation problems, the permanent loss of soil productivity due to erosion is the worst on a global scale. Accelerated erosion occurs nearly everywhere agriculture is practiced and is irreversible in nature. Loss of nutrient rich fine soil not only reduces productivity, but also results in silting of water bodies and streams and induces release of soil carbon from particulate organic material, which contributes to global warming. Asia has suffered the most from human induced *soil erosion* than any other continent of which agricultural activities account for 25%[2] (Wani et al, 2001).

On an average, nation wide soil loss rate is about 16 tons/ha/year with about 29% being permanently lost to sea and another 9% deposited into major reservoirs reducing their capacity by 1-2% annually. This adds up to 5334 million tons of soil eroded every year (Dhruvanarayana and Ram Babu, 1983). This is much higher than the acceptable rate of erosion at 11 tons/ha/year (El-Swaify et al, 1982). According to another estimate, India is losing about 8.2 million tons of nutrients every year as a result of soil erosion (Prasad and Singh, 1990). According to the National Commission on Floods, the country suffered losses totaling Rs. 3180 crores during 1976, 1977 and

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[2] It has been estimated that globally among the causes of soil degradation, overgrazing accounts for 34% followed by deforestation 30%, agricultural activities 28%, overexploitation and industrialization are responsible for 7 and 1 per cent of the degraded land, respectively (UNEP, 1993).

1978. The losses were Rs. 2,292 crores in 1983 and Rs. 1650 crores in 1984 (Prasad and Sharma, 1993).

The annual *water erosion* rate values ranged from less than 5 tons/ha/yr for dense forest, snow clad cold deserts, and the arid region of western Rajasthan to more than 80 tons/ha/yr in the Shiwalik hills. Ravines along the banks of the Yamuna, Chambal, Mahi, Tapti, and Krishna rivers and in the shifting cultivation regions of Orissa and the northeastern states also revealed soil losses exceeding 40 tons/ha/yr. The annual erosion rates in Western Ghats coastal regions varied from 20 to 30 tons/ha (Singh et al, 1992).

Erosion rates in the black soil region (vertisols) of the country was reported at 20 tons/ha/yr while red soils of Chhotnagpur plateau recorded a soil loss value of 10 to 15 tons/ha/yr. The hilly regions have rates up to 20 tons/ha/yr. Erosion rates on alluvial Indo-Gangetic Plains of Punjab, Haryana, Uttar Pradesh, Bihar and West Bengal are moderate (5-10 tons/ha/yr). The salt-affected saline and sodic soils of these plains were within limits of 5 tons/ha/yr (Singh et al, 1992).

Erosion rates in the black soil region (vertisols) of the country, occupying a 64-million-ha area in Karnataka, Andhra Pradesh, Madhya Pradesh and Maharashtra states were around 20 tons/ha/yr (Singh et al, 1992). However, this estimate is much higher by Dhruva Narayana and Ram Babu (1983) at 64 tons/ha/yr while runoff is estimated as high as 40%. On an average about 24 kg N/ha is lost per year (Kanwar et al, 1989). Krantz et al (1978) argued that soil erosion due to rainy season fallowing is the reason why the proportion of Vertisols area classified as deep in Sholapur district of India has shrunk from 46% to only 29% in a span of 75 years.

Of the 286,000 km^2 of Indian deserts, *wind erosion* is active over 129,000 km^2. The removal and deposition of sand during a 70-day period from April to June may vary from 1,449 to 5,560 tons/ha (Singh et al, 1992). However, this rate can differ for different land uses. *Wind erosion* is more severe for cultivated lands as compared to pasturelands and within cultivated lands, it assumes much greater dimension for lands that are tilled and disc ploughed (Dhir et al, 1992). During a sand storm of 1985 in the Jodhpur-Barmer tract, the following ranges of *wind erosion* were noted in cultivated and pasturelands.

Table 3: Wind erosion in relation to land use in western Rajasthan

Land use/Management	Soil loss (tons/ha) Range	Mean (tons/ha)
Cultivated		
Long fallow	124-320	207
Untilled since previous crop	220-377	283
Tilled	756-1180	932
Disc ploughed	2630-3160	2837
Pasture land		
Undegraded	Nil	Nil
Degraded	217-683	472

Source: Dhir et al, 1992

In the Arid zone, the share of pastureland has been decreasing over time due to the increased cultivation activity. This clearly contributes to the soil erosion. Adaptation of disc plaguing adds to the severity of the problem with very high *soil erosion* rates.

Soil erosion is a major problem in the arid, rainfed and hill regions in India. Change in land use practices from forests and grazing lands to agriculture, introduction of tractors and disc ploughs in the arid region, practices such as shifting cultivation in the hilly regions and leaving rainy season fallows in the rainfed areas are the major causes of soil erosion in these farming systems. Erosion rates are much higher in Hill and Mountainous AES in general and in Shiwalik hill and shifting cultivation regions of Orissa in particular. *Soil erosion* is less intensive in Indo-gangetic plains.

The northwestern hills of Jammu and Kashmir, Himachal Pradesh, and Uttar Pradesh and the northeastern hills of Bengal, the northeastern states and foothills of Himalayas and the Doon Valley produced 20 tons/ha/yr of soil loss while a rate of 80 tons/ha/yr was reported in the Shiwalik hills.

Quantitative facts on soil erosion hazards from *soil erosion* studies in the hilly region indicate that except forestland use, none of the land uses are safe and lead to *land degradation* process. About 4.9 million ha is degraded by shifting cultivation (Indiastat, 2001). Estimates reveal that nearly 88.3 million tons of soil is lost annually as a result of shifting cultivation in North East Hill (NEH) region (Sharma and Prasad, 1993) the rate of loss ranging from 30 to 170 tons/ha/yr (Singh and Venkataramanan, 1990; Satapathy and Sarma, 2001). In another study, *soil erosion* under the first and second year of shifting cultivation, from an abandoned field, and from a bamboo forest is reported to be 146.6, 170.2, 30.2 and 8.2 tons/ha/yr, respectively. It is estimated that nearly 18.1 million tons of soil is eroded and 603 tons of organic carbon, 97 tons of available P_2O_5 and 5690 tons of available K_2O are lost annually from the land subjected to shifting cultivation (Prasad et al, 1981). Grass cover would reduce erosion rates to 10.83 tons/ha/yr while natural bamboo forest in a field would cut it to 0.04-0.52 tons/ha/yr (Satapathy and Sarma, 2001). Table 4 presents the details of *runoff* and *soil losses* under different land use patterns in Hill and Mountainous AES.

Under tea plantation 15.8% *runoff* and *soil loss* of 16.4 tons/ha/yr (E Ghats) were reported while it was the lowest for land use under secondary forest with *runoff* at 0.26% and *soil loss* 0.28 tons/ha/yr (NEH). Intensified tea cropping in Hill and Mountainous zones (AES) lead to increased *runoff* and *soil losses*.

Table 4. Runoff and soil loss under different land uses

Land use	**Watershed area (ha)**	**Runoff (%)**	**Soil loss (tons/ha)**
Livestock fodder	1.39	1.32	0.16
Forestry	3.80	7.22	0.07
Agro-forestry	2.4	3.15	0.07
Agriculture	0.64	1.47	0.33
Agri-horticulture	1.58	1.71	1.22
Horticulture	3.13	3.28	4.37
Natural fallow	1.03	1.53	Nil
Shifting cultivation	0.52	15.6	40.8

Source: Narain et al, 1994

Estimates made for Doon valley show that the rate of soil loss for dense forest was 3.49 tons/ha while that of open forest was 34.54 tons/ha and under scrub/grassland it was around 620 t /ha. However cultivation in the hills had a very high rate at 763 tons/ha (Kumar, 2001).

Due to the increased demands, land use change towards cultivation has been observed in Doon Valley. Hill cultivation accounted for more than 35% of total *soil loss* in the Doon valley and the *soil loss*, which was about 5 million tons in 1972 has gone up to 9.9 million tons in 1994. Major nutrient loss due to soil erosion in 1994 was segregated as loss of Nitrogen at 64820 tons, phosphorous at 1190 tons, potassium at 241752 tons and organic carbon at 509328 tons. Resource value of soil erosion in the valley based on replacement cost approach was at Rs. 2,61,770 crores[3] at 3% discount rate over 10 years. The annual (one time) cost of soil erosion based on loss in productivity lies between Rs. 1715/ha and Rs. 3427/ha while the cost on the basis of resource value in terms of lost nutrients, comes out at Rs. 21,583/ha (Kumar, 2001).

2.1.2 Salinity and Waterlogging

The irrigation potential in India through all major, medium and minor projects increased from 22.6 million ha in 1950-51 to 79.5 million ha in 1989-90, showing one of the highest annual rate of irrigation development in a single country. The country has now the second highest total net area under irritation next to China, accounting for about 25% of the world's irrigation. However, faulty management of irrigation water has resulted in widespread occurrence of the twin problem of *waterlogging* and *soil salinity* in several irrigation projects, particularly in the arid and semi-arid areas (Joshi & Agnihotri, 1984).

Once the ground water table rises within 2-3 meters of the soil surface, it contributes significantly to evaporation from the soil surface and water uptake by plants. Evaporation from the soil surface and plant water uptake leaves the soluble salts in the profile resulting in their gradual accumulation in the root zone such that in course of time soils become salinised. In semi arid and arid regions soluble salts are often present in substantial quantities in the soil profile and also in ground water. The rise of water table in such areas brings in serious problems of *secondary salinization*. In the initial years, crop yields get affected, later salinity appears as patches in otherwise normal fields and when the severity of the problem is high, lands have to be abandoned because they become unproductive.

The continued rising trend in the water table in most command areas of arid and semi arid regions resulting from a disturbance of hydrological balance due to recharge far exceeding discharge is causing extensive *waterlogging*. Large areas of land even in newly commissioned projects like Sharda Sahayak (UP), Sri Ram Sagar (AP), IGCP (Rajasthan) and Tungabhadra (Karnataka) are going out of cultivation because of *waterlogging* and *salinity*. Table 5 presents the details of *soil salinity* and *waterlogging* in selected irrigation projects in India.

[3] At 1994 prices.

Out of a total irrigation potential of 1.35 million ha in the Sharda Sahayak Command area (Irrigated AES), an area of 0.75 million ha has water-table within 2 m from the surface and the area with water-table less than 1 m almost doubled in five years (1980-85) from 17,000 ha to 32600 ha and the area with water-table within 1.5 m increased by about three times, from 0.31 million ha to 0.75 million ha showing a high rate of water table rise. In the year 1976, there was no area, which had a dept of water table less than 1.5 m and only 6000 ha less than 2 m (Yadav, 1993). The water table rose at an average annual rate of 90 cm following introduction of Bhakra canal in 1963 at the experimental farm of the Haryana Agricultural University (Yadav, 1996). In the Indira Gandhi Nahar Project initiated in 1961 to provide irrigation to the desert districts of Bikaner and Jaisalmer in Rajasthan, rise in water table at an average annual rate of 0.8 m between 1981-84 was recorded. In stage I command, the area with water table within 3 m increased from 260 km^2 to 504 km^2 during that period. In Chambal Irrigation Project too there were extensive problems of waterlogging and soil salinity. Another estimate puts the rise in water table in the IGNP and in the adjacent command areas of the Ganga and Bhakra systems in Rajasthan at rates ranging from 0.2 to 2.0 m/yr (Barner and Pathak, 1987; Hooja et al, 1998).

Table 5. Extent of *soil salinity* and *waterlogging* in selected irrigation projects in India (000 ha)

Irrigation project	State	Waterlogging	Soil Salinity
Sri Ram Sagar	Andhra Pradesh	70.60 (42)	1 (0.8)
Nagarjuna Sagar Right Canal	Andhra Pradesh	114 (24)	NA
Tungabhadra	Andhra Pradesh & Karnataka	4.65 (1.35)	24.48 (6.7)
Upper Krishna	Karnataka	59 (59)	28 (28)
Ukai-Kakrapar	Gujarat	16.25 (4.3)	8.29 (28)
Mahi-Kadana	Gujarat & Rajasthan	82.01* (16.8)	35.76 (7.3)
Malaprabha	Karnataka	1.05* (1)	-
Chambal	MP & Rajasthan	98.70 (20.3)	40(8.2)
Tawa	Madhya Pradesh	--	6.64(3.8)
Indira Gandhi	Rajasthan	43.10 (8)	29.11(5.4)
Sharda Sahayak	Uttar Pradesh	30 (28.3)	50*(4.7)

Figures in parentheses are the percentages of the irrigation potential created in the respective command areas. Compiled by Joshi (1984)
* Includes waterlogged and saline area

Increased irrigation for rice based cropping system further enhances the existing problem of *waterlogging* in coastal areas (Mishra, 1999). Coastal Orissa which mostly constitutes of alluvial plains when put to irrigation by the major river valley projects become highly *waterlogged* due to flow gravity, this is particularly noticed in the Paradeep to Chilka zone under the Mahanadi Delta Irrigation System Stage II. About 20% of the total area is waterlogged and about 1200 sq km has been moderately *waterlogged* due to agricultural activity. The total waterlogged area in the coastal area of the State is 60,50,000 ha and out of every 100 ha that have come under irrigation in the State about 8 ha every year have gone out of cultivation due to over irrigation (Mishra, 1999).

A major portion of the estimated 9.38 million ha inflicted by *soil salinity* and *sodicity* in the country occurs in the irrigated land (GoI, 1990). The potentially saline soils occupy vast tracts in the black soil region and in the Indo-gangetic plains and many of these areas were salinized when brought under canal irrigation. Prolonged use of poor quality water for irrigation can also cause salinity or sodicity.

It has been estimated that in the poor quality areas of Haryana the water table is rising by 0.15-1.0 m per year (FAO, 1985). In Haryana, up to 0.4 million ha already has high ground water levels and up to 1.5 to 2 million hectares may be affected by high water levels, waterlogging and in the long run, by soil salinization due to which a loss of Rs. 26.8 crores was estimated for the year 1982 and predicted it to rise to Rs. 71.9 crores by 2000 (Gangwar and Toorn, 1987; Joshi and Tyagi, 1991). In central-southern districts of Jind, Rohtak, Bhiwani, Hisar and Sirsa where most area is irrigated by canals there is a very fast increase in water table (8-22 cm/year) leading to waterlogging (624 thousand hectares) and salinization (526 thousand hectare). Unfortunately, most of the underground water in these districts is sodic/saline, which makes the reclamation of these soils more difficult. Already 73% of the salt affected soils of the state fall in these districts (Bhargava, 1988). The saline water belt of Punjab also shows similar trends, for eg. in Muktsar block of Faridkot district, the water table rose from 17 to 2 meters (Khepar and Kaushal, 1991) (Joshi and Tyagi, 1991). Sehgal et al (1985) noted that in Faridkot district of Punjab the salt affected area increased from 6000 ha in 1973 to about 82000 ha in 1984.

Salinity and *alkalinity* also leads to other forms of impacts. Grazing of forages grown on alkali soils results into alkali disease in animals locally known as “Degnala” or “Deknala” in Haryana and Punjab. Gupta (1988) indicated that injury may develop on sensitive plants when irrigated with water containing boron in excess of 3 ppm as in salt affected soils, boron may be to the extent of 10 ppm. Some of the calcareous alkali soils, particularly under *waterlogged* conditions contain excess of molybdenum. The plants may accumulate molybdenum in higher quantities toxic to cattle, which results in diarrhea, loss in body weight, and reduction in milk yield. This condition is known as “Teartness”. Nayyar (1977) reported that 17 to 43 per cent of berseem collected from different calcareous flood plains of Punjab had toxic levels of molybdenum.

In salt affected areas, particularly where ground water is also saline, fluoride toxicity may be found. According to Tewari (1988) 20% of the area in India can be designated as endemic fluoride and about 5-8 per cent of the Indian population is drinking water containing 1.5 mg/kg or more of fluoride. Gupta (1988) reported that the concentration of fluoride ranges from trace to >10 ppm in natural waters. The cases of fluorosis have been reported from Punjab, Haryana, Rajasthan, Bihar, MP and AP where soils, underground wares and plant materials contain excess of fluoride (Kanwar and Mehta, 1968; Susheela et al, 1987).

2.1.3 Soil compaction

Due to the increased use of saline groundwater (containing high residual sodium carbonate) for irrigation purposes, the soils develop a high pH of 8.9-9.8, nutrient availability declines and soils acquire unusual hardness and surface crusting takes place in the arid regions.

Seasonal cycles of puddling (wet tillage) and drying, over the long term, lead to the formation of hardpans in paddy soils. The productivity of the wheat crop is affected by its poor establishment following puddled rice. It increases bulk density of surface soil with consequent decrease in infiltration rate and also water absorption in deeper soil layers, which restricts prolification of wheat roots. Large scale adoption of rice-based cropping systems has increased this problem in the Indo-gangetic plain.

The following table (Table 6) presents various soil related issues observed in different agro-eco systems in Indian agriculture and the intensity of the problems with indicative figures collected from various studies in the literature.

Table 6. Indicative soil related environmental impacts resulting from various human interventions segregated into different Agro-eco systems in Indian agriculture

Agro Eco Systems	Particular practice (driver)/ Human interventions	Soil erosion	Rise in water table	Waterlogging	Soil Salinization	Nutrient Depletion	Chemical Pollution
Arid	• Wind erosion in tilled soils • Disc ploughed • Large irrigation projects	756-1180 tons/ha (-) 2630-3160 tons/ha (-)	0.2 to 2 m/yr (-)	Significant (-)	Significant (-)		
Coastal	• Increased irrigation • Mono cropping and low fertilizer use • Increased aquaculture			20% of the area (-)		Significant (-) Significant (-)	Significant (-)
Hill and Mountain	• Shifting cultivation • Hill cultivation in the Doon valley - dense forest - open forest • Tea cultivation - secondary forest • Land use change in doon valley	30 to 170 t/ha/yr 4.9 mill ha 88.3 mill t/yr 763 t/ha (-) 3.49 t/ha 34.54 t/ha 16.4 t/ha/yr (-) 0.28 t/ha/yr 5 mill t in 1972 to 9.9 mill t in 1994 & 20-80 tons/ha/yr (-)				603.13 t org C, 97 t available P_2O_2, 5690 t available K_20/yr Significant (-) Significant (-) Significant (-)	
Irrigated	• Increased canal irrigation • Subsidies on electricity		1 m/yr (approx)	624000 ha in few districts of Punjab (-)	Punjab – 6000 ha in 1973 to 82000 in 1982 (-)		Significant (-)

	• Grazing on saline zone in Haryana • Rising levels of saline waters • Installation of vertical wells in Punjab and Haryana saline zones		Drop in water table by 0.15-0.3 m/yr (+)					Alkali disease "Degnala" Molibdinam accumulation Flouride contamination
Rainfed	• Rainy season fallow	20-64 t/ha/yr					Significant (-)	

'-' indicates a negative impact and '+' indicates a positive impact

Source: Compiled by the authors

2.2 An over view of water related externalities arising from Indian agriculture

India with diversified rainfalls and soil types faces a wide variety of water related problems in Indian agriculture. Runoff losses, ground water depletion, waterlogging, reservoir siltation and non-point source pollution are some of the issues related to water in Indian agriculture.

India receives an annual average rainfall of about 117 cms. Out of total precipitation of 400 million hectare meters (Mha.m), 70 Mha.m is lost through evaporation and 150 Mha.m enters the soil mass, while the remaining 180 Mha.m goes as run-off, of which about, 160 Mha.m of excellent quality is lost into the sea. Of the total precipitation utilized, 92% is used for irrigation and only 8% is used for industrial and domestic needs. In India, about 8-9 Mha are ravaged by floods every year (Government of India, 1990). National availability of surface waters (119 Mha-m) and ground waters (69 Mha-m) is estimated at 188 Mha-m annually (CWC, 1988). Actually utilizable water resources, however, are only 110.85 Mha-m per year. Utilizable surface waters contribute 69.0 Mha-m, ground waters make up the balance of 41.85 Mha-m. Estimates suggest that only 32% of the annually exploitable ground water potential (13.5 Mha-m) is currently being used in different sectors (Gupta and Yadav, 1996).

Owing to faulty management roughly 70 to 75% of irrigation water diverted from reservoir to the farm is lost and not used by the crops, thereby resulting in very low irrigation efficiency (25-30%). India is one of the countries where water management is at its worst. Government of India has been spending considerable resources to improve the irrigation level and efficiency. By the end of VII Five Year Plan in 1989-90, the irrigation potential increased to 79.5 Mha from 22.6 Mha in 1950-51, and the ultimate potential after harnessing all sources is estimated at 113.5 Mha by 2010 A.D. Approximately, half of the cultivated land will still remain rain fed, thereby indicating the dire necessity of most efficient use of water to stabilize agricultural production in the non-irrigated areas.

2.2.1 Decline in water tables

State-wise ground water potential, ground water utilization and percentage distribution of low quality ground waters are listed in Table 7. Low quality groundwater constitutes around 32 to 84% of the total ground water development. Estimates suggest that of the present ground water development of 13.5 Mha-m/year, poor quality ground waters account for about 3.2 Mha-m/year (Gupta and Yadav, 1996).

Irrigated area has increased by 174% and presently covers 57 M ha. Net irrigated area has increased from 18% to 40% of net sown area from 1950-51. About 19 M ha area is irrigated more than once (1998-99). About 30% of the net irrigated area is by Government Canal irrigation, another 36% is under tube wells and 22% under other wells. Canal irrigation has fallen from 40 to 31%, while that of wells has increased from 29% to 58% and that of tanks has fallen from 17% to a mere 5% since 1950-51. Thus groundwater has been increasingly more exploited over the period.

Nearly 89.3 per cent of the total supply of good quality ground water resources are used in agriculture of the 55.2 million ha-m total water supply in 1990. However the current demand for fresh water is rising for domestic use, energy and industry and agriculture might have to depend on marginal quality waters for irrigation.

Table 7. Development of ground water resources and distribution of low quality water in states

State	Utilizable	Net draft	Potential available	Use of low quality ground waters	
(Mha-m/year)				Actual	Percent
Punjab	1.31	0.93	0.36	0.38	41
Haryana	0.88	0.61	0.27	0.38	62
Uttar Pradesh	9.27	2.68	6.59	1.28	47
Gujarat	2.03	0.69	1.34	0.21	30
Rajasthan	1.83	0.46	1.37	0.39	84
Madhya Pradesh	5.95	0.79	5.46	0.20	25
Karnataka	1.30	0.18	1.12	0.07	38
Maharashtra	0.45	0.66	2.80		
Tamil Nadu	2.69	0.99	1.70		
Andhra Pradesh	3.66	0.74	2.92	0.24	32
Bihar	2.86	0.69	1.34		
Others	2.15	0.09	2.06		
Total	42.29	10.01	32.28		

Source: Ministry of water Resources, GOI, 1988; adapted from Minhas and Gupta (1992)

Due to the increase in well irrigation, there has been a fall in the water tables in many areas. This has especially been noted in the irrigated belt of the Indo-Gangetic plain and also in the arid and semi arid areas.

The groundwater resources in large parts of Punjab and Haryana of late have been showing signs of over development. Of the 118 development blocks in Punjab and 108 in Haryana, about 56 per cent of the blocks in Punjab and 29 per cent in Haryana have been classified as 'dark'. The water table in vast portions of the region has already reached a level of more than 15-20 meters below the ground surface and is declining at the rate of almost one meter per year. The over development of groundwater resources in this semi-arid region with an annual average rainfall of about 600 mm has in large part been the result of large scale cultivation of such water intensive crops as rice and wheat and installation of a large number of private tube wells. The area under rice and wheat have increased from 47 per cent in 1970-71 to more than 70 per cent in 1990-91 for Punjab and from 28 to 60 per cent for Haryana in the same period. The large scale shifts in the cropping pattern towards rice-wheat have primarily been the result of its relative private profitability vis-à-vis alternative cropping systems (Malik, 1994).

According to State Ground Water Board in Rajasthan, 39% of the potential zone is already seriously over drafted (dark zone) and 6% is marginally so (grey zone). The overdraft is maximum in tracts where water quality is good (Dhir, 1993). The present practices of draft, viz. deepening of wells and use of powerful pumps to bore ground waters are unsustainable. Over exploitation of water has resulted in deterioration of the water quality and quantity in the wells of Jhanwar and Doli village. The share of farmers using engine/motors for lifting agriculture water has gone up from 4% to 24 % (Raina and Sen, 1991).

Bore irrigation in Punjab and parts of Haryana causes fall in groundwater tables by more than a meter each year while canal irrigation in Uttar Pradesh, Bihar and West Bengal has led to waterlogging and salinisation. The problem thus differs between lower Gangetic and Trans-Gangetic plain zones.

In Punjab there has been a significant decline in the area under waterlogging due to rapid growth in the utilization of groundwater through tube wells (Chopra 1990, Ramesh Chand, 1996), but now the state is facing a serious problem of ground water depletion. The water table is reported to be falling annually by 30-45 cm in the districts of Ludhiana, Patiala and Sangrur, which together contribute 30 per cent of rice and wheat production in the state (DRR 1991). A study of Sudhar block in district Ludhiana reported an increase in the number of tube wells from 2000 in 1965 to 65000 in 1980 resulting in a fall in the water table from 3 to 11m (Khepar and Kaushal, 1991). The water table in Punjab is receding at a rate of 0.3 to 0.5m per year (Joshi and Tyagi, 1991).

There are evidences of increase in number of tube wells in Haryana where the increase has been 18 fold during the last 25 years resulting in 328% increase in the total area irrigated by tube wells in this region. Due to this over exploitation of ground water in the North-eastern region of Haryana, there has been a lowering of water table at the rate of 12 to 33 cm per year (Chand and Haque, 1998). In Karnal and other places in Haryana too the magnitude of area under salt affected lands has considerably declined but there are signs of rapid depletion of ground water (Chaudhary and Harrington 1993). The water table in Karnal district fell from 4.8m in 1974 to 7.7m in 1989 (HSMITC, 1990).

Such observations are made in Western UP as well where the water table was found falling by 50 to 100 cm, annually. Due to this the farmers are compelled to lower their borings every third or fourth year (Ram and Sharma, 1997-98). In some upland areas of WB and Bihar some farmers have started grossing rice-rice-wheat, which requires even more irrigation (Chand and Haque, 1998). Average fall in water tables was found to be one meter a year (Vaidyanathan, 1994). And in some places deep drilling has led to saltwater intrusion into aquifers, rendering water unfit for agricultural or domestic use (Kerr, 1996).

In the case of close vicinity of seacoast, over-exploitation of ground water induces the inflow of seawater, thereby causing impairment of ground water quality. Such adverse affects of excessive ground water withdrawal are noticed in Saurashtra of Gujarat and deltas of Krishna, Godavari and Mahanadi.

2.2.2 Water pollution

Most fresh water used on continuous basis adds 2-3 tonnes of salts per hectare per year, thus it is natural for groundwater quality to deteriorate. This may be due to weathering of soil minerals under favorable moisture regimes, concentration of solutes applied in irrigation, and their subsequent leaching downwards during the monsoon season. Movement of saline waters from nearby or underlying aquifers may also deteriorate the ground water quality. Human interventions in terms of industrial effluents in irrigation water, like use of coolant water for irrigation, which has an increased salt load of at least 2 to 3 times and other effluents like steel, textile, leather, paper, detergent industries and sugar factories deteriorates both ground and surface water. Heavy metal pollution in irrigation also has the additional threat of entering the food chain.

Nitrogenous fertilizers are the main source of NO_3 pollution in ground water and other water bodies (Pain and Thomson, 1989). Bijay-Singh and Sekhon (1979) reported that nitrate leaching is more when rainfall exceeds evapotranspiration, where irrigation is practiced, lands are devoted to shallow rooted crops, soils having low water holding capacity and high infiltration rates and where fertilizers and manures are applied in amounts and ways that result in the accumulation of nitrate-N in the soil. Only a limited number of studies correlate the nitrate pollution of groundwater with the use N fertilizers. However, evidences indicate that such applications in intensive cropping during 10 years have resulted in increased nitrate concentrations in groundwater.

Table 8. Nitrate content of ground waters in India

State samples	**District**	**Total Number of samples**	**Number of samples having NO_3>45 mg L^{-1}**	**Percentage of samples having NO_3>45 mg L^{-1}**
Andhra Pradesh	Kurnool	143	26	18
Bihar	Rohtas	209	55	26
Bihar	Palamu	191	40	21
Gujarat	Mehsoma	200	37	19
Haryana	Faridabad	200	45	23
Haryana	Gurgaon	415	104	25
Karnataka	Gulbarga	529	261	49
Madhya Pradesh	Jhabna	55	11	20
Maharashtra	Nagpur (villages)	47	14	21
Maharashtra	Nagpur (city)	100	73	73
Maharashtra	Satara	1001	163	16
Orissa	Phulbani	225	29	13
Orissa	Koraput	503	71	14
Rajasthan	Barma	351	220	63
Tamil Nadu	Ramnad	66	7	11
Total		4496	1290	29

Source: Handa, 1987

Studies have reported high nitrate concentrations (>10 mg 1^{-1}) in groundwater in a significant number of samples (Bijay-Singh, 1996; Majumdar and Gupta, 2000). Groundwater samples from Haryana and Punjab where fertilizer consumption is highest showed high amounts of nitrate in the groundwater (Lunkad, 1994). Kumar and Singh (1998) have reported high nitrate concentration in ground water samples from Mohindragarh District of Haryana (> 45 mg 1^{-1} in 75% of the samples). Handa (1987) and Pathak (1999) reviewed the work done on nitrate pollution in India and reported that in the tube well water samples, about 60% of the samples had less than 1 mg nitrate N l^{-1} and less than 5% had more than 5 mg nitrate N 1^{-1}. The remaining 35% of the samples showed intermediate values. But a considerable number of water samples from dug wells had high (>50 mg 1^{-1}) nitrate content.

According to Handa (1987) the nitrate concentration in well water samples from selected locations in Punjab, Haryana and western UP was several fold higher than the upper safe limit. For example, in Haryana it was 296 mg/l at Mahendragarh while in Ambala it was 223 mg/l and 157 mg/l in Meerut, UP. Singh et al (1987) reported that the mean concentration of NO_3 in ground water from central Punjab was 3.88 mg/l during 1982 against 1.02 mg/l in 1975. They also reported that 10 per cent ground water samples contained NO_3 concentration of 10 mg/l which is the upper limit of NO_3 in drinking water prescribed by WHO (1963). Besides nitrate contamination, a substantial amount of heavy metals present in fertilizers and sewage sludge are also leached into the groundwater aquifers.

Bajwa et al (1993) in a study of some districts of Punjab observed that 78.4% of the tube well (21 to 38 m deep) water samples contained less than 5 mg nitrate and the remaining ranged from 5 to 10 mg nitrate. In the groundwater samples collected from 9 to 18 m deep hand pumps located at homesteads/villages in Punjab, 64% of the samples contained 5-10 mg and 2% of the samples more than 10 mg nitrate. They concluded that animal wastes dumped in the inhabited areas could be the possible cause of higher nitrate concentration in the hand-pump samples than in the tube well samples. Nitrate concentration in the groundwater were also higher under the rice, maize, orchards and vegetables than for other crops (Pathak et al, 2001).

Lunkad (1994) observed that the high nitrate concentration in some groundwater samples reported from Haryana, Punjab and UP in the north, TN in the south, Orissa (Ganjam district) and Bihar in the east and Gujarat in the west of India are associated with high N-fertilizer consumption. The Indo-Gangetic plain is more prone to nitrate pollution of groundwater as it is almost flat and consists of thick pile of unconsolidated and permeable alluvial sediments as compared to peninsular plateau and north and northeaster India. Lunkad suggested that in this region fertilizer application must be accompanied by good drainage facilities, which are lacking in Punjab and Haryana.

With green revolution and adaptation of HYV in Indo-Gangetic Plain the application of pesticides has shot up substantially over time. The plant protection increased from 2-4 million ha in 1956 to

80 million ha in 1987. Insecticides share the maximum at 80% followed by fungicides (10%) and herbicides (7%). Dhaliwal and Singh (1993) reported that even small quantities of residues ingested daily along with food could build up several folds in the body. Excessive and inefficient application of pesticides results in contamination of various spears of the environment, especially in the irrigation zone (AES). The studies conducted by Kathpal et al (1992) have revealed the presence of DDT and HCH residues in 50 milk product samples from different parts of Punjab. Similarly, about 90 per cent of 980 milk samples from AP, Maharashtra, Delhi and Punjab showed HCH residues at levels ranging from 0.13 to 40 ppm on fat basis (Kalra and Chawla, 1981). Shah et al (1992) reported 0.02 to 7.63 mg/kg of DDT and 0.02 to 4.96 mg/kg of HCH in ghee samples. There are several reports of insecticide residue contamination mostly DDT and HCH in human breast milk also. Singh and Dhaliwal (1993) reported the mean level of total DDT, HCH and Aldrine as 0.52, 0.20 and 0.14 ppm in 50 samples collected from rural areas of Punjab. Similarly, the milk samples from Lucknow were found to be contaminated with Aldrine. In buffalo milk its concentration was 0.02 ppm while in goat milk its concentration was 0.005 ppm.

Instances of pesticide pollution in Indian fresh waters are also quite frequent. Bidai (1982) reported nearly 1000 and 1300 ppb of BHC and Methyl parathion in Cauvery water near Srirangapatnam in Mysore and 20-200 ppb of BHC in drinking water in Hasan district of Karnataka. A detailed report by Pillai and Agarwal (1979) indicates the presence of DDT and its metabolites in Yamuna water (0.602-3.416 ppb) and fish (0.059-7.575 ppm) near Delhi. Contaminations of aquatic food chain by DDT have also been reported by Joshi (1986 a & b). By the process of biomagnification, the DDT residue level increased by 2500, 7500, 3660 and 15800 times of its ambient level in water by plankton, fish, gastropods and bivalve mollusks, respectively (Joshi, 1988). Through food chain, these toxic chemicals enter the livestock and human bodies and cause various health hazards.

A study of some of the material fluxes in the east and west coast of India reveals that a considerable proportion of the non-conservative nutrient are deposited into the Indian estuaries. The contribution of DIP (dissolved inorganic phosphorus) and DIN (dissolved inorganic nitrogen) to the Tapi estuary from agricultural wastes is of the order of $573*10^3$ $mol.d^{-1}$ and $4860*10^3$ $mol.d^{-1}$ respectively. Similarly, a large runoff of fertilizers and pesticides is expected in the productive lands of Ganga basin and of all the non-point sources, uncontrolled agricultural land use may cause highest degree of pollution. 92,700 tonnes of nitrogen, 10,559 tonnes of phosphorous, and 19,412 tonnes of potassium were used in 1976-77 in Ganga basin alone (de Sousa, 2001). Fertilizer residue of $5*10^6$ tonnes, pesticides residue of 65,000 tonnes and sediments of 1600 million tonnes enters the coastal waters of India annually (Elrich de Sa, 1999). There have been many incidents of metal contamination in estuaries due to aquaculture and industrial activity. In Ennore estuary, influence of industrial effluents from refinery and fertilizer industries have increase the Cr and Zn concentrations. (Joseph and Srivastava, 1993)

A variety of pathogens can be contracted and transmitted thorough irrigation water. In India infestation of crops by pathogens that originated from irrigation water is not very common (Gupta and Yadav, 1996). However, year round irrigation and consequent multiple cropping coupled with increased waterlogging due to poor drainage, and coastal and inland salinity conditions have given rise to an increase in the incidence of malaria in certain project areas like Mahi-Kadana in Gujarat. Paddy growing areas with poor drainage facilities are severely affected. Better water management thorough rotational water supply is increasingly introduced in projects in India under which crops in a given outlet command are irrigated at weekly or fortnightly intervals in accordance with crop-soil-water requirements and amounts of water are administered on a per-hectare-time basis (Jayaraman, 1981).

2.2.3 Water runoff

Runoff is high in the hilly regions ranging from less than 1% for land use under secondary forest in the North East Himalaya to 6.5%-15% in agriculture to 50% (Singh, 1994) in the denuded hills in the western Himalayas and tea plantations the runoff has been reported 16% (Annon, 1981). Runoff of about 40% is reported from traditional agriculture in the rainfed areas. For the country as a whole runoff is 45%. This is a loss of potential water resources.

2.2.4 Siltation of water bodies

Another impact of s*oil erosion* is the in the reduction in the capacity of the reservoir basins. The siltation of water bodies can be inferred from the rise in level bed from 0.5 to 1.35 meters of Putimari river due to soil erosion, silting of Bhakra reservoir at the rate of $35.8*10^6 m^3$ annually, half of which comes from Himalayan basin (Sharma et al, 1991) and shrinking of the water surface area of Loktak late by 50%. In the hilly regions, Loktak Lake is drying up constantly and its water surface area is understood to have shrunk by more than 50% (Anonymous, 1990). Umium reservoir in Meghalaya is facing the problem of silting. About 400 villages in West Kashi hills are faced with the problem of scarcity of water and other sources are polluted with iron and turbid. The hydrographic sediment deposition is of 11,703 ac ft during the last 25 years, giving an annual rate of sedimentation of 26.05 ha m per 100 sq km of catchment area (Anonymous, 1990). The

Brahmaputra is one of the most heavily sediment laden among large rivers of the world carrying an average annual suspended load of 15,200 ha m (402 million metric tons) at Pandu in Assam (Satapathy and Sarma, 2001). Hill areas provide principal water catchment areas, and source of most of the water for lower hills and plains below. Thus the water supplied to areas below gets affected besides leading to floods and droughts (Narsimham, 1995).

On an average the Himalayan hills are reported to generate 28 tons/ha/yr sediment (Singh and Gupta, 1982), resulting in siltation of reservoirs and affecting hydroelectric generation adversely. Glaring examples of siltation of Bhakra reservoir at the rate of $35.8*10^6m^3$ annually, half of which comes from Himalayan basin (Sharma et al, 1991) (Narian, 1994). The Nilgiri district of TN is situated in W. Ghat. The change of land use in the form of extensive agriculture after 1820 AD has not only resulted in the washing of top soil thus resulting in development of unfertile land and silting of various multipurpose reservoirs but has also resulted in change of hydrological behavior of the region which is also a responsible factor for the landslide events now occurring with greater frequency. The erosion of the hills can be understood by the siltation of Ketty reservoir, which has to be abandoned in 1975.

The destruction of vegetative cover in the catchment areas of the nadis (ponds) due to the increased human and livestock activities like cutting of trees, overgrazing etc have accelerated removal of sediments from those catchments and their subsequent deposition in the nadis (Sharma and Chatterji, 1982). As a result the storage capacity of the nadis has decreased in the arid zone.

Table 9. Indicative water related environmental impacts resulting from various human interventions segregated into different Agro-eco systems in Indian agriculture

Agro Eco Systems	Particular practice (driver)/ Human interventions	Fall in Water tables	Water pollution	Water runoff	Siltation of water bodies
Arid	• Overuse of ground water • Shift in cropping pattern to water intensive crops	39% is over drafted in Rajasthan			Fall in catchment area of rivers
Coastal	• Runoff of agriculture chemicals into coastal areas • Aquaculture • Integrated farming (diversification)		Fertilizer residue of $5*10^6$ tons, pesticides residue of 65,000 tons and sediments of 1600 million tons enters the coastal waters annually Significant (-) Significant (+)		
Hill and Mountain	• Shifting cultivation and deforestation for agriculture			High water runoff 15-50%	Loktak Lake, Umium reservoir, Brahmaputra river, Bhakra reservoir etc
Irrigated	• Overuse of groundwater • Rice-wheat rotation • Intensive use of chemicals • Technology intervention (RCT) *– quantified in a case study by IGIDR*	1-3 meters per year Significantly potential (+)	Nitrate contamination Significantly potential (+)		
Rainfed	• Overuse of ground water • Leaving rainy season fallows in vertisols	Significant		Runoff of about 40%	

'-' indicates a negative impact and '+' indicates a positive impact

Source: Compiled by the authors

2.3 Air related externalities arising from Indian agriculture

Agriculture is known for its external impacts on soil and water more that air quality and biodiversity. However, due to the intensification of agriculture there have been many cases of impacts on air quality and also on biodiversity. The major impacts on air are the GHG emissions from rice fields and burning of rice-wheat straw. These problems are predominant in Irrigated AES.

2.3.1 GHG emissions from rice fields

Earlier large emissions of methane from rice fields have been ascribed to India because of larger area (42.5 m ha) under rice. According to US-EPA estimate in early nineties based on extrapolation of measurements in USA and Europe, the annual methane emissions from Indian rice paddies were 37.8 Tg. Now, according to the measurements made by Indian researchers annual methane budget of 3 - 4 Tg is ascribed for Indian rice fields. Saturated soil in paddy fields gave higher CH_4 emission compared to intermittent wetting and drying soil conditions. Increased irrigation and waterlogging conditions in IGP enhances the methane emissions substantially. Subsidizing electricity and canal irrigation water has indirectly influenced the GHG emissions from Irrigated AES. The table below shows the differences in emission levels given the various practices[4]:

Table 10. Emission estimates according to various water regimes in lowland rice fields

Water Regime (Lowland)		**Total Emissions, Tg/yr**
Rainfed	Flood prone	0.80 (+/- 0.25)
	Drought prone	0.41(+/- 0.10)
Irrigated	Continuously flooded	1.70(+/-0.57)
	Intermittently flooded	
	Single Aeration	0.60(+/-0.15)
	Multiple aeration	0.08(+/-0.03)
Deep-water	Water depth 50-100 cm	0.48(+/-0.15)
	Water depth > 100 cm	
Total		4.07(+/-1.25)

Source: ADB et al, 1998

An inventory for nitrous oxide emission from Indian agriculture was prepared using the Inter-Governmental Panel on Climate Change methodology. State wise emission of nitrous oxide was estimated to be 91.25 thousand tons for the year 1994-95. The state of Uttar Pradesh emitted the highest amount of nitrous oxide (17.58 KT) followed by Andhra Pradesh (10.87 KT). Larger area under cultivation, higher use of N fertilizer and more animal population are responsible for higher emission in these states. Estimates of nitrous oxide emission in India from 1980-81 onwards ranged

[4] No emissions were estimated for upland fields.

from 38.16 to 107.88 KT per year (Pathak, 2003). Methane emissions from the rice wheat system, given the most common fertilizer practice in Indo-Gangetic plains was put at 21.2 kg ha^{-1} and N_2O-N emission is 1.57 kg ha^{-1} (Pathak et al, 2003).

2.3.2 GHG emissions from livestock

Live stock GHG emission is another major air quality issue arising from the agriculture sector. Most of the AESs have predominant livestock with Arid AES leading the list with around 45% share of income coming from livestock. The population of livestock has increased from 293 million to 480 million from 1951 to 1997. Both enteric fermentation from animals and their manure are important factors in GHG emissions.

Emissions from Indian buffalo, the bovine stock (including goats and sheep) and cattle have been estimated. CH_4 emissions released from the stock in these three categories are estimated to be 1.7 Tg/yr, 1.9 Tg/yr and 3.9 Tg/yr respectively. The total emissions are estimated at about 7.5 Tg/yr. Assuming emission factors that are relevant for dry manure management systems, 0.9 Tg/yr were estimated for 1990.

2.3.3 Carbon Dioxide Emissions from burning crop residues

Crop residues are burnt in India mainly to clear the remaining straw and stubble after the harvest to prepare the field for the next cropping cycle[5]. Wheat is the crop residue that contributes most to the net emissions of non-CO_2 GHGs emissions in India. The next important source is rice straw. (ALGAS). Thus, emissions are expected to be high in the Irrigated AES where rice wheat rotation is dominant.

In a questionnaire survey conducted in Punjab, it was observed that 8 million tons of rice straw out of 9.9 million tons was burnt. This was found less in case of Wheat straw with only 9 million tons burnt out of 18.9 million tons (Sidhu et al, 1998). The total quantity (14,035 t) of rice-straw of the sample farmers ranged from 43.8 tons/farmer in Jalandhar to 73.1 tons/farmer in Patiala district with an average of 59.2 t per farmer per year. The quantity of wheat straw ranged from 42.3 t per farmer per year in Gurdaspur to 64.6 t per farmer per year in Amritsar. It was observed that

[5] It is estimated that the fraction of residues burnt in the Indian fields are as follows: 40 percent for rise husk and wheat straw, 20 percent for maize cobs, 40 percent for all types of millets, 20 percent for bagasse, 10 percent for coconut shells, 40 percent for cotton stalks and 90 percent for jute stalks. Ninety percent of all types of crop residues is considered to be oxidized.

majority (82 per cent) of the farmers burnt rice straw. But only 48 per cent farmers burnt the wheat straw. It may be noted that wheat straw is a common dry fodder for animals in Punjab. Wheat straw was sold while rice straw was just given away for fodder or to paper mills (Sidhu et al, 1998). This is a prominent practice in IGP (Irrigated AES).

In Punjab alone it is estimated that burning of rice and wheat straw would have resulted in 28.2 million tons of carbon dioxide. Also, significant quantities of valuable nutrients are lost during the burning estimated to 85,506 tons/yr amounting to $17.7 million (Rs. 617.3 m). In addition, the suspended particles as smoke are a health hazard for the local population (Sidhu et al, 1998).

There have been no effective technologies to reduce this practice. Research shows that incorporation of rice and wheat straw in long term experiments for at least seven years improved soil health but not yield of the subsequent crops. (Sidhu and Beri 1989; Beri et al 1992, Beri et al 1995). Also burning has been found to boost growth of the following wheat (Sidhu and Beri, 1985, Sidhu and Beri 1989) at least for 30-40 days, after which the affect disappears. Farmers indicated that incorporating straw into soil involved additional cost of labour, irrigation, and extra tillage; and less than 1 per cent of the farmers incorporated rice and wheat straw (Biswas et al, 1971; Kumar et al, 1992; Biswas and Benbi, 1997; Sidhu et al, 1998). Table 11 gives the total GHG emissions from Indian agriculture.

Table 11. India's GHG inventory from different sources in agriculture for 1990 (Tg)

Greenhouse gas sources and sinks	CH_4	N_2O	NO_x	CO	Total (CO_2 equivalent)
Enteric fermentation	7.56				158.82
Manure management	0.91				19.01
Rice cultivation	4.07[b]				85.47
Agricultural soils	0.00	0.24			74.40
Field burning of agricultural residues	0.12	0.00	0.11	3.04	3.37
Total emissions from agricultural sources	12.65	0.24	0.11	3.04	341.06

b. – CH_4 emissions according to IPCC 1996 methodology
Source: ADB et al, 1998

2.3.4 Toxic emissions from aqua farms

Excessive nutrient application results in severe contamination of water with rich organic content. In a study it was estimated that the deposition of organic waste beneath a well fed fish farm might be as much as 10 $kg/m^2/yr$ directly beneath the cages and 3 $kg/m^2/yr$ in the immediate vicinity of the farm (Donard, 1996). One of the major effects of organic enrichment of sediments is an increase in oxygen consumption by heterothric organisms within the sediment. When the demand for oxygen exceeds the supply, the sediment becomes anoxic and anaerobic process predominates. This makes it unsuitable for subsequent use of that soil. This may lead to formation of methane (CH_4), a major green house gas (Patra, 2001).

2.3.5 Formation of gases in the wells

Substantial subsidies on electricity have resulted in increasing tube wells, especially in Irrigated AES. Formation of toxic gases due to lowering of tube wells is another externality of intensified agriculture practice in this System. During the onset of monsoon lethal gases are formed in deep pits of tube wells and there are reports that since 1985, 63 persons lost their lives due to asphyxia in deep pits of tube wells. Of this, 40 in Haryana and 8 in Punjab died during 1988 (Taneja et al, 1988; Joshi and Tyagi, 1991). In 1987-88, a comparatively dry year, farmers lowered their tube well motors by 3-6m and this caused a number of deaths due to presence of poisonous gas in these tube wells.

Table 12. Indicative air related environmental impacts resulting from various human interventions segregated into different Agro-eco systems in Indian agriculture

Agro Eco Systems	Particular practice (driver)/ Human interventions	GHG emission	Emission of toxic gases	Air contamination
Arid	• Increased grazing and conversion of pasture land to cultivation			Drift causing particulate pollution in the down wind localities (-)
Coastal	• Intensive aquaculture practice	Methane emissions due to the accumulated fertilizers on the farm bed (-)	Toxic emissions due to prevailing anaerobic conditions and anoxic conditions (-)	
Hill and Mountain	• Increased land use changes from forestry to agriculture	Fall in effective carbon sink		
Irrigated	• Subsidizing electricity	Increasing methane emissions, 37.8 Tg/yr (-)		
	• Application of nitrification inhibitors	R-W methane emissions reduced by 30% (+)		
	• Intermittent wetting and flooding	Reduced methane and nitrous oxide emissions (+)		
	• Increased fertilizer use in IGP	Nitrous oxide emission increased from 654 to 1570 g/ha (-)		
	• Rice-wheat in IGP with 240K N; and use of inhibitors FYM & DCD	Nitrous oxide emissions: 1570 g/ha and 1415/1096 g/ha, respectively (+)		
	• Burning of Rice-wheat straw 59.2 t/farmer/yr	28.2 million tons of CO_2 (-) and Nutrients loss (-)		Smoke particles and health hazards (-)
	• Lowering tube wells 1987-88 deepened by 3-6mt		Emission of toxic gases (63 deaths since 1985 in Punjab) (-)	
	• Modified irrigation patterns	Reduced emissions (+)	Reduced emissions (+)	
	• Suitable crop cultivers Pusa 169 Pusa 933	15.6 kg/ha 27.2 kg/ha (+)		

	• Increased pesticides application • IPM (reduced pesticide usage in terms of number of applications 61.7%) • Technology intervention (RCT)	Significantly potential (+)		DDT and HCH residuals in food samples (-) Water contamination (-) Declining trends of pesticides dietary intake (+)

'-' indicates a negative impact and '+' indicates a positive impact

Source: Compiled by the authors

2.4 Biodiversity related externalities arising from Indian agriculture

Biodiversity can be two types – agro-biodiversity and species biodiversity. Here we focus on the loss of flora and fauna in the environment due to agricultural practices. Hill and Mountainous AES are hotspots of biodiversity. Increasing trends of change in land use pattern result in loss in biodiversity. Especially, practices like shifting cultivation essentially involve destruction of forest and it results in tremendous loss of biodiversity. The annual removal of various types of forest products in Meghalaya due to shifting cultivation is given below -

Table 13. Forest product removal due to shifting cultivation

Forest product	Average annual removal
Timber	253206 Cu.m
Firewood	0.2 Cu.m. per capita
Bamboo	70500 Nos
Broomstick	65220 Q
Thatch	38790 bundles
Cane	112460 R. M

Source: Forest Department, Meghalaya (Prodhani, 1994)

2.4.1 Depletion of fauna

Most of the wild fauna are now being threatened to extinction due to forest depletion, hunting, jhuming etc. As per the Zoological Survey of India, in Shillong there are over 66 species that are already listed as endangered animals that once thrived well in the region (Sarkar, 1994). The sturdy and swift ponies of Manipur are facing extinction due to their inability in adjusting themselves to the changing environment. Besides 200 wild elephants, there are other rare and endangered animals including gaur, buffalo, tiger, serow, golden cat, hallock, caped languor, leopard, cat etc, which are on the verge of extinction. The duck, Deohanh is listed as endangered by International Union Conservation of Nature and Natural Resources (IUCN) and is protected by Indian law. Mahaseer, one of the world's finest sporting fish found in Meghalaya is facing extinction. The one horned great Indian rhino, only 1600 of which continue to survive in the Kaziranga National park in Northeastern India, has been enlisted as endangered by WWF (Prodhani, 1994). Though it is difficult to attribute all this to the agriculture alone, changing land use patters in the hilly regions certain has its share.

2.4.2 Depletion in flora

The habitat of curious plants is shrinking and is now confined to Jaraini area of Jaintia Hills of Meghalaya. One of the important plants locally called 'Safed Back' which was found in Kashmir, Manipur and Nagaland only a few years ago is now being imported. The BSI inventory showed that *D. hauciflorum* grown in West Bengal and Sikkim is in all probability extinct due to indiscriminate felling of trees and human interference. Similarly, an orchard species *Deplomeris hirsuta* was seriously threatened, as it grows in an area of Meghalaya vulnerable to land slides and forest clearances. *Coptis elata* found in Arunachal Pradesh has also become rare owing to over exploitation and destruction of habitats in Mishmi Hills in Lohit district (Prodhani, 1994).

The following listed (local names) forest species (14) are affected by shifting cultivation as reported by Borthakur (1992):

Koko bamboo	*Ahani, Kokan*	*Jia*
Bahara	*Toon or Poma*	*Amloki*
Sunaloo	*Oksi, Ghargra*	*Sida*
Dhobisnut	*Kanchan*	*Gamari*
Sal	*Silika*	

An estimated amount of diversities in major crops on the Northeast India is reported to be 9650 in rice, 15 races and 3 sub-races (1200) in maize, 300 in taros, 230 yams, 17 species + 52 varieties in citrus, 16 texa in banana, 78 texa in bamboo, 700 texa in orchids and 19 texa in sugarcane. Establishment of biosphere reserves is being promoted which will facilitate *in situ* conservation of valuable plant varieties developed and protected by farmers for centuries in hill agriculture systems. The 80 sq. km. Nokrek Biosphere reserve in the Burman Monsoon bio-geographic region of Meghalaya is a case in point with enormous genetic wealth (Rana, 1995). The flora of Khasi hills is the richest in India and probably in Asia (Satapathy and Sarma, 2001).

Indian coasts (Coastal AES) have a large variety of sensitive eco-systems. Sand dunes, coral reefs, mangroves, sea grass beds and wetlands are some that deserve special mention. Some of these are the spawning grounds and nurseries of a number of commercially important fishes, gastropods and crustaceans. A critical feature of these ecosystems is the variety of bioactive molecules that they host.

Estuarine and backwater lagoons present important eco-system in this farming system. The wetlands provide essential habitat for many important estuarine species and serve other roles such as shore stabilization, flood control and water purification. Vegetation plays the key role in converting inorganic compounds and sunlight into the stored energy of plant tissue. Mineral nutrients are washed down from the upper wetlands to the lower wetlands, which ultimately are transported into the coastal waters to provide basic nutrients for the food chain of coastal water ecosystems. About half of the plant tissue created in the grass marshes and mangrove swamps of the lower wetlands is flushed out into the estuary (Teal, 1962). Wetland vegetation removes toxic materials and excess nutrients from estuarine waters. Sediment and other inert suspended materials are also cleared. The vegetation also slows the surge of floodwaters and stabilizes estuarine shorelines and prevents erosion. Estuaries possess special character of varying salinity. Increasing practice of aquaculture results in contamination of these potential systems and increased and intensified commercial aquaculture activity in and around mangroves disturbs the most sensitive eco-system and lead to loss of valuable biodiversity. Destruction of mangroves in this region due to aquaculture, leading to large scale felling of trees etc is an irreversible loss to the biodiversity.

Also there is a shrinking of backwaters in Kerala. The state has 41 rivers draining water from their catchment areas. Many of them drain into these backwaters. Increased deforestation in catchment areas has resulted in extensive soil erosion and silting of river mouths. A recent study found a very high annual sedimentation rate in one of the irrigation reservoirs. Apart from the silt from mountains, ocean currents also bring up sediment and deposit them in backwaters. Silting and sedimentation are the biggest problems in Cochin estuarine region.

Rangelands/grasslands are a single resource base, which contribute maximum herbage for 15% of the livestock population in India. The annual livestock population has been increasing while the area under grazing lands has been decreasing all over India (Singh, 1995). For example, in Jodhpur district over a period of 28 years, the extent of the grazing lands decreased by 9 to 30% under the different eco systems, mainly due to increasing biotic activities like cultivation and construction of settlement and buildings for industries (Sharma et al, 1989; Singh, 1995)

In Arid AES, due to enormous grazing pressure, the grasslands have undergone a tremendous change. The edible species have been replaced by noxious weeds and poor regeneration of plants leading to scanty vegetation cover. The degradation has taken place to such an extent that the once productive grasslands are rated now as wastelands (Singh, 1995).

As a result of different human induced desertification the vegetation cover, particularly in rangelands, in western Rajasthan is getting depleted. The basic cover of *Lasiurus Sindicus and Eleusine compressa* declined from 5.14 % to 2.40%. The total vegetation cover declined from 6.59% to 0.95 % and its yield declined by half. The density of *Salvadora* declined from 10-20 trees

ha^{-1} to 1-3 trees ha^{-1} (Shankar and Kumar, 1987). Due to increased human activities and accelerated erosion, the vegetation cover of *Prosopis cineraria, Capparis deciduas, Ziziphus nummularia, Cynodon dactylon, Cenchrus Ciliaris and Dicapthium annulatum* decreased from 4-8 % to 1-2 % and bio mass yield from 4000 kg ha^{-1} to 130-1100 kg ha^{-1} (Saxena, 1985; Singh, 1995).

In a study by Dhir (1988), it was estimated that nearly two thirds of the pasturelands, which constitute about 26% of the geographic area of western Rajasthan, are in a state of severe degradation or are already desertified due to various technogenic activities related to IGNP and other human interventions. The losses of vegetation cover lead to increased surface instability and to poor regeneration. Before human intervention these lands supported some stands of *Accacia senegal, Commiphora mukul, Capparis* and also a ground storey of low perennials and grasses which later became almost barren (Dhir, 1993).

Continuously increasing pressure of animal population and erratic rainfall are another major cause of the loss of vegetation, mostly permanent. They have resulted in the disappearance of perennial and annual grass species from the grazing land of Doli and Jhanwar villages and these have been substituted by partially palatable and non-palatable species (Raina and Sen, 1991).

In the Arid AES with less than 300 mm rainfall the total vegetation cover declined from 6.59 to 0.95% and its yield declined from 2 to 4 t ha per year to less than 1 ton per ha per year (Shankar and Kumar, 1987). With the construction of IG canal, natural cover of *Haloxylon salicornicum, Prosopis cineraria* and *Lasiurus sindicus* is being fast depleted due to waterlogging and salinity problems. Such changes in plant cover indicate desertification process.

In the more than 300 mm rainfall zone grasses are being replaced by shrubs. It has been estimated that the protected vegetation has 4-8 per cent cover and around 4000 kg ha^{-1} biomass yield, while under degraded situation, the cover decreases to 1-2 per cent and yield to 130-1100 kg ha^{-1} (Saxena 1982). A survey in Bandi catchment of Luni basin of Arid zone revealed that the degradation was so much that over 50 per cent area of grazing land was highly degraded and 30 per cent moderately degraded (Kumar & Shankar, 1987). It has been noted that when degraded the regular vegetation gets replaced with *Prosopis juliflora* and *Oropetium thomaeum* (Singh et al, 1994).

Table 14. Indicative biodiversity related environmental externalities resulting from various human interventions segregated into different Agro-eco systems in Indian agriculture

Agro Eco System	Particular practice (driver)/ Human interventions	Loss of flora	Loss of fauna	Loss of vegetation/grass	Loss of coastal bi-diversity
Arid	• Cultivation, construction of settlements and buildings for industries			Fall in grazing land by 9-30% in Jhalandhar over a period of 28 years (-)	
	• Increased livestock and increased grazing pressure	Edible species are replaced by noxious species and poor regeneration (-) Disappearance of perennial and annual grass species Doli and Jhanwar villages in Arid zone (-)			
	• Human induced desertification			Vegetation loss in western Rajasthan. basic cover of *Lasiurus Sindicus and Eleusine compressa* declined from 5.14 % to 2.40% (-)	
	• Technogenic activity like IGNP			Stands of *Accacia senegal, Commiphora mukul, Capparis* and also a ground storey of low perennials and grasses are disappearing (-)	
Coastal	• Encroachment of wetlands • Conversion of wetlands • Destruction of mangroves	Saline water resistant species are affected (some time irreversibly) (-)	Reproduction cycles got disturbed (commercial spesices like *black tigers*) (-)		

	• Increased agriculture activity in ecologically sensitive areas • Integrated farming enterprise	 Increased flora due to reduced use of pesticides (+)		Loss of vegetation due to excessive soil sedimentation in Cochin estuary (-) Increase in green cover (+)	Loss of coastal biodiversity due to the adverse effect of the sediment (-)
Hill and Mountain	• Shifting cultivation	Loss of timber, Fire wood, Bamboo, Cane etc. (-) 14 plant species have been identified as affected by shifting cultivation (-)	Many species from the NEH regions have been identified as endangered and changing land use pattern adds to it (-)		
Irrigated	• Excessive use of pesticides in IGP • Technology intervention (RCT)	Effects the soil primary productivity (-)	 Showing potential (+)	Loss of weeds (-) Showing potential (+)	
Rainfed	• Rainy season fallow			Loss of green cover due to the soil erosion (-)	

'-' indicates a negative impact and '+' indicates a positive impact

Source: Compiled by the authors

3. Conservation Measures and Environmental Impacts

Negative environmental impacts due to the changing agricultural practices have been well documented in the literature compared to the positive impacts. However, agricultural research has made breakthroughs in terms of various conservation measures in negating negative environmental impacts. In the present study, the negation of negative impacts is considered as a positive impact of the changed agriculture practice. Some of these studies have been experimented at the plot/field level, watershed level and certain other conservation practices were traditionally followed in certain areas or are being adopted through agricultural extension in the recent years. The following sections present an indicative review of various conservation practices that have been documented in the literature. These practices either show a positive environmental impact or negation of negative impacts.

3.1 Mechanical and agronomic soil and water conservation (SWC) measures

Ridges and furrows, graded furrows, broad bed furrow, broad bed and tied furrows, raised and sunken bed system etc are important in *in situ* rainwater conservation and prevent soil loss. Gabion structures, graded bunds, water diversion bunds, bench terracing, grassing of waterways, stabilization of washes, provision of drainage between waterways etc are important erosion control measures. Agronomic measures like contour cultivation, contour strip-cropping, mixed cropping, tillage and surface mulching, zero tillage and living mulch form important components of SWC measures.

In the arid AES, graded bunds reduced runoff from 15-20 per cent to 4.8 per cent of rainfall and increase yield of crops by 22 per cent (Prasad et al, 1990). Permanent gully control structures constructed in Chhajawa agricultural watershed during 1986-87 have completely halted the widening and deepening of main gully and stabilized it (Prasad and Singh, 1994). Contour furrows and contour bunds were found to store 26-32% soil moisture in grasslands western Rajasthan which in turn resulted in 14 to 181% increase in forage yield[6] (Wasi Ullah et al, 1972).

The contour bunding reduced the runoff to the range of 8.5-32.4 mm depending on the slope and soil loss to 3.14-8.75 tons/ha the hill AES (Sastry, 1994). The practice reduced 80 per cent soil loss at all slopes. Contour maize produced the highest runoff and soil loss and bench terracing reduced

[6] Contour furrows have been extensively used in the rangeland areas receiving annual rainfall from 170-460 mm for moisture conservation and better establishment and growth of grasses.

them to the minimum. At 8% slope the runoff and soil loss were at 175 mm and 43.08 tons/ha respectively in the case of contour maize, 75.6 mm and 14.33 tons/ha for graded bunding, 32.4 mm and 8.75 tons/ha for contour bunding and 18.2 mm and 3.11 tons/ha for bench terracing (Narian, 1994). Contour cultivation reduced runoff by 20.6% and soil loss by 43.51% and improved maize yield by 23% in Shiwalik hills (Mittal et al, 1986). In a study carried out in northeastern hilly region, contour bunding reduced runoff and soil loss by 57 and 61 per cent, respectively (Singh, 1988). The table below shows the efficacy of certain conservation measures at different land slopes (Narian, 1994).

Table 15. Effectiveness of various conservation measures in the hill AES

Land Slope (%)	Conservation measures	Runoff (%)	Soil loss (t/ha)	% Reduction	
				Runoff	Soil loss
44-53	Traditional agriculture	15.6	40.9		
36-44	Agriculture on contour bunds similar to puetorican type	6.68	16.0	57.2	60.88
33-44	Agriculture on bench terraces	2.29	2.1	85.3	94.86
40-58	Agri-horticulture on bench terraces (1/3) and half moon terraces (2/3)	2.29	2.6	85.3	93.64

Source: Narain et al, 1994

Other mechanical measures that have been successfully tried are in the alluvial soils of Indo Gangetic plain and the black soils of Gujarat and Maharashtra to alleviate the problem of rising ground water level. Horizontal drainage controlled the water table in the depth range of 1.20 to 1.80 m except for very few days in rainy season when the water table came within 20 cm. The salinity was reduced to less than 10 dSm^{-1} by the third season. Similarly, experiments in Karnataka and Gujarat also show success in desalinization and in reduction of water table (Yadav, 1973; Narayana and Kamra, 1983). Subsurface horizontal drainage provided in Vertisols of Mahi-Kadana command at Dabhou in Gujarat showed significant improvement in the root zone conditions. With the installation of the drainage system area under cultivation and crop yields went up (Singh et al, 1990). Similarly, successful attempts have been registered in vertical drainage through bore wells. In certain districts like Kurukshetra and Karnal districts of Haryana the water table is dropping at rates ranging from 0-0.15 to 0.30 m per year due to installation of private and government tube wells (nearly 20 tube wells per sq km.) and the problem of *waterlogging* has been alleviated in these districts (Anonymous, 1983). The problem of sodicity has also been alleviated in many parts especially in the irrigated AES through the addition of gypsum.

Green manuring, weed management, growing appropriate cropping systems and grasses are the other cover management measures, which help in conservation of soil. Contour vegetative barrier (CVB) fields lost an average of 8.07 kg ha^{-1} yr^{-1} soil as compared to 526.84 kg ha^{-1} yr^{-1} under control in arid AES. There is a 43 to 74% decrease in the soil loss with Vetiver CVB (World Bank, 1990) while the CVB of native plant species decreased soil loss within tolerance limit of 5-10 kg ha per year (Morgan, 1979; Sharma et al, 1997). In another experiment CVBs from locally adapted fast growing perennial grasses reduced runoff by 28 to 97% stored about 2.5 times higher soil moisture and increased yields by 20 to 50% (Sharma et al., 1997a). This technique has been adopted widely by the State Government Departments on a large scale in Watershed Development Programmes. Marvel grass proved another effective vegetative barrier in controlling soil and runoff loss (Prasad and Singh, 1994). Shelterbelts on field boundaries may effectively control injuries to the tender seedlings from sand blasting and hot wind. Similarly, development of wind breaks across the wind direction reduce wind velocity by 20-46% and soil loss by about 76%. Windbreaks of natural vegetation maintained 14% higher soil moisture on the leeward side and pearl millet crop recorded 70% higher grain yield (Gupta et al., 1997,NRM)

Grass covers reduced soil loss from 3.7 to 8.9 tons/ha/yr under cultivated to 0.03 to 0.86 tons/ha/yr. Intercropping of low canopy legumes and double cropping sequences can be taken up to reduce erosion. Studies conducted at Kota (Prasad et al 1993) indicate that contour cultivation of castor and castor+green gram (1:2) intercrops reduced the runoff (9.2-14.2 per cent) and soil loss (17.6-25.1 per cent) and increased the yield of crops (15.4-26.6 per cent) as compared to along the slope planting of respective crops. Weeds too play an effective role in erosion control. The unweeded maize reduced the runoff by 58.4% and soil loss by 22.3%, compared to chemically weeded maize but also reduced yields drastically thus leading to a trade off between yield and soil runoff (Bharadwaj et al, 1979).

Low and evenly distributed canopy and fibrous root systems with high soil binding capacity make grasses highly effective in controlling soil erosion. Chrysopogon grass alone could reduce the runoff and soil loss by 91.3 and 98.1%, respectively (Narain et al 1988). Further, they could reduce the soil loss completely when grown along with trees. At 9 to 11 per cent slopes at Dehradoon, efficiency for erosion control of various grasses was more than 98% (Tejwani et al, 1975). In Doon valley on 4% slope Bhardwaj (1990-91) reported that live bunds of Guenia grass, bhabar grass and khus grass reduced the runoff by more than 18% and soil loss by more than 78% compared to cultivated fallow which produced 52% of rainfall as runoff and 45 tons/ha soil loss. Vegetative barrier of paired rows of Leucaena were effective in controlling erosion at 4 per cent slope in Doon valley (Narain et al, 1992).

Inter planting of erosion resistant leguminous crops, such as cowpea, soybean etc., which develop quick canopy cover has been found efficient in reducing soil erosion from corn. The cultivation of pure maize on 8 per cent slope at Dehradun lost 33.3% of rainfall as runoff and produced 25.1 tons/ha of soil loss. Inter planting cowpea reduced the runoff and soil loss to 26% and 20.6% tons/ha, respectively (Khybri, 1988). Inter cropping of maize and soybean resulted in the maximum production and reduced soil and runoff losses (Singh et al, 1981).

Experiments conducted by CSWCRTI in the Nilgiris revealed that up and down potato cultivation accounts for silt loss of about 39.3 tons/ha/year. This could be brought down to 14.9 tons/ha/yr when cultivated on contour and to only 0.31 tons/ha/year when cultivated on bench terraces. Newly established tea plantation accounts a soil loss of about 16-40 tons/ha/yr, which comes down to less than 1.5 tons/ha/year with canopy development of 15 per cent and above. The soil loss from newly established tea plantation with spreading of mulch, construction of drains and introduction of mulch and drain brings down the soil loss to 0.30 to 0.05, 0.4-1.0 and 0.03 to 0.05 tons/ha/year, respectively (Tripathi and Samaj, 1994).

Inclusion of the legume crops, clusterbean or mungbean in the rotation had a beneficial effect on soil properties under desert conditions as compared to mono cropping which will decrease soil productivity over the years. Organic farming practices using animal-crop residues, legumes and green manure crops in rotations help improvement in soil quality (Rao et al, 1995). Historically, legumes are known to improve soil fertility[7]. Their importance is more significant in the R-W cropping systems where organic sources of fertility improvement have rapidly declined. Crops like Sesbania and their incorporation improve physio-chemical properties of saline-alkaline soils, leading to increased growth and yields of subsequent crops. Joshi (1996) documented the evidence that legumes are contributing to the savings of nitrogenous fertilizers and improving soil fertility. Improved varieties for eg. extra short duration pigeonpea varieties are now available which can very well fit in a rotation with wheat (Singh et al 1996). Research is on to develop other varieties and improve the stability of their yields (Kumar et al, 1998).

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[7] Ladha et al. (1996) reported the following benefits of legumes in sustaining soil fertility: potential to make substantial contributions to the nitrogen economy of the cropping system, legumes often exert favorable influences on several other soil fertility parameters through their extensive and deep root systems, ability to extract nutrients from deep soils layers, utilize insoluble or fixed form of nutrients like phosphorous and make them available to the succeeding crops.

A combination of mechanical and agronomic measures reduced the soil loss to a negligible amount in the completely deforested catchment area of Sukhna Lake near Chandigarh. The sediment inflow to the tune of 945 tons/ha/yr has silted Sukhna Lake substantially (Mishra et al, 1990).

In the hilly region of Gaharawa village, Bundelkhand, an area of 83.75 ha barren and deforested hills was treated with appropriate SWC measures. The forage yield improved by 21 times. The percentage organic carbon over the slope of the hills as reflected before plantation was 0.12-0.37% while after two years it rose to 0.24-0.76%. The rise in N, P and K are to the extent of about 74, 6.6 and 31 kg/ha over initial level respectively due to afforestation and pasture development. Sedimentation in few check dams in the watershed area which was 0.28-0.45 m prior to the initiation of work came down to 0.05-0.10 m. Soil loss from barren hills came down from 41 tons/ha to to 9.5 tons/ha in two years and soil loss on the degraded wasteland site was brought down from 20.5 tons/ha to 5.5 tons/ha. Water loss decreased from 75% of the rain-water to the level of 35% of the average annual rainfall of 940 mm. Water table rose from 1-4 m. Yield rose from 3.6 q/ha to 20.0 q/ha and cropping intensity increased from bare 81 per cent to 156 per cent. The cost benefit ratio of the program stands at 1:2.89 (Hazra and Singh, 1992). This presents an excellent demonstration of effort to negate negative environmental externalities of changing agriculture practices.

In Aravali region of South-West Haryana, an integrated approach at soil and water conservation was implemented. Treatment of hilly catchment area by providing a series of structural measures reduced the run-off, soil loss, increase in ground water recharge and natural regeneration of vegetation. Besides afforestation of hills and wastelands not only provided ground cover but also increased the availability of fodder, fuel and timber in the region. Various in situ-water harvesting techniques implemented in the command area increased moisture content in the soil profile which in turn increased crop yield. The fertilizer consumption went up and there was an increase ground water levels and in the number of tubewells. Thus the benefits that have accrued due to the resource conservation and management were increased biomass production from command areas, flood and drought control, ground water augmentation and improvement in socio-economic status of the people (Singh et al, 1994).

3.2 Change in land use

The soil characteristics of a region have comparative advantage to certain farming systems. In the arid AES pasture-based livestock farming has an advantage, whereas agro forestry is recommended for the hill AES and integrated farming systems maybe be more productive in coastal regions.

Nearly 40% of the rainfed soils are found unsuitable for arable farming (land capability class IV and worse). In order to make their optimum use, a number of alternative land use options have been devised (Katyal et al, 1994). These include tree or pasture based cropping in harmony with agriculture on a catchment basis (watershed). Agro-forestry, including agri-horticulture and silvi-pasture are typical examples of alternative land use systems. Multi value crops that generate food and ensure uninterrupted supply of fuel and fodder and are soil health restorers have been identified. The role of alternative land use systems besides stabilizing biological productivity moderated impact of climate induced drought. (Katyal et al, 1994; Katyal, 1997). Integrated farming systems result in improvement in resource base, animal productivity and sustained economy. They also prove more profitable than arable farming in the arid and the semi-arid region (Gajja et al, 1999).

Ley farming is a system in which grasses and / or legumes are grown in short term rotation with crops. It helps to improve fertility and provides green fodder to animals; also helps up to build up soil structure and prevent soil erosion (Llioyd et al., 1991; Saha and Gupta, 1997). Studies by Gupta and Aggarwal (1980) showed that maximum sand depletion took place from bare unstabilised sand dunes (5560.5 t ha^{-1}), followed by bare sandy plains (1449.0 t ha^{-1}). Fields with grass cover and stabilized sand dunes recorded accumulation of sand (13.5 t and 151.5 t ha^{-1}, respectively). The trends are similar in case of organic matter, total N, mineral N, total P and total K (Kaul, 1996) (Aggarwal and Lahiri, 1981). Grass clumps helped increase humus content, phosphorous and potash by nearly 25 to 40% near the clumps as compared to in the soil away from the rhizome.

In Jhanwar watershed comprising an area of 1200 ha, about 60 ha community grazing land was developed as an ideal pasture land. Due to the conservation measures followed, biodiversity increased by 813%. Groundwater recharge increased at the rate of 0.75 m per year in the area. An additional 3240 m^3 run off water was collected in farm ponds of 271 m^3 capacity. Adoption of soil and water conservation measures reduced wind and water erosion, created additional storage, reduced the soil loss on sloping cultivated lands (5-6%) and increased the yields of dryland crops, grasses and fruit trees. Silvipastoral systems consisting of perennial vegetation comprising tree and grass systems can provide the much desired production stability. They are suitable for degraded lands in areas where annual rainfall is less than 200 mm.

Ley farming also improves soil physico-chemical properties, minimizes wind erosion and nutrient losses and increases crop yields (Rao et al., 1997; Singh and Gupta, 1977; Raina and Joshi, 1994). Decrease of the organic carbon content in the soil of degraded sites was more in oran (50.7%), followed by cultivated (50.3)% and least in pasture (39.4%) (Raina, 1992). In case of potassium the decrease was apparent in cultivated (55%) soils, followed by oran (35.2%) and pasture lands (12%). Decrease in available phosphorous was maximum (72.4%) in pasture soils, followed by cultivated (52.9%) and oran land (52.3%).

Integrating field and horticultural crops, fishery, poultry, duckery, apiary, mushroom, dairy and agroforestry has been extensively suggested not only for ensured high returns and employment but also for better resource use efficiency for the coastal AES. Resource recycling is possible through the interdependence of different components of the total farming system[8]. This reduces the application of organic fertilizers and pesticides. In a study carried out in Bhubaneswar, multi-layer cropping enterprise showed very high potential with high returns (II-e Behera and Mahapatra, 1999). Given the saline and even acid sulphate soils occurring in certain coastal areas, some of the vegetation/plants of fodder are much more suitable for the environment as compared to the many agricultural crops which will give not only better economic returns but also improve the soils.

A long term study conducted at Canning (West Bengal) showed 296% increase in yield, as compared to monocropping with rainfed rice alone, under the package consisting of deepwater rainfed rice + fresh water fish (rainy season) combined with brackish water fish in summer, and brinjal on the bund (throughout the seasons) is socio economically viable and sustainable and has been recommended especially lowland rice fields, prone to saline water inundation from adjoining rivers and lying otherwise barren during summer (Bandyopadyay and Maji, 1993).

Agro-forestry is a traditionally followed sustainable land use system. Arid zone farmers have been growing suitable drought-hardy and multiple-use species of trees and shrubs like khejri, ber and

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[8] The by product of dairy, ie. cowdung, forms a major raw material for biogas. Digested slurry of biogas forma a major part of feed of pisciculture for increasing plankton growth as well as supplying valuable manure to raise the productivity of crops. Similarly, the by products of field crops like paddy straw forms a major ingredient of mushroom cultivation. Again straw used for mushroom production may be utilized for cattle feed and compost preparation. The by product of poultry, ie poultry dropping forms an important ingredient of pisciculture for increasing the plankton growth as well as increasing the fertility of the land. Even apiary can have indirect benefits like pollination etc.

babool trees in the cultivated fields for sustainable production under the agro-forestry system. There is a common belief that crop productivity increases in association with khejri trees and helped in the recharge of the aquifer and conservation of moisture. During the normal rainfall years this system provides sustainable crop and fodder production, while under adverse conditions, it provides top feed, fuel and fruits. Some species like *P.cineraria* enrich soil fertility and provide nutrients to the crops. The adopted species help to check the environmental degradation, especially during consecutive droughts and famines (Saxena, 1994).

In a study, Upadhyaya (1991) mentioned that one and two year old plantations reduced sand deposition by 0.513 m^3 and 1.023 m^3 per running meter length of the canal, respectively. In economic terms, these plantations saved cost of desilting by Rs. 6156 per km in one year old plantations and Rs.12,276 per km in the two year old plantations compared to other conventional afforestation measures (Kaul, 1996).

Various land use options have been developed as alternatives to shifting cultivation. Agro forestry[9] has especially been recommended as an alternative to jhuming to combat resource degradation and in meeting the needs of the people (Borthakur et al, 1981; Awasthi et al, 1985; Parmar, 1983). Silvi-pastoral and horti-agriculture system might also be a suitable system for hill slopes from soil conservation and soil productivity point of view (Singh and Singh, 1980). Inclusion of forest, forage, and horticultural plants in the system besides food crops, assures the inherent capacity of the system to meet timber, fuel, fodder, money (from horticultural crops) and food requirement of the rural population (Prasad and Sharma, 1993). Loss of soil productivity, which forces the family to shift, is also taken care of in these systems. Emphasis is on multipurpose trees (MPTS), nitrogen fixing trees (NFTs), fast growing trees, trees for fodder, food, cash, timber, medicine etc. MPTS and alley cropping, which will play a special role in hill agriculture in preventing soil and water erosion, are the major research components in agro forestry research. Horticulture plantations with proper management increased soil nitrogen from 0.08 upto 0.385 percentage, potash from 0.077 to 1.745%, organic carbon from 0.705 to 3.625% and water holding capacity from 32.08to 49.25% (Mishra, 2002).

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[9] Agro forestry is a collective name for land use system and technologies in which woody perennials (tree and/or shrubs) are deliberately combined on the same land management unit with crop and/or animals either in some form of spatial arrangement of temporal sequence (Lundgren, 1982)

North East regions are confronted with the problem of acid soil. About 95% of the net cultivated area of 0.90 m ha is acidic in nature. The soil pH varies from 4.5 to 6.5. The soils of higher altitude and those receiving high rainfall are more acidic than the soils of lower elevations and less rainfall (Prasad and Laskar, 1985). Raising mungbean in the interspaces of coffee, napier grass in the interspaces of the rubber plantation and *Stylosanthes humilis* in association with *Acacia auriculiformis* are some of the agro forestry systems which could be suitable (Gill, 1990).

Deb Roy and Gill (1990a) described the serious problem of energy crisis and the acute shortage of fuel wood and subsequently its high price leading to the burning of dry cow dung cake at the rate of 60-80 m. t annually representing 300-400 m t freshly collected dung depriving the cultivated land the much needed precious organic manure for increasing crop and biomass production. Deb Roy (1989) highlighted the low input agroforestry land use system as a principal approach to avert risk and uncertainty of crop failure. Optimal integration of top feed trees with grasses/legume species in silvipastoral system has resulted in several times higher productivity than traditional land use system (Singh, 1989).

The Table 4 compares the runoff and soil loss in different land uses. Agriculture with suitable conservation measure allows negligible runoff and soil loss while agro forestry and forestry land uses allow relatively more runoff but less soil loss than agriculture. Horticulture alone allows substantial soil loss, which can be reduced by growing agricultural crops in interspaces. (Singh, 1988). In another watershed experiment with different land uses it was seen that livestock and agriculture uses with appropriate conservation measures reduced soil loss, surface flow was relatively higher for horticulture use followed by agriculture and agri-horti-silvipastoral while it was least for livestock based watershed (Gill and Roy, 1993).

Silvi-agro-horticulture model land use has been suggested by ICAR research Complex as an alternative to shifting cultivation (Singh, 1981). The system comprises agricultural land use towards the foothills, horticulture in the mid-portion of the hill slope and silvipastoral land use towards the top of the hill. This mixed land use system is suitable up to 100% slope having soil dept more than 1 m and includes forestry, horticulture, agriculture and pisciculture arranged in a toposequence. Agricultural crops in the foothills, horticulture in the middle and silvi-pastoral towards the top also yields an input-output ratio 1:1.47 (Borthakur et al, 1981).

The NEH Research Complex for NEH Region initiated research to suggest alternative to shifting cultivation and wastelands with appropriate conservation measure at each level, the system recommends agriculture land use[10] on hill slopes up to 50% gradient and where soil depth is more than 1 m, horticulture land use upto 100% slope and soil depth at minimum of 1.1 m, livestock land use[11] at 100% slope with minimum of 0.5 m depth (Prasad, 1993).

The jhum control schemes implemented by NEC and other State Governments provided a means of deciding on the strategy to tackle the problems of NEH region. Allotment of wetland terraces with assured irrigation has been the most effective means of attracting jhumias to settled agriculture, particularly among traditional paddy growing tribes (Prodhani, 1994). Encouragement of horticulture along with forest based cottage industries particularly cane units and animal husbandry on a smaller scale may be suggested while construction of good road connecting the interior villages was highly essential to bring the jhumias of far flung village to the national mainstream (Puia, 1994).

Bench terrace cultivation in certain areas of Nagaland, Sikkim and Manipur, bamboo drip irrigation in Jowai District of Meghalaya, efficient water management system of Apatani plateau of Arunachal Pradesh, 'Zabo farming system' and the growing of alder trees to retain soil fertility in Nagaland, high altitude farming of Buddhist Monpas of Kameng district of Arunachal Pradesh are examples of excellent management of biophysical resources based on local skill (Prodhani, 1994) (Singh, 1981; 1987). Excellent bench terraced land cultivation system is widely practiced in Nagaland and Manipur which takes care of soil and water conservation (Prasad, 1993).

3.3 Water harvesting through tanks

Harvesting water for the time when it is needed is an important constraint for farming in India. In the rain fed system water harvesting is a major tool used to cater the needs of agriculture. Small-scale operations like ponds, stop dams, Haweli Bundhies (a traditional way of water harvesting practice in which rain water is impounded in bounded fields during monsoon and sowing of rabi

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[10] Such land uses are expected to retain over 90% of annual rainfall in the slope and reduce the soil loss below 2 tons/ha/yr. (Prasad and Singh, 1990).

[11] Carrying capacity of such land use has been estimated to be 4 to 5 livestock units per ha. Out of the total geographical area in the NE, 47% is under forest, which is 24% higher than the national average. Land per human being and land per livestock is 0.96 and 2.5 ha against the national average of 0.5 and 0.93, respectively. This indicates great opportunities for livestock production. The eastern region has very little area under pasture except Sikkim (13.3%). In Manipur, Meghalaya, Nagaland, Tripura, W. Bengal and Bihar states pastures are below 1%. Almost 20% of the total area of NE region has been clasified into watershed, which can be brought under silvipasture system.

crops is generally done after draining the impounded water) are the most common measures adapted to harvest rainwater. Runoff harvesting in the form of embankment type tanks has been in practice for centuries. Silting due to increased soil erosion resulted in silting of those ponds over time. In Datia district of MP from the 16 ponds constructed for irrigation the actual area under irrigation has reduced to a mere 40% of the designed command area. Most of the runoff harvesting ponds are shallow, covering large surfaces exposed to rapid evaporation and seepage. In the red soil zones these structures stop dams/check dams are important as they recharge the ground water as surrounded wells are reported to have increased water yield. Primarily the stop dams are meant to collect and provide water for irrigation but these also help recharge ground water and check soil erosion down below (Tiwari et al, 1999).

Though attention has shifted to integrated watershed management in the 1980's, water harvesting through small tanks and reservoirs still remain a very important component, as moisture stress is the most important constraint in this area. At least the high rainfall areas like in central Madhya Pradesh with moisture retaining black soils may prove to be cost effective. In south India too, tanks have held a historically important place. However, over time tank irrigation has come down from 4.8 million ha in 1969-70 to less than 4 million ha in 1975-76 (von Oppen and Rao, 1982).

In a study conducted at Tejpura watershed it was found that the water harvesting structures (WHS) have made an overall improvement in watershed (Hazra, 1991). The well, which used to run for 2 hours, ran for more than 10 hours after these efforts. WHS increased the irrigated area from the initial 83 to 188%. The productivity of the crops increased by 220% during *Kharif* and 387% during *Rabi* when compared with the yields of base year 1983-84. The production increased by 3.47 times and gross income by 7 times over the base year (Tiwari et al, 1999).

Sahu et al (2001) have tried to asses the potential of such SFRs in various aspects like water harvesting potential, sediment trapping efficiency etc. It was found that about 20-35% annual rainfall is usually available in cultivated red soils of Karnataka for harvesting. In Doon valley it is 16.5% of monsoon rainfall. In the sub-mountain region of Maharshtra it was recorded as 23% of monsoon rainfall. SFRs are very effective in controlling soil erosion and flooding. The long term sediment trapping efficiency in micro-watersheds ranges from 60-100%. The nutrient trapping efficiency was 72% for phosphorous and 82% for nitrate nitrogen (Sahu et al, 2001). SFRs raise the ground water table and increase water yields in shallow dug wells of micro-watersheds (MW). Installation of SFRs has increased the water yields of the shallow dug wells by 11-27% in the first year and 15-34% during second year. There is a rise in water table by 0.25-1.5m for the first year and 0.75 – 1.75 m for the second year.

A study conduced to compare the costs and benefits of desilting the tanks and returning the sediment to the fields showed that the B/C ration for the desilting operations from water tanks based on the economic plant nutrient value (N and P content) of the district of Medak was calculated to be 1.23 which reflects a positive net benefit. This shows that the application of desilted sediment from the water tanks to agricultural fields is economically viable for returning N, P nutrients along with organic C back to the soil. The ratio would be higher with benefits like environmental protection, increased soil microbial bio-diversity, improved soil quality and increased water storage are added (Padmaja et al, 2003).

Possibility of rainfed aquaculture

Water resource structures like farm ponds, percolation tanks, check dams etc retain large quantities of water for 6 to 8 months or even more. Fish culture in Trapa and makhana ponds in traditional agriculture has been a recent introduction (Tripathi, 1997). Common carp in trapa ponds and air breathing catfish such as singhi and magur in makhana ponds give yields of about 1.0-1.5 tones per hectare per annum. Common carp and grass carp are being introduced into the Haveli wheat fields of Madhya Pradesh. Grass carp also helped in controlling weeds. Aquaculture absorbs all the wastes and by products of agriculture and livestock at the farm and recycles the same through production of protein food. Livestock wastes are used as fertilizers in fish ponds, those from poultry goat and rabbit being far richer in nitrogen than from cattle (Tripathi, 1997). This is an added benefit of water harvesting structures that could be harnessed.

3.4 Watershed based management system

Watershed, a hydrological unit, is an area, which has only one outlet for draining runoff/surface flow. *In situ* management of rainfall and its optimal use within any manageable area, large or small, is the basic philosophy of a watershed. Watershed management is defined as an integration of technologies within the natural boundaries of a drainage area for optimum development of land, water and plant resources to meet the basic needs of the people in a sustainable manner. Watersheds have assumed importance over the last two decades indicating a shift to micro level conservation orientation. Here we look at some of the studies indicating the positive environmental benefits of watersheds.

A study conducted in Chaapoli water shed area of Jhunjhunu district in Rajasthan revealed an increase in water table as well as the volume of water due to the various land treatment measures implemented. From the total wells of selected beneficiaries, 60% wells recorded an increase in the water table more than 5 feet (Lal, 1999). With the construction of anicuts in Ujalian watershed, Jodhpur district, static water level in wells located downstream increased from 1.8 to 2.2 m compared with increase of only 0.5 m in wells located in adjoining areas. It has also helped in regeneration of plants of different species and grasses in the upstream area.

Integrated measures in watershed management, tested in the NEH region between 1976 to 1990 was successful in retaining over 90% of the rainfall within the watershed. In high rainfall zone of Easter-Himalayas where slope is quite steep, watershed management could retain 80% of the annual rainfall and stabilize soil erosion within permissible limits (Singh 1987). Similar results have also been reported from Western Himalaya and Eastern Ghats (Dhruva Narayana et al 1985).

The success stories of Operations Research project (by CSWCRTI) watersheds namely Sukhomajri of Shiwalik Hills, Fakot in Himalayas and Siha and Bajar-Ganiyar in Aravali Hills are models of successful integrated watershed management. Sukhomajri watershed was initiated in 1975 at the Shiwalik foothill region of Haryana, Punjab and HP. This region suffered from choes (torrents) created due to large scale denudation of forests caused by overgrazing. Erratic distribution of annual rainfall, lack of irrigation and low soil fertility has made agriculture an uneconomical prospect in this region. Erosion rate was as high as 90-900 tons/ha/yr due to presence of steep naked slopes and weak geological formations in the region. The objective of the watershed was to bring down sediment rate (100-150 tons/ha/yr of catchment area) in the Sukhna Lake. The development activities undertaken reduced soil loss from 150 tons/ha/yr to less than 5 tons/ha/yr. The tree stocking in the forest catchment has significantly increased from 194 trees/ha in 1980 to 561 trees/ha in 1988 through natural vegetation. Similarly, Fakot watershed was successful in reducing soil loss from 11.0 to 2.7 tons/ha/yr as a consequence of reduction in run off from 42 to 13% at the interior of the outer Himalayan hills which is under constant threat of denudation due to vertical slopes, thin vegetation, high intensity storms and faulty cultivation practices. The area has problem of roadside erosion, trail erosion, landslip erosion and erosion in agricultural lands. The development activities at the watersheds at Bajar-Ganiyar and Siha helped to control severe gully and rill erosion. Crop failures due to uncertain rainfall, degraded land, low forest cover and limited groundwater of poor quality resulted in low crop yields were some of the problems in this area.

These watersheds also facilitated increase in net irrigated area, cropping intensity, consumption of N and P, food grain production, fodder grass yield, and milk production.

The ecosystem of the Konkan region of Maharashtra is greatly disturbed due to the indiscriminate felling of trees and cultivation of steep slopes for growing hill millets with age old farming practices. This has led into considerable soil erosion, which has adversely affected the soil fertility. The various measures followed under the Kumbhave watershed with the land uses of afforestation and silvi-pastoral crops at higher elevations (above 25%) and horti-pastoral systems in middle elevations (8 to 25%) and arable crops at lower elevations (upto 8%). The estimated annual soil loss from research farm is as high as 5 tones per hectare, while 90% of the rain water is subjected to loss by surface runoff resulting into the problems of flooding of rice fields and sedimentation of fine particles in the beds of nalas and streams. A variety of land development measures were followed. The two nala bunds helped in reducing the flow of velocity of nalas and further extension of gullies. The ground water level increased and benefit: cost ratio of these nala bunds worked out to be 1.3:1.0 considering 20 years life with 15% discount rate. The benefit cost of terracing was 1.6:1.0, land leveling 2.1:1, mango orchard of 20 years old trees was 3.1:1 and cashew orchard of 20 years old trees 3.5:1 (Talashilkar, 1990).

Traditional agriculture in the rainfed areas means low yields, generally one crop per year, low inputs, degradation of the natural resource base, low incomes and out migration, both seasonal and permanent of family members. The productivity of the soil has been declining and also there were high losses of water and soils. Better technologies are now being developed to ameliorate the problems related to the rainfed areas. The small watershed is a natural framework for resource development through in situ conservation measures.

The present farming systems of Vertisols are characterized by inefficient use of total available precipitation and low productivity. Thus an integrated watershed management technology that focuses on moisture retention and use is important. The various components of watershed management technology are dry season tillage, land and water management through grassed waterways and storage of runoff water in the farm ponds and tanks, land configuration especially broad bed and furrow (BBF) on grade, dry sowing ahead of the rainy season, improved cropping systems, use of HY and stress tolerant crop varieties, improved fertility and pest management (Binswanger et al, 1980; Kanwar, 1989).

For the cultivated rainy season fallow treatment, on average about 42% of the precipitation was lost as evaporation from the soil. In an average year this would amount to 290 mm. On the contrary, the graded ridges introduced to facilitate rainy season cropping the runoff on average amounted to only about 14% approximately 100 mm in an average rainy season. With runoff collection the total water available crop use would have increased and the effectively used rainfall would have increased to 82% (Krishna, 1979). The improved systems also increased the rainfall productivity (Kampen and Krishna, 1978). Thus the improved technology as compared to traditional fallowing can reduce the surface runoff by more than 50% and evaporation loss is reduced by over 75% while evapotranspiration is increased from 41% to 73% indicating greater availability of water for production purposes. Binswanger et al (1980), Kanwar, (1989) concluded that the improved management system could reduce soil erosion up to one fourth of the fallow treatment.

The traditional system in even normal rainfall years resulted in extremely high average soil loss of 7.75 tons/ha compared with 0.88 tons/ha from the broad bed and furrow system. The soil erosion hazard (soil loss per unit of runoff) in improved land management systems gradually reduced as the crop cover increased (Pathak et al, 1985).

In Alfisols, the contour and graded bund watersheds had the lowest runoff and soil loss even as compared to broadbed and furrow system (Pathak et al, 1985). Runoff and soil loss were found to be highest in cultivated fallow Alfisols and minimum in grassed plots. Off season shallow/deep ploughing in Alfisols in Hyderabad followed by harrowing and deep ploughing in Vertisols was found to increase yields of crops (Venkateswarlu, 1981) specially sub-normal rainfall years because this reduces runoff and allow more infiltration (Reddy, 1998).

The improved system utilizing graded braodbeds and furrows generated profit averaging Rs. 3650/ha per year over 5 years as compared to Rs. 500/ha per year from the traditional system (Kanwar, 1989). Ryan and Sarin (1981) estimated a rate of return of 250% on the increased working expenditure necessitated by changing from the traditional system of cultivated rainy season fallow.

Well distributed rains of Madhya pradesh and vertisols with good moisture holding capacity can be used to double crop (Virmani and associates, 1985). Alternative land use patterns are gaining importance with net area under rice declining and other crops viz. soybean, rapeseed-mustard, maize, pulses and horticulture showing increasing trends (Kanwar, 1995). It is estimated that 2.02

million ha accounting for 6.57% of the total area of the state were under fallowing. After the successful introduction of soybean in the state of Madhya Pradesh, which accounts for 87% of the area and 83% production of the crop in the whole country, it was assumed that the rainy season fallow has declined (Wani et al, 2002).

In Adarsha watershed, Kothapaplly, after the watershed management practices farmers obtained a two fold increase in yields in sole maize and a four fold increase with intercropped maize and pigeonpea. Along with the improved systems productivity the cost benefit ratio (1:3.47) was more compared to the farmers traditional cotton based systems (Wani, 2000). This along with the added benefits of improved greenery in the area and increased levels of groundwater and decreased runoff, soil loss etc. (Wani et al, 2001). The soil loss in the improved system is 1.5 t ha^{-1} as compared to 6.4 t ha^{-1} in the traditional system (Wani et al, 2001; Wani et al, 2002).

In another experiment, the average grain yield of the improved system over 24 years was 4.7 tons/ha/y nearly five-fold increase over the traditional system and there was an improvement in soil quality (Wani et al. 1994a; Paustian et al. 1997b) (Wani et al, 2001). The cowpea/pigeon pea intercrop system provided more than 40 kg N/ha/y to the succeeding sorghum crops, producing 3.3 tons/ha/y without N fertilizer (Rego and Seeling 1996). The improved system of BBF landform reduced runoff from 220 mm measured within the traditional systems to 91 mm, improving soil water content and reducing soil losses from 6.64 tons/ha/y to 1.5 tons/ha/y (El-Swaify et al, 1985, Wani et al, 2000). The BBF system also improved soil chemical properties by increasing soil organic C content, total N, and available N and P. An additional quantity of 7.3 t C/ha/y was sequestered in the soil under improved system over the 24 year period as compared to the traditional system. The results indicate that a crop rotation involving rainy season bare fallow accelerated the loss of soil organic C in the traditional system compared to improved system.

A clear tested approach in management of alfisol soils has not yet evolved (Al-Swaify, 1985). However, runoff management (Pathak et al, 1993) provides dependable water storage for supplemental irrigation. Success has also been reported from minimum tillage, generous residue inputs eg., mulching, and necessarily heavy dependence on herbicide use within the cropping systems. Agro forestry has been recommended. Also integration of animal component involves the application of legume-ley farming systems on SAT Alfisols (El-Swaify et al, 1985).

The national watershed program launched in 1983 with 47 Model Watersheds spread across 16 states of the country. Currently, a large number of watershed projects are being implemented in India through various initiatives sponsored by the government, externally-aided projects, non-government organizations and local communities. In the mid 1990's the total annual budget for watershed projects from various sources exceeded US$ 500 million (Farrington et al. 1999; Kerr et al. 2000) (Kerr, 1996).

The general results from most watersheds can be summarized as follows: productivity increased two to several fold, erosion was virtually eliminated and land degradation was halted, rainwater use efficiency increased which was reflected in both increases of cropping area and cropping intensity. As the water availability became more assured, high value crops like groundnut replaced traditional low yielding low value cereal like finger millet. Offsite flooding of low-lying areas of the catchment was eliminated. Additionally excessive siltation of water bodies was prevented (Sinha and Prasad, 1989). Also, the number of working days/year were more when compared to non-watershed villages (Satpathy and Bhoj, 1989). Most watershed studies list the benefits cost ratio as greater than one and sometimes close to two. Many studies cite increased yields of various crops; they range from 10 to 100%. Other studies cite qualitative improvements such as increased cropping intensity, rising water tables, increased irrigated area, higher input use and higher employment (Kerr, 1996).

However, on withdrawal of institutional support it was seen that the farmers did not sustain many of the soil and water conservation techniques. In fact thousands of watershed programs provide subsidies reaching up to 90% of investment costs in order to foster sustainable development. The program on alternate land uses involving perennial vegetation could not be sustained because of uncontrolled grazing in the absence of social fencing. The integration of new technologies with already existing traditional measures would improve acceptability in the farmers (Katyal and Venkateshwarlu, 1992). The problems of distribution of benefits and costs among farmers in the upper and lower reaches of a watershed and issues of social organization can be often addressed through integrated approaches to watershed management and innovative policies and institutional arrangements which enhance private and public participation (Kerr, 1996).

3.5 Resource Conservation Technologies

Resource Conservation Technologies (RCTs) have been mostly researched and introduced into the fields in the IGP through the Rice-Wheat Consortium. RCTs are any practice that results in higher production at less cost. These result in more efficient use of the natural resource used to produce a crop. The successes achieved with RCTs have been in the areas of crop establishment options for wheat, crop establishment options for rice and site-specific nutrient management.

The crop establishment options for wheat include surface seeding which is becoming popular in eastern parts of the IGP in areas for its potential of increasing the cropping intensity in many areas where soils remain waterlogged for long or fields are vacated late for winter season crops. The zero till system improved the productivity of wheat by nearly 15 per cent and affects saving in irrigation water, efficient use of inputs and better weed management. Saving in irrigation water with zero-tillage is in the range of 20 per cent of total irrigation water applied to wheat in conventionally tilled fields. In village Teak, Haryana, studies have shown that the combined use of new herbicides and zero-tillage completely controls the menace of *Phalaris Minor* weed, which facilitates further improvement in yield of wheat over the period (Malik et al., 1998). Reduced till systems combine the tillage done by a rotovator with seeding. This system is being promoted in the sandy soils of NW India.

Zero-tillage saves ~ 70 L of diesel/ha and 1.0 m L water and prevents yield losses due to late planting of wheat @ 35 kg/ha/day in northwest of IGP and up to 60 kg/day/ha in the eastern parts. Farmers save Rs. 2500-4000 per hectare in tillage operations. Just 0.1 m ha of zero-till in 2000-01 in IGP, saved 7ML diesel, and savings in water can fill a lake of 5 sq. km to a depth of 100 m. Environmentally, there are tremendous benefits in terms of GHG emissions through reduced diesel use and less burning of residues. It is estimated that if zero-tillage is adopted on 1 m ha of the 13.5 m ha under rice-wheat systems in S.Asia, CO_2 emissions could be reduced by 0.26 m tonnes.

Raised bed planting system is growing crops on raised beds and using the beds permanently with consecutive crops which adds to the benefits of zero-till to bed planting and is a more sustainable system. The main benefit of bed planting is savings in water. Almost all farmers report 30-35 % less irrigation time in tube-well irrigated areas. This technology is gaining popularity as it opens up avenues for farmers for diversification and intensification of the cropping systems in the IGP even during the monsoon season. Raised bed prepared from the amended soils increases the depth of the rooting zone and improves crop productivity. The technology can be used in at least more than 3 m ha of partially reclaimed or un-reclaimed soils with advantage in the northwest IGP.

Crop establishment options for rice also consist of zero till rice. In western parts of the IGP rice wheat area sown with zero-till drills has increased from virtually nothing to around 200,000 ha in Pakistan and India. Bed planting is transplanting of rice on beds used for growing wheat. Savings in irrigation water could be anywhere around 35-40 per cent and more. Urea super granules in puddle soils saves nitrogen up to 25 per cent with no reduction in yield of the rice crop. Parachute planting or seedling broadcasting is another RCT for rice.

The LCC is a good eco-friendly cheap tool for Site-specific nutrient management in the hands of small farmers to approximately optimize N use, irrespective of the source of N applied-organic, bio-, or chemical fertilizers. It was observed that 74 per cent of the farmers obtained equal or higher yields in LCC N-managed trails and saved N on an average 25 kg ha^{-1}. The remaining 26 per cent of farmers affected saving of N but had lower yields due to several reasons (Table 1). With LCC the N applied was 124 kg ha^{-1} as compared to 149 kg ha^{-1} in the farmer's practice and grain yield was 6371 as compared to 6359 kg ha^{-1} and the PFP-N was 51.4 as compared to 42.7 with nitrogen saved amounting to 25 kg ha^{-1} in LCC use.

<u>Some Estimates of Savings from RCTs</u>

A survey done by Haryana Agricultural University appears to indicate that RCT is scale neutral. (Malik et al, 2002, Punia et al, 2002). Farmers felt that zero till was profitable and resulted in $ 75 per ha more cost reduction than conventional practices. Yields for zero till were 5.4 tons/ha/y against 5.1 tons/ha/y for conventional practices.

Data in the table 16 show that 60 L of diesel can be saved per hectare in zero-till. If eventually used on even 1 million ha of rice-wheat area, zero-tillage would reduce diesel use by 60 million liters. Using conversion factor of 2.6 kg CO_2 produced per liter of diesel burned, this would represent a reduction of more than 156 000 tons yr^{-1} in CO_2 emissions. Changing how rice is grown can and promoting more non-puddled rice cultivation on beds or on flat surfaces can reduce methane emissions. Improving fertilizer efficiency can also reduce nitrous oxide emissions. No-tillage practices also result in less oxidation of soil organic matter and might help with sequestering of C. Zero till also reduces water use by about 10 cm or approximately 1 million L ha per year (Malik et al, 2002). In bed planting, farmers have also said that it takes half the time to irrigate their fields than on the flat surface.

RCTs also help in reducing organic chemicals for weed and insect control. Zero tillage results in less wheat germination because less wheat seed is exposed than with normal tillage Malik et al (2002). In bed planting weeds can be controlled mechanically instead of using expensive herbicides. This is especially important in areas where *Phalaris Minor* has developed resistance to the herbicide (Malik et al, 1998; Yadav et al, 2002). The data suggests that the diversity of beneficial insects was higher in zero tilled fields than in conventionally tilled ones.

Table 16: Benefits from RCTs

Item	Farmers Perceptions	Researchers Findings
Sowing	Wheat sowing earlier by 5-8 d (smaller to medium farms) to 2 wk (large farms)	On average, wheat sowing can be advanced by 5-15 d
Fuel saving	Not available	On average 60L diesel per ha
Cost of cultivation	$42-92/ha	$37-62 per hectare per year
Plant population	20-30% more plants in zero till fields	13.5% more plants in zero-tillage fields
Weed infestation	20% less and weaker weeds in zero-till fields	43% less weeds in zero-till fields
Irrigation	Saves 30-50% water in the first irrigation and 15-20% in subsequent irrigations	36%less water used, on average
Rice stem borer	Less, because of less stubble sprouting	Winter coolness impairs sprouting and thus borer development. Beneficial insects in stubble help control borers
Rice stubbles	Decayed faster	Decayed faster
Fertilizer use efficiency	High	Higher because of placement
Wheat yields	Higher than under conventional system depending on days planted earlier	420-530 kg more per hectare

Source: Malik et al, 2002

3.6 Integrated Pest and Nutrient Management

Integrated pest management can help combat many of the problems of increased use of chemical fertilizers and pesticides. IPM has evolved in this region as a control measure for pesticide contamination without loosing on productivity (Dhaliwal et al, 2000). Policy interventions in the year 1985 had helped its adaptation successfully in IGP. The adoption of IPM technology resulted in 61.70 per cent reduction in the number of insecticides sprays for control of sucking pests and whereas number of sprays for bollworms increased by 13.17 per cent. The reduction in bollworms incidence in operational research project villages was 38.55% as compared to non-ORP villages, which resulted in an increase in yield of 25.8% and increase of 31.2% in the net income (Sidhu et al, 1990). Ten percent of the farmers in the IPM villages have not used any pesticide and the average expenditure on pesticide was much lesser in these villages (Rs. 364 as compared to Rs. 1063) and yield was higher (Dhaliwal et al, 2000).

Over time pesticides have undergone considerable changes and environmental friendly pesticides in place of more stable organochlorine pesticides have reduce the impact of pesticides on the environment. In a recent survey on total dietary intake of pesticides the corresponding levels DDT have declined to 61 and 30 μg/person/day in vegetarian and non-vegetarian diet, respectively (Dhaliwal et al, 2000). In Haryana, use of plant protection chemicals has been increasing, and the spectrum of chemicals shifting from total dependence on organo-chlorine chemicals to the introduction of alternatives that are less harmful and leave only degradable residues (Pathak et al, 2001).

Over the years most of the organo-chlorine insecticides have been replaced by less persistent organo-phosphorous insecticides. A chemical with a toxicity index of 1.0 and a persistence index of 1.0 if applied at the rate of 10 kg ha y will almost disappear from the soil within one year. The biocide application index for such an application would be 100, which is considered safe. BRI<100 is considered desirable and BRI< 200 as permissible in terms of environmental safety (Pathak et al, 2001). BRI for different crops and land use types do not suggest any alarming situation for the environmental impact of biocide use in rice and wheat based systems. However, for cotton and potato based land use systems BRI attain very high values mainly because of the use of toxic and persistent insecticides. For this reason maize-potato-wheat and cotton-wheat systems had the highest BRI at all technology levels. Decreasing trends of cotton and potato based crops in IGP is a clear indication of reduce pesticide contamination of the environment (Pathak et al, 2001).

Long-term experiments on continuous rice wheat rotations show evidence of depletion and imbalance in soil nutrients, including micronutrients, and a general reduction in soil organic matter, all or some appear linked to stagnating or lower yields. On farm SSNM has focused on: 1) crop nutrient requirements based on an economically efficient yield target; 2) estimation of potential soil supply of N, P and K; and 3) plant N status during critical periods of rice growth. Yield gains were from 10-20% because of SSNM.

3.7 Mitigation of methane emissions

Continuously saturated soil in paddy fields gave higher CH_4 emission compared to intermittent wetting and drying soil conditions. Increased irrigation and waterlogging conditions in IGP enhances the methane emissions substantially. Subsidizing electricity and canal irrigation water has indirectly influenced the GHG emissions from IGP. Application of DCD, a nitrification inhibitor, with urea reduced emission of CH_4 in rice-wheat system by 30% while substituting 50% of inorganic N with FYM increased emission by 172% compared to application of entire amount of N though urea. In wheat, negative fluxes of CH_4 ranging from 0.01 to 0.13 kg ha^{-1} were recorded. Intermittent wetting and drying of soil in rice has a potential to reduce the emission (Pathak et al,

2003) (Pathak, 2003). Application of FYM and DCD also reduced emission of nitrous oxide in rice and wheat. In rice-wheat system, typical of a farmer's field in Indo-Gangetic plains, where 240 kg N is generally applied through urea, nitrous oxide emission is 1570 g/ha (0.38% of applied N) and application of FYM and DCD reduced it to 1415 and 1096 g/ha, respectively (Pathak et al, 2002; Pathak, 2003).

With the growing emission levels of methane from Rice-Wheat cropping system and increasing pressure on various international platforms, certain measures have been tried to control the methane and nitrous oxide emissions from this potential GHG emitting sector. The improved awareness for the conservation measures and resource conserving technologies like RCT showed a positive sign in controlling these emissions and the following are few potential measures, which are proved potential on experimental basis in the Irrigated AES

- Modifying irrigation pattern: Drainage is a major modifier of seasonal methane emission pattern. Intermittent flooding practices are very effective in reducing methane (Pathak, 2003).

- Managing organic inputs: Organic amendments to flooded soils increase methane production and emission. However, application of fermented manure like biogas slurry reduces this emission.

- Use of suitable crop cultivars: Rice cultivars like Pusa 169 had a emission level of 15.6 kg/ha while that of Pusa 933 emitted about 27.2 kg/ha.

- Modifying fertilization practices: A frequently suggested mitigation option is the use of sulphate-containing fertilizers such as ammonium sulphate because the sulphate reducing bacteria can out compete methane producing bacteria and thus reduce the amount of methane produced from rice fields. Thus, midseason drainage instead of continuous flooding, direct crop establishment like dry seeded rice and use of low C:N organic manure and biogas slurry and use of sulphate containing fertilizers would result in reduced GHG emissions from IFS.

- Use of nitrification inhibitor: Curtailing the nitrification process by the use of nitrification inhibitor may decrease nitrous oxide emission from soil.

Section B: Agricultural Policies and their Implications for the Environment

1. Introduction

Indian agricultural development has been marked by four different phases, where the period of pre-independence to 1966-67 was marked by acute food shortages, frequent famines followed by import of food grains. In the next period from 1966-67 to 1980-81, adequate food grain production was achieved by recognizing the role of science and technology[12]. Policies for procurement of food grains, buffer stock and public distribution system were put in place along with the Commission on Cost and Price in agriculture. The period from 1981-82 saw an increasing growth rate in most cereals, but shortage of oilseeds and pulses. Thus, 1981-90 was a period of boom in growth of crop-based agriculture, except pulses. Since 1991, a phase of economic liberalization, the Oilseed production has increased resulting in decrease of vegetable oil imports. Changes in seed policy increased the activity of private sector in horticulture. All the above phases are essentially policy driven changes in Indian agriculture.

The Draft Agricultural Policy Resolution in June/July 1990 was the first attempt at a National Agricultural Policy by the Ministry of Agriculture, GoI. It sets out eight objectives for the new agricultural policy focusing on increased output, efficiency in resource management and technologies, strengthening the institutional infrastructure and facilitating farmers participation in the formulation of agricultural policies and programmes, encouraging processing of agriculture produce and increasing agricultural exports and so on (Singh, 1992). The agricultural development strategy included a package of market intervention policies over the years. The instruments of market intervention currently in vogue inter alia, include, minimum support prices for 24 agricultural commodities, buffer stocking for wheat and rice, subsidized distribution of wheat, rice and sugar, levy on rice millers and sugar mills, subsidy on fertilizers, lower user charges for canal water and electricity for irrigation, regulation of domestic trade practices including inter alia stocking restrictions. All these have increased the physical and economic access of the masses to food and accelerated the growth of agricultural commodities (Acharya and Chaudhari, 2001).

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[12] Some of the measures were reorganization of the Indian Council of Agricultural Research, establishment of new organization and institutions such as The National Dairy Development Board, The National Seed Corporation of India, The Food Corporation of India, Fertilizer Industry, State Agriculture Universities and others by the Government of India.

2. Overview of the major characteristics of Indian agriculture

Agriculture and allied activities contribute 24.9% (2000-01) to the gross domestic product (GDP), with agriculture (includes all crops, animal husbandry and dairying) contributing 22.7% and forestry and fishing at 1 and 1.2% respectively. The share of agriculture and allied activities has fallen from 57.7% in 1950-51, when agriculture contributed 50% of the GDP, with forestry contributing 6.7% while fishing contributed 0.89%. In absolute terms, contribution of agriculture and allied activities has more than tripled from about 81000 crores to 290000 crores (at 1993-94 prices).

Agriculture is the dominant land-use type with a net sown area of around 143 Mha since the 1970s, accounting for 47% of the reporting area. The forest areas occupy 22.5% of the area, while 3.6% is under permanent pasture and grazing lands, 4.7% is culturable wasteland and 7.6% is under current and other fallows. Around 34% of the area under agriculture is sown more than once, amounting to a gross cropped area of 191 Mha (1997/98). The share of forests has increased from 14% to 22% of the reporting area though it still falls much shorter of the targeted 33% of the total landmass, according to the National Forest Policy. Net area sown has increased from 42% to 47% while, area sown more than once as a percentage of total cropped area has shot up from 10% to 24%. Fallow lands have fallen from 10 to 8% of the reported area, culturable waste lands have fallen from 8 to 4.5%, a huge decline has been noted in the area under land under miscellaneous tree crops and groves from 7 to 1%, a slight increase from 2.3 to 3.6% in area under permanent pastures and other grazing lands, and a fall in the area not available for cultivation from 17% to 14%.

Cereals account for about 53%, pulses account for 13%, thus the area under food grains occupies 65% of the total gross cropped area, commercial crops as a whole (including oilseeds, sugarcane, tea, coffee, cotton, jute, mesta, tobacco etc) make up 25% with oilseeds alone accounting for 15% and horticultural crops at 4%. Among the important crops, rice occupies 23% while wheat occupies 13% with jowar and bajra occupying 6 and 5% respectively among cereals. Sugarcane occupies 2.3% while groundnut occupies 4%, rapeseed and mustard 3.3%, cotton almost 5%.

Over time, in terms of relative shares in cropped area, rice has more or less retained its share, while wheat occupied only about 7.6% of the area in 1950-51, jowar had a higher share at 11.8%, bajra at 7.4%. Total cereals as a whole has actually fallen from 61% to the current 53%. Pulses were at 15.6%. Sugarcane has risen from a mere 1.3% and horticulture crops were at 1.7%. Total oilseeds share has gone up from 8.3% while cotton has slightly improved from 4.3% in 1950-51.

In terms of employment patterns in agriculture sector, population of total workers has increased from 140 to 402 million while the total population has risen from 361 million in 1951 to 1027 million in 2001. The share of rural population has declined from 82.7% to 72.22%, while that of cultivators in the workforce has declined from 49.9% to 31.7% and that of agricultural laborers has risen from 19.5% to 26.7% in the workforce (Source: Indiastat.com). More than 60% of the country's population still depends on the primary sector directly or indirectly.

The production of food grains has increased from 51 million tonnes in 1950-51 to 212 million tonnes in 2001-2002. The yield of food grains has risen from 522 kg/ha in 1950-51 to 1739 kg/ha in 2001-02 while that of cereals has risen from 542 kg/ha to 1983 kg/ha in the same period. The growth rate of agricultural production was 3.2% in the first plan period of 1951-56, dipped to a negative of 0.8% in the third plan 1961-66, peaked at 6.2% in the sixth plan period of 1980-85 and was at 4.1% in the eight plan, 1992-97. Crop-wise, while rice, wheat and oilseeds surged forward during the eighties, there was stagnation in the production of coarse cereals, pulses, cotton, jute and sugarcane (Nadkarni, 1993). Fish production rose from 752 million tonnes in 1950-51 to 5262 in 1998-99.

In terms of geographical spread, the five states of Punjab, Haryana, Uttar Pradesh, Uttaranchal, Bihar and West Bengal contribute 50% of the total rice production in India, 82% of wheat production, 57% of total cereal production and 55% of total foodgrain production while the semi-arid states of Andhra Pradesh, Karnataka, Tamil Nadu, Goa, Maharashtra, Gujarat, Orissa, Madhya Pradesh, Jharkhand and Chattisgarh contribute 42% of total rice production, 9% of wheat production, 33% of total cereal production, 62% of total pulses production and 35% of the total foodgrain production. These states account for 52% of the total cropped area (56% of the net sown area), while the five states of the Indo Gangetic Plain account for 31% of net cropped area and 27% of the net sown area. The hilly states of north east and north west Himalayas account for 4% of the net cropped area and account for 4.25% of total food grain production. Rajasthan accounts for 11% of the area and 5% of the total food grain production.

3. Review of the various policies

3.1 Input and Output Price Policies

Output Price Policies: Output price policies have influenced certain important changes in cropping patterns across the country. The strong favor towards rice and wheat became more pronounced after 1980 mainly due to the advantage of the minimum support price (MSPs) for these two crops. This has led to the accumulation of huge grain stock, ironically from diverting cereals from consumption to government warehouses. The MSP has been increasing year after year. For paddy the MSP increased from Rs. 105/ quintal in 1980-1981 to Rs. 530/ quintal in 2001-2002 and for wheat, from Rs. 130 / quintal to Rs. 580/ quintal (FAI, 1999-2000; Acharya, 2001). Crop specific policies have heavily protected oilseeds in the recent years (Gulati et al, 1989). These policies have apparently influenced the choice of crop for the farmers who choose to grow cereals or oilseeds in disregard of the available natural resource endowments, given the availability of irrigation on their plot. In the IGP, introduction of legumes has promise of increasing productivity and also environmentally beneficial. However, given the present price policies it will be highly unlikely that farmers will take up legumes in a significant way to replace either of the two cereals. Govt. policies make rice and wheat more remunerative than chickpea and pigeonpea (Sidhu et al, 1998).

Input Subsidy Policies: The growth in agricultural output achieved over the nineties because of higher output support prices was combined with a range of input subsidies on water, fertilizers and power. Subsidies on farm inputs have meant subsidies on fertilizers from the Central Government and on canal irrigation and electricity from the State Governments through low user charges. These account for the bulk of the total subsidy for the farm sector.

Considering all the three major inputs together total input subsidy works out to be Rs. 25094 crores during 1995-96, of these fertilizer subsidy accounts for 25.8 %, electricity for 54.2% and canal irrigation for 20.9%. These three taken together, which accounted for 3.38 per cent of GDP from agriculture during 1980-81 increased to 9.82 per cent during 1995-96. In real terms, the implicit subsidy on canal irrigation at 1981-82 prices increased from Rs. 417 per hectare to Rs. 1038 per hectare during 1981-82 and 1995-96, while fertilizer subsidy increased from Rs. 0.62 per kg to Rs. 1.52 per kg and the electricity subsidy increased from Rs. 0.26 per kwh to Rs. 0.54 kwh. (Acharya, 2001).

Fertilizers and Pesticides

The fertilizer (NPK) consumption in India has increased from 0.5 MT in 1963/64 to 5.5 million tons in 1980/81 and to 19.3 million tons in 2001/02. The fertilizer production of 14.3 MT during 1999/2000 fell short of the consumption by 27% (Moef, 2002). Fertilizers have been heavily subsidized since 1973-74 and maintained as the the diffusion of HYV was gathering momentum. The growth in the subsidy began in Nov. 1977 when the fertilizer retention price scheme was introduced to encourage investment in the domestic fertilizer industry (Acharya, 2000a; 2000b). The total subsidy on fertilizers (including imports) was estimated at Rs 14170 crores in 2001/02 (MoF, 2002; Moef, 2002).

Government policies to accelerate food production have played a key role in the growth of fertilizer use[13] (Desai, 1982,83, 1986a&b, Desai and Singh, 1973; Desai, Chary and Bandyopadhyay, 1972). This had exercised certain bias towards the states with more/better irrigation infrastructure and irrigation intensive crops like rice and wheat. The required orientation in policy now lies in exploiting the potential of the more than 70% of the unirrigated land (Desai, 1983) (Stone and Desai, 1989), with particular emphasis on state like north-east or Madhya Pradesh, Rajasthan and Himachal Pradesh, where agriculture is prone to high risks.

In India the consumption of technical-grade pesticides increased from 8,620 tons in 1960/61 to 75,000 tons in 1990/91. Higher usage of pesticides has resulted in several pesticide–induced pest outbreaks, loss in biodiversity of natural enemies, secondary pest outbreaks, and development of resistance to pesticides, food contamination, adverse health impacts, and ecosystem damage. Hence, certain restraints have been enforced on their usage. Out of 166 registered pesticides in India under the Insecticide Act 1968, 34 are either banned or restricted in developed countries and 27 pesticides have been banned and 10 other pesticides have been put under restriction so far in India.

The subsidy on fertilizers have led to their overuse especially in the irrigated areas. However, nutrient overload is not yet considered a major environmental problem for India. Most of chemical pollution that is reported is however, from the intensive agriculture areas of the irrigated AES. Also

[13] Some of the salient features of the government policies were investment in irrigation, development of agricultural research, extension, credit-linked fertilizer distribution systems, establishment of national markets for farm products, active role in developing modern technology based domestic fertilizer industry, maintenance of uniform prices of crops and fertilizers at reasonable levels.

the imbalance between nitrogen, potash and phosphorous usage with the relative use of nitrogen being excessive is a matter of concern (MoF, 2002; Moef, 2002). Centrally-sponsored schemes on the balanced and integrated use of fertilizers and a national project on the development and use of organic/biofertilizers have been undertaken. It is proposed to promote the use of organic manure and organic farming in a big way during the Tenth Plan (Ninth Five-Year Plan, 1997-2002).

As a measure to reduce the chemical pesticides, IPM is being practiced since 1985 with the emphasis on pest management through a combination of agronomic, chemical and biological methods. IPM is being promoted in the country through 26 Central Integrated Pest Management Centers located in 22 States and 1 Union Territory. This has resulted in the reduction in the technical-grade pesticides consumption from 75,000 tons in 1990/91 to 49,160 tons in 1998/99 (MoA, 2001a).

Irrigation

The creation of irrigation potential and its optimum utilization have been accorded a high priority in governmental planning. The net irrigated area has increased from 22.6 Mha in 1950/51 to 94.7 Mha in 1999/2000[14] (MoF, 2002). Because of the storage works created the country today has a designed live storage capacity of 177129.4 thousand million cubic meters at full reservoir levels.

Typically, water rates for agriculture and domestic consumption do not cover even the working expenses of providing the service, let alone capital costs. In the irrigation and urban sectors, the percentage recovery of working expenses through gross receipts in recent years is only about 10% and 30%, respectively. The subsidy regime has on the one hand encouraged inefficient use of the resource and on the other, led to poor financial health of the sector, resulting in poor services and user dissatisfaction (Moef, 2002). The low charges on irrigation have prevented the farmers from using efficient water regimes which could in turn reduce the emission of methane. There are wide variations in these rates between crops and among states. However, cheap irrigation have encouraged farmers to opt for water intensive crops vis-à-vis crops which could be more environmentally sustainable. The subsidy on canal irrigation is estimated to have increased from Rs. 598 crores during 1980-81 to Rs. 5253 crores during 1995-96 (Acharya, 2001).

[14] The government launched the Accelerated Irrigation Benefit Programme (AIBP) in 1996/97, under which the Centre has committed additional financial support to states for the early completion of selected large irrigation and multi-purpose projects

Electricity

Electricity has been heavily subsidized for the agriculture sector. The subsidy involved in the sale of electricity for agricultural purposes, which during 1980-81 was Rs. 334 crores, is estimated to have increased to Rs. 13,606 crores during 1995-96. It is estimated to have crossed Rs. 20,000 crores during the last two years. According to the Planning Commission (1994) the average unit cost of supply of electricity in India during 1992-93 was Rs. 1.35 per kilowatt-hour and it went up to Rs. 2.43 per kwh by1998-99. The average tariff of Rs. 0.16 was the lowest among all consumer groups (Acharya, 2001).

Heavy subsidy on electricity has greatly contributed to increased irrigation levels and over extraction of ground water. This subsidy has shown considerable bias to the irrigated farming system and led to changes in cropping patterns, which is a major cause of environmental externalities. The cost of extracting water due to the declining water table does not get reflected in the private costs as the farmers are paying flat rates on electricity to operate tube wells and their marginal cost of extracting ground water is zero (Dhawan, 1986; Joshi and Tyagi, 1991). It was found through a cross-district regression that one percent increase in rice acerage will increase net draft by 318 mcm and one percent increase in the number of tube wells will extract 495 mcm additional volume of groundwater.

The state of Punjab incurs a subsidy cost of Re. 0.40 for every unit of electricity consumed in agriculture amounting between Rs. 100 crores and Rs. 120 crores of the total expenditure every year (Johl, 1984). It is reported that the Punjab farmers get a subsidy of Rs. 5.90 on electricity to produce one quintal of rice, Rs. 3.95 for cotton and Rs. 1.46 for wheat (Gulati, 1990). These subsidies create disparities among states and different agriculture practices and encourages intensive cropping in irrigated areas leading to various water, soil and air related environmental problems. Improved water and energy pricing policies (for RCT) could reduce water use by 25 per cent (Pingali and Shah, 1999).

Allowing private sector participation and competition is expected to improve the sector's financial viability and also serve the overall objective of sustainable development by arresting the inefficient generation and use of power, promoting technological innovations and encouraging the use of non-conventional energy by correcting the under-pricing of conventional sources of electricity.

Thus subsidies have led to distortions in the cropping pattern in favour of water intensive crops, adverse environmental effects like waterlogging and salinity, depletion of groundwater and the bulk of the benefits have gone to irrigated areas with serious long term implications for inter regional disparities in development.

The subsidy on electricity encourages the use of mechanized inputs. The use of animal power declined from 45.30 percent in 1971-72 to around 9.50 percent in recent period. Tractors and power tillers have become widespread. The power tillers account for the recent farm power requirement about 44 percent in 2001-02 from 7.75 percent in 1971-72. The level of electrification across states in the agricultural sector as a proportion of total usage of electricity for 1998- 99 shows that electricity consumption ratio is quite high in states like Andhra Pradesh, Gujarat, Haryana, Karnataka, Madhya Pradesh, Punjab, Rajasthan and Uttar Pradesh at around 40%. However, the level of electrification is quite poor for states like Assam, Kerala, and West Bengal below 10%. (Debashis, 2003).

However, the question of input subsidies is intricately linked with the overall philosophy of maintaining low input and low output prices, which also helped in keeping the food subsidy bill low. A decrease in subsidies might have other macro level impacts like reduction in private investment in agriculture, decrease in incomes of small and marginal farmers (even if reduction in input subsidy is compensated with a rise in output prices), increase in product prices and cost of living of buyers. Higher fertilizer price to farmers would lower fertilizer use, yields and output. Similarly, part of the gain for the central budget of raising fertilizer prices for the farmers may be lost as it would necessitate raising of procurement prices/support prices (Parikh, 1993). Parikh and Suryanarayana (1992) through a general equilibrium model conclude that a policy to reduce fertilizer subsidy would be beneficial if simultaneously a rural work programme providing employment or a program to develop additional irrigation at the rate of 2 million hectare per year could be taken up (Parikh, 1993). Finally, investment subsidies are preferable to input subsidies and would lead to higher growth and income subsidies can be used to protect the poor against higher agricultural prices. This further adds to the betterment of environment and natural resources base with better utilization and exploitation patterns and balance in cropping patterns development.

Credit

The National Bank for Agriculture and Rural Development (NABARD) is the key institution directing flow of credit to agriculture. Some noteworthy developments in recent years have been the launch of the Rural Infrastructure Development Fund (RIDF) in 1995/96 and the Kisan Credit Card Scheme (KCCS) in 1998/99, to facilitate short-term credit to farmers. The RIDF has been set up to assist the state governments while state-owned corporations provide financial support for ongoing rural infrastructure projects. Successive Union Budgets have been raising the allocations to the RIDF. Cooperative banks, the Regional Rural Banks and the commercial banks together had issued 14.4 million KCCs up to the end of March 2001, with the amount sanctioned at Rs 26,058 crores (Planning Commission, 2001c).

To encourage the flow of credit to the agriculture sector, a share of 18% of net bank credit is targeted for lending by commercial banks. The Reserve Bank of India (RBI) has also evolved an annual plan of action for disbursement of credit to agriculture called the Special Agricultural Credit Plan (SACP) that targets 25% growth in disbursements each year. The availability of credit to agriculture from nationalized banks has not been growing at desired rates; the share of agricultural credit has been declining from the targeted 18% and is a matter of concern. However, there has been no decline in absolute terms in the credit flow to agriculture. Credit flows to agriculture and rural sector have tended to be concentrated in a few regions and on well-to-do farmers and business in rural areas. Regionally, the northern, southern and western states had the highest credit disbursement per hectare, the eastern and central states used less than half. In aggregate terms, eight States (Andhra Pradesh, Tamil Nadu, Karnataka, Kerala, Punjab, Haryana, Gujarat and Maharashtra) received a substantial proportion – about 70 per cent of total commercial bank credit advanced for agriculture in recent years (Nadkarni, 1993). Given the fact that major share of landholding is from small to medium farmers, the enhanced credit system could encourage the development of arid and semi-arid zones which could help subsequently in reducing the environmental and natural resources concerns.

The agricultural insurance programmes are also gaining importance. Major insurance programmes involve National Agricultural Insurance Scheme (NAIS), which has replaced Comprehensive Crop Insurance Scheme in 1999-2000. The scheme covers all food crops, oilseeds, and eleven commercial/horticultural crops. At present the scheme is operational in 21 states and 2 union territories. The Pilot Scheme on Seed Crop Insurance was initiated in 1999-2000 for Rabi crops in ten states. The cattle are also insured by four insurance companies, and provides up to 100 percent of the market value of an animal at the time of death. All these steps have been instrumental in lowering the risk associated with agricultural activities. The budget 2002-03 has also proposed to set up a separate corporation for agricultural insurance in the coming years. This helps farmers in exercising variations in cropping patterns breaking the prolonged routine sequences, which are among the basic causes of environmental concerns.

Seeds

The distribution of certified seeds had increased to 0.83 million tons by 1998/1999 (MoA, 2001b). The area under HYVs was 78 Mha in 1998/99. Nearly 73% of the area covered by HYVs is under rice and wheat. While the availability of certified/quality seeds has increased substantially, the seed replacement rate (SRR) has still remained much below the desired level of 20% for self-pollinated crops. For rice and wheat it ranges between 8-9% and is much below desirable levels for other crops such as pulses and oilseeds.

3.2 Investment policies

The capital expenditure on agriculture has fallen from 4376 crores in the fifth plan to 2666 crores in the eighth plan (Chand, 2001). The proportion of public investment in total agricultural investment has declined from 38.7 per cent 1980-81 to 27.0 percent in 1989-90. Private investment in agriculture increased from Rs. 2840 crores in 1980-81 to Rs.3165 crores in 1989-90 (at 1980-81 prices) during the decade; it is however, marked more by fluctuations. The increasing private investment was not significant enough to offset the decline in public investment. Proportionately, there is now less resource flow to agriculture from plan outlays (Nadkarni, 1993).

Analyzing head wise expenditure, investment in major and medium agriculture projects continued as the dominant item of capital expenditure on agriculture. Major irrigation project occupied 31% of the public expenditure in the fifth plan, which has increased to 37% in the eighth plan while allocation on minor irrigation has gone up from 3 to 7%. The share of soil and water conservation has declined from 1.92% to 1.46%. The investment on fertilizer industry fell from 6% to 0.7% in the same period. Animal husbandry, dairy development, fishery, forestry and wildlife put together were allocated only 0.11% of the public investment. The emphasis on major irrigation has been to the exclusion of investment on other categories. Irrigation through major projects instead of micro-level projects has already led to large areas becoming waterlogged and saline.

3.3 Trade Policies

Both domestic and foreign trade have been highly regulated. Domestic trade in rice and wheat is regulated through the Essential Commodities Act of 1955, which were lifted in 1993/4 by the central government though some states still impose restrictions under the ECA. The food grains segment as well as the oilseeds external trade remains largely restricted with the notable exceptions. Thus, domestic prices often deviate from their corresponding border prices.

The new treaty of GATT has included an "agreement on agriculture" which needs member countries to undertake reforms in four principal areas: market access, domestic support, export competition/subsidy and sanitary and phyto-sanitary measures. The globalization objective is embedded in the GATT accord that requires agricultural policies to be geared towards establishing a market oriented agricultural trading system and in our structural reforms that call for deregulation of foreign trade and foreign investment. In area of market access the obligations are to dismantle all physical barriers or quantitative restrictions such as quotas, bans etc on imports and exports and replace these by bound tariffs and reduce tariff level by 24% over ten years. In India quantitative restrictions on imports of most agricultural commodities have been removed and exports are being liberalized.

The crops having low resource cost ratios or lower protection coefficients are likely to flourish more in an open economy environment. Wheat has the lowest RCR at 0.49, followed by gram, rice, cotton and coarse cereals like jowar, maize and bajra indicating that these crops can be encouraged as their domestic production is resource efficient. Groundnut and rapeseed-mustard have RCRs above 1, thus oilseeds do no appear good on the allocative efficiency test. However, domestic policies have worked in such a way as to make rapeseed-mustard highest on the profitability index dissuading farmers from opting for wheat and rice during the late 1980s and early 1990s. Under an insulated agriculture, Indian policy making has encouraged cash crops like oilseeds at the cost of cereals. The various measures introduced under the Technology Mission on Oilseeds, launched in 1986 led to a rapid shift in favour of oilseeds. The impact of trade liberalization on rice, wheat cotton and sugar/sugarcane will increase their production and there would be an export of these items (Gulati, 1998).

Trade liberalization is expected to encourage business oriented agricultural activities such as the production and marketing specialty items in the fields of horticulture, floriculture, fisheries and etc (Rao, 1994; Chand and Jha, 2001; Gulati and Sharma, 1994). As against this some fear that liberalization would destabilize prices and change the crop pattern away from food resulting in sharp price increases for food grains (Chand and Jha, 2001). The strategies needed would be different for the eastern regions, dryland regions and fallow and waste lands (Rao, 1994). Dry land areas could benefit significantly from trade as they have a comparative advantage in horticulture and livestock products, the demand for which is less inelastic than for foodgrains (Rao, 1994). The country should harness the export potential for processed agricultural products and therefore the country should move in the direction of diversifying its agriculture, particularly in rice growing areas, which show symptoms of degradation in their natural resource base. (Chand and Jha, 2001).

Effective rate of protection and terms of trade

It has been well established now, that in spite of heavy input subsidization in Indian agriculture, the sector has been net taxed rather than net protected. Taxation comes in the form of direct restrictions on interstate and international trade, output price controls and an overvalued currency that discriminates against tradable goods sectors such as agriculture. Both the measures of support, namely aggregate measure of support (AMS) and the producer support estimate (PSE) worked out to be negative for the period of 1986-2000 under the importable hypothesis and also under the exportable hypotheses except in year 2000 (Gulati and Narayan, 2003). The protection level of agriculture was found to be on an average about half the level of protection of manufacturing (Gulati and Kelley, 1999).

Studies (Gulati and Sharma, 1992,1994) show that while the agricultural sector in India has remained (net) disprotected, the subsidies arising out of the inappropriate pricing of inputs and outputs have led to inefficient resource use, the erosion of government's capacity to finance public investment and has benefited only the producers of a few crops in a few states. As regards input subsidies, the volume of subsidies on fertilizers is not entirely attributable to the farm sector (Gulati, 1989; Tyagi, 1991; Vidya Sagar, 1993; Moef, 2002). In spite of huge subsidies and no income tax levied on the farm sector, the net effective rates of protection for the producers of important commodities like wheat and rice work out to be negative (Gulati, 1987, 1989). In fact a high protection rate accorded to the manufacturing sector has been acting as an indirect tax on agriculture. (Johl, 1995)

3.4 Research and Extension Policies

The share of agricultural research and education in public investment (annual capital expenditure) in agriculture was 0.02% in the fifth plan period which increased to 0.15% in the seventh plan period but has fallen to 0.08% in the eighth plan. One drawback of liberalization is that the economic reforms aimed at fiscal stabilization have reduced the public funds available for research and infrastructure development (Rao and Gulati, 1994). The resulting negative effect on the agricultural growth rates was partly offset by efficiency gains as an effect of trade liberalization measures. The public agricultural research system is establishing new priorities for its resource allocation and by encouraging private-sector participation. The growing commercialization in of agricultural research will allow making up for the deficits in budget outlays. However, complementarities between private and public research, with the public research system focusing on the disadvantaged areas and research focused towards sustainable agriculture will prove beneficial (Srinivasan and Jha, 2002). Another important milestone for agricultural research and planning has been the introduction of the agro-climatic approach, which differentiates development objectives of each region according to its endowments, constraints and needs.

3.5 Institutional Issues and People Participation

Land ceilings set the maximum size of farm holding. Land reforms implemented since 1950's by the Central and state governments helped to abolish intermediary tenures and redistribute ceiling surplus land. Under various ceiling laws, until September 2000, 2.97 million hectares of land had been declared as surplus of which 2.14 million hectares have been distributed to 5.51 million beneficiaries mostly belonging to the weaker sections. In addition, about 0.88 million hectare of Bhoodan land and 5.97 million hectares of government wasteland have also been distributed. Legislative provisions have been made for consolidation of holdings and 66.10 million hectares of land have been consolidated so far (MoRD, 2001). Looking from the perspective of sustainable development it can be argued that small unviable units cannot invest in resource conserving technology, however, it has been noted that MNC's and other profit oriented firms also look at environment as a free good and can plunder the natural resources.

Tenancy reforms involved three measures, regulation of rents, security of tenure and conferment of ownership on tenants to prevent eviction of tenants. Land-to-the-tiller laws have led to a situation in which tenancy is widespread but unofficial and leases are limited to a year or two in order to avoid potential ownership claims by tenants. From the conservation perspective this system will lead to tenants management decisions to be guided by short time horizons. Pender and Kerr (1996) have found that land under tenancy is less likely to receive soil conservation investments (Kerr, 1996).

Co-operatives here present the other enterprise, which impart a modicum of balance and restraint. Structures along maximum stakeholder participation have been suggested as the best institutions for sustainable development. The Constitution (Seventy third) Amendment Act, 1993, has given some impetus to the processes of decentralization insofar as it mandates periodic elections to the Panchayati Raj Institutions, reservations for seats etc. (Rao, 1994; Shah, 1995). The rural poor will be increasingly involved in the implementation of land reforms with the help of Panchayati Raj Institutions, Voluntary Groups, Social Activists and Community Leaders. A few voluntary agencies like Myrada (Mysore Resettlement and Development Agency) have taken initiative in encouraging alternative management systems for saving and credit on the basis of group co-operation, participation and collective action (Nadkarni, 1993).

The revised guidelines for watershed development assigned greater role for Panchayati Raj institutions, NGO, women, and financial institutions while implementing area development programmes. The 73rd and 74th amendments of the Constitution ensured a definite role for local bodies in the management of natural resources including land, water and forests. Through the District Agriculture Technology Management Agency (ATMA) model, Government has increasingly involved farmers in decision-making to ensure a greater representation and voice for farmers in recognition of their role as the primary stakeholders; to provide a greater say to the farmers in allocation of resources and to increase their accountability to stakeholders; to increase programme coordination and integration between departments. Greater emphasis is given to participation of rural women. Voluntary organizations, NGOs and Cooperative structures in the area have an important role to play to supplement the role of the Government and need to be persuaded to play a major role in the development of the region/villages (Singh, 1992).

3.6 Other policies

SeveraNational Land Use and Conservation Board (NLCB) and State Land Use Board (SLUB) were established with the objective of formulating national land-use policies and preparing a perspective plan for optimum utilization of land resources. Some of the initiatives taken by the ministries that have a bearing on the prevention of degradation of lands are: Improved policy framework for natural resource management, Improved data on land resource degradation and its management, Draft grazing and livestock management policy, 1994, Draft national policy for common property resource lands (CPRLs). National Wastelands Development Board (NWDB) focused on land degradation. Some of the programmes undertaken are: The Desert Development Programme (DDP), Drought Prone Areas Programme (DPAP), Wasteland development, Soil conservation in the catchment of river valley projects (RVP) and flood- prone rivers (FPR), reclamation of alkaline soils and other programs.

As high as 70% of livestock market in India is owned by 67% of small and marginal farmers and by the land less. Indian Livestock is reared in close human proximity where they form component of the life system of the people. Even though the government has not given due impetus to this sector yet its contribution to GDP has been showing 6.8 per cent growth rate as against 2 per cent in crop production. Rajasthan, Jammu, Kashmir, Uttar Pradesh, Gujarat, hilly regions of North and Eastern Himalayas are the Indian regions with maximum livestock population. The Livestock Policy Perspective 1995-2020 developed by the Government of India and the Swiss Development Cooperation has invited considerable criticism as a threat to India's farm animal biodiversity and to the survival of small farmers who depend on diversity based decentralized livestock economy (Shiva, 1996).

The National Bureau of Plan Genetic Resources, National Bureau of Animal Genetic Resources, National Bureau of Fish Genetic Resources have been set up for protecting plant and livestock, poultry and fish genetic resources.

3.7 A note on policies related to Rice-wheat systems

Input price subsidies and output price supports like unpriced irrigation water, cheap fertilizers, subsidized power supply and low-interest farm credit lead to success of GR in this zone. Over time there has been a reduction in the productivity growth rates of the rice wheat systems. Slackening of infrastructure and research investments and reduced policy support partly explain this slowdown in these systems. It is argued that in addition to the above factors, degradation of the lowland resource base due to intensive use, over the long term, also contributes to declining productivity growth rates. Intensification per se is not the root cause of lowland resource base degradation, but rather the policy environment that encouraged inappropriate land use and injudicious input use, especially water and chemical fertilizers. Trade policies, output prices policies as well as input subsidies have all contributed to the unsustainable use of the lowlands.

The Table 17 provides details on policy interventions that contribute to resource base sustainability and will help in reversing the current degradation trends (Pingali and Shah, 1999). Thus, for efficient and more environmentally friendly water allocation, water subsidies (and power subsidies for operation of tube-wells) should be phased-out. Non-price policies for fertility management are important, including location specific research on soil fertility constraints and agronomic practices, improvement in extension services, development of improved fertilizer supply and distribution systems, and development of physical and institutional infrastructure (Desai 198, Desai, 1988). IPM should be vigorously pursued. Sustainability of rice wheat system depends on crop sequence diversifications and rotations to include fodders, legumes and oilseeds as a means of pest control. Adoption will depend on the profitability and pricing of additional crops (Pingali and Shah, 1999). Injudicious and indiscriminate pesticide application is related to policies that have made these chemicals easily and cheaply accessible.

Table 17: Overview of the resource degradation, farm level indicators, economic impact and technological and policy interventions in rice-wheat systems

Resource base degradation problem	Possible/probable causes	Farm-level indicators of resource degradation	Economic impact	Possible technology intervention	Policy Change
Buildup of salinity/ waterlogging	a. Poor design of irrigation systems b. intensive use of irrigation water	a. reduced yields and/or reduced factor productivities b. reduced cropping intensities c. abandoned paddy lands in the extreme	Declining trends in TFP	a. improved irrigation system and design b. increased water use efficiency	Pricing irrigation water at its true cost
Hardpan (sub-soil compaction)	Increased frequency of puddling (wet tillage)	Reduced flexibility non-rice crop production in the dry season.	Declining profitability of rice and wheat cultivation	a. improved farm-level drainage systems b. increased water use efficiency	Pricing irrigation water at its true cost
Changes in soil nitrogen supplying capacity.	a. changes in organic matter quantity and quality b. long-term flooding/water saturation of paddy soils	a. Declining efficiency of nitrogen fertilizer b. reduced yields and/or reduced factor productivities.	Increased social costs of negative externalities on the environment and human health	a. crop diversification b. increased fertilizer use efficiency c. balance application of all nutrients	a. output price reform b. removal of fertilizer subsidies.
Increased pest buildup and pest-related yield losses.	a. continuous rice monoculture b. increased asymmetry of planting schedules c. greater uniformity in varieties cultivated.	a. increased pesticide use		a. improved varieties with host plant resistance b. appropriate varietal turnover c. adoption and use	a. removal of pesticide subsidies b. investments in farmer education

Source: Pingali and Shah, 1999

Finally, we present a possible policy matrix that explains the linkages of externalities with various policies over the years.

Table 18. Indicative matrix of policies and environment interaction

	Environment Externality			
Policies	**Soil**	**Water**	**Biodiversity**	**Air**
Command area development	-	-		
Support policies for Rice and Wheat	-	-		-
Support policies for oil seeds	-	-		
Subsidies on fertilizers and pesticides	-	-	-	-
Subsidies on water (canal irrigation)	-	-		
Subsidies on electricity		-		-
Livestock (policies promoting dairy industry)	+/-			-
Decrease in public expenditure	-	-	-	-
Tenancy reforms	+	+		
Integrated pest management and control (1985)		+	+	+
Integrated nutrient management	+		+	
Trade liberalization (possible diversification in agriculture activities)*	+	+		
Agro-ecological approach	+	+	+	+
Conservation measures	+	+	+	+
Water shed development/management	+	+		
Policies to increase public participation	+	+	+	+

* trends need to be examined further before making any inference on externalities

Source: Prepared by the authors.

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