सत्यमेव जयते
Ministry of Agriculture &
Farmers Welfare

Report of the Committee on Doubling Farmers' Income

Volume V

"Sustainability Concerns in Agriculture"

A Sustainable Agricultural System Ensures Stability of Production and Secures Farmer's Income

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Document prepared by the Committee on Doubling Farmers' Income,
Department of Agriculture, Cooperation and Farmers' Welfare,
Ministry of Agriculture & Farmers' Welfare.

November 2017

Foreword

The country has witnessed a series of concerted discussions dealing with the subject of agriculture. In 1926, the Royal Commission of Agriculture was set up to examine and report the status of India's agricultural and rural economy. The Commission made comprehensive recommendations, in its report submitted in 1928, for the improvement of agrarian economy as the basis for the welfare and prosperity of India's rural population. The urban population was about 11 per cent of the whole, and demand from towns was small in comparison. The Commission notes, that communication and physical connectivity were sparse and most villages functioned as self-contained units. The Commission encompassed review of agriculture in areas which are now part of Pakistan, Bangladesh and Myanmar. The net sown area in erstwhile British India was reported as 91.85 million hectares and cattle including buffaloes numbered 151 million. Almost 75 per cent of the cultivated area was under cereals and pulses, with rice and wheat occupying 46 per cent of the net sown area. The area under fruits and vegetables was about 2.5 per cent and that under oilseeds and non-food crops was about 20 per cent. In the ensuing years, as well known, the country underwent vast changes in its political, economic and social spheres.

Almost 40 years later, free India appointed the National Commission on Agriculture in 1970, to review the progress of agriculture in the country and make recommendations for its improvement and modernisation. This Commission released its final report in 1976. It refers to agriculture as a comprehensive term, which includes crop production together with land and water management, animal husbandry, fishery and forestry. Agriculture, in 1970 provided employment to nearly 70 per cent of the working population. The role of agriculture in the country's economic development and the principle of growth with social justice, were core to the discussions. The country was then facing a high population growth rate. After impressive increase in agricultural production in the first two Five Year Plans, a period of stagnancy set in and the country suffered a food crisis in the mid-1960s. The report in fifteen parts, suggested ample focus on increased application of science and technology to enhance production.

Thirty years hence, the National Commission for Farmers was constituted in 2004 to suggest methods for faster and more inclusive growth for farmers. The Commission made comprehensive recommendations covering land reforms, soil testing, augmenting water availability, agriculture productivity, credit and insurance, food security and farmers competitiveness. In its final report of October 2006, the Commission noted upon ten major goals which included a minimum net income to farmers, mainstreaming the human and gender dimension, attention to sustainable livelihoods, fostering youth participation in farming and post-harvest activities, and brought focus on livelihood security of farmers. The need for a single market in India to promote farmer-friendly home markets was also emphasised.

The now constituted DFI (Doubling Farmers' Income) Committee besides all these broad sectoral aspects, invites farmers' income into the core of its deliberations and incorporates it as the fulcrum of its strategy. Agriculture in India today is described by a net sown area of 141 million hectares, with field crops continuing to dominate, as exemplified by 55 per cent of the area under cereals. However, agriculture has been diversifying over the decades. Horticulture now accounts for 16 per cent of net sown area. The nation's livestock population counts at more than 512 million. However, economic indicators do not show equitable and egalitarian growth in income of the farmers. The human factor behind agriculture, the farmers, remain in frequent distress, despite higher productivity and production. The demand for income growth from farming activity, has also translated into demand for government to procure and provide suitable returns. In a reorientation of the approach, this Committee suggests self-sustainable models empowered with improved market linkage as the basis for income growth of farmers.

India today is not only self-sufficient in respect of demand for food, but is also a net exporter of agri-products occupying seventh position globally. It is one of the top producers of cereals (wheat & rice), pulses, fruits, vegetables, milk, meat and marine fish. However, there remain some chinks in the production armoury, when evaluated against nutritional security that is so important from the perspective of harvesting the demographic dividend of the country. The country faces deficit of pulses & oilseeds. The availability of fruits & vegetables and milk & meat & fish has increased, thanks to production gains over the decades, but affordability to a vast majority, including large number of farmers too, remains a question mark.

The impressive agricultural growth and gains since 1947 stand as a tribute to the farmers' resilience to multiple challenges and to their grit & determination to serve and secure the nation's demand for food and raw material for its agro-industries.

It is an irony, that the very same farmer is now caught in the vortex of more serious challenges. The average income of an agricultural household during July 2012 to June 2013 was as low as Rs.6,426, as against its average monthly consumption expenditure of Rs.6,223. As many as 22.50 per cent of the farmers live below official poverty line. Large tracts of arable land have turned problem soils, becoming acidic, alkaline & saline physico-chemically. Another primary factor of production, namely, water is also under stress. Climate change is beginning to challenge the farmer's ability to adopt coping and adaptation measures that are warranted. Technology fatigue is manifesting in the form of yield plateaus. India's yield averages for most crops at global level do not compare favourably. The costs of cultivation are rising. The magnitude of food loss and food waste is alarming. The markets do not assure the farmer of remunerative returns on his produce. In short, sustainability of agricultural growth faces serious doubt, and agrarian challenge even in the midst of surpluses has emerged as a core concern.

Farmers own land. Land is a powerful asset. And, that such an asset owning class of citizens has remained poor is a paradox. They face the twin vulnerabilities of risks & uncertainties of production environment and unpredictability of market forces. Low and fluctuating incomes are a natural corollary of a farmer under such debilitating circumstances. While cultivation is boundarised by the land, market need not have such bounds.

Agriculture is the largest enterprise in the country. An enterprise can survive only if it can grow consistently. And, growth is incumbent upon savings & investment, both of which are a function of positive net returns from the enterprise. The net returns determine the level of income of an entrepreneur, farmer in this case.

This explains the rationale behind adopting income enhancement approach to farmers' welfare. It is hoped, that the answer to agrarian challenges and realization of the aim of farmers' welfare lies in higher and steady incomes. It is in this context, that the Hon'ble Prime Minister shared the vision of doubling farmers' income with the nation at his Bareilly address on 28th February, 2016. Further, recognizing the urgent need for a quick and time-bound transformation of the vision into reality, a time frame of six years (2016-17 to 2022-23) was delineated as the period for implementation of a new strategy.

At the basic level, agriculture when defined as an enterprise comprises two segments – production and post-production. The success of production as of now amounts to half success, and is therefore not sustainable. Recent agitations of farmers (June-July 2017) in certain parts of the country demanding higher prices on their produce following record output or scenes of farmers dumping tractor loads of tomatoes & onions onto the roads or emptying canisters of milk into drains exemplify neglect of other half segment of agriculture.

No nation can afford to compromise with its farming and farmers. And much less India, wherein the absolute number of households engaged in agriculture in 2011 (119 million) outpaced those in 1951 (70 million).Then, there are the landless agricultural labour who numbered 144.30 million in 2011 as against 27.30 million in 1951. The welfare of this elephantine size of India's population is predicated upon a robust agricultural growth strategy, that is guided by an income enhancement approach.

This Committee on Doubling Farmers' Income (DFI) draws its official members from various Ministries / Departments of Government of India, representing the panoply of the complexities that impact the agricultural system. Members drawn from the civil society with interest in agriculture and concern for the farmers were appointed by the Government as non-official members. The DFI Committee has co-opted more than 100 resource persons from across the country to help it in drafting the Report. These members hail from the world of research, academics, non-government organisations, farmers' organisations, professional associations, trade, industry, commerce, consultancy bodies, policy makers at central & state levels and many more of various domain strengths. Such a vast canvas as expected has brought in a kaleidoscope of knowledge, information, wisdom, experience, analysis and unconventionality to the treatment of the subject. The Committee over the last more than a year since its constitution vide Government O.M. No. 15-3/2016-FW dated 13th April, 2016 has held countless number of internal meetings, multiple stakeholder meetings, several conferences & workshops across the country and benefitted from many such deliberations organized by others, as also field visits. The call of the Hon'ble Prime Minister to double farmers' income has generated so much of positive buzz around the subject, that no day goes without someone calling on to make a presentation and share views on income doubling strategy. The Committee has been, therefore, lucky to be fed pro-bono service and advice. To help collage, analyse and interpret such a cornucopia of inputs, the Committee has adopted three institutes, namely, NIAP, NCAER and NCCD. The Committee recognizes the services of all these individuals, institutions & organisations and places on record their service.

Following the declaration of his vision, the Hon'ble Prime Minister also shaped it by articulating 'Seven Point Agenda', and these have offered the much needed hand holding to the DFI Committee.

The Committee has adopted a basic equation of Economics to draw up its strategy, which says that net return is a function of gross return minus the cost of production. This throws up three (3) variables, namely, productivity gains, reduction in cost of cultivation and remunerative price, on which the Committee has worked its strategy. In doing so, it has drawn lessons from the past and been influenced by the challenges of the present & the future.

In consequence, the strategy platform is built by the following four (4) concerns:

- Sustainability of production
- Monetisation of farmers' produce
- Re-strengthening of extension services
- Recognizing agriculture as an enterprise and enabling it to operate as such, by addressing various structural weaknesses.

Notwithstanding the many faces of challenges, India's agriculture has demonstrated remarkable progress. It has been principally a contribution of the biological scientists, supplemented by an incentivizing policy framework. This Committee recognizes their valuable service in the cause of the farmers. It is now time, and brooks no further delay, for the new breed of researchers & policy makers with expertise in post-production technology, organisation and management to take over the baton from the biological scientists, and let the pressure off them. This will free the resources, as also time for the biological scientists to focus on new science and technology, that will shift production onto a higher trajectory - one that is defined by benchmark productivities & sustainability. However, henceforth both production & marketing shall march together hand in hand, unlike in the past when their role was thought to be sequential.

This Report is structured through 14 volumes and the layout, as the readers will appreciate, is a break from the past. It prioritizes post-production interventions inclusive of agri-logistics (Vol. III) and agricultural marketing (Vol-IV), as also sustainability issues (Vol-V & VI) over production strategy (Vol. VIII).The readers will, for sure value the layout format as they study the Report with keenness and diligence. And all other volumes including the one on Extension and ICT (Vol. XI), that connect the source and sink of technology and knowledge have been positioned along a particular logic.

The Committee benefited immensely from the DFI Strategy Report of NITI Aayog. Prof. Ramesh Chand identified seven sources of growth and estimated the desired rates of growth to achieve the target by 2022-23. The DFI Committee has relied upon these recommendations in its Report.

There is so much to explain, that not even the license of prose can capture adequately, all that needs to be said about the complexity & challenges of agriculture and the nuances of an appropriate strategy for realizing the vision of doubling farmers' income by the year of India's 75th Independence Day celebrations.

The Committee remains grateful to the Government for trusting it with such an onerous responsibility. The Committee has been working as per the sound advice and counsel of the Hon'ble Minister for Agriculture and Farmers' Welfare, Shri Radha Mohan Singh and Dr. S.K. Pattanayak, IAS, Secretary of the Department of Agriculture, Cooperation and Farmers' Welfare. It also hopes, that the Report will serve the purpose for which it was constituted.

12th August, 2017

Ashok Dalwai
Chairman, Committee on
Doubling Farmers' Income

About Volume V

The fifth volume of the Report of the Committee on Doubling Farmers' Income (DFI) examines the strengths and weakness in the agricultural system, keeping sustainability as the focal point. Topics such as soil management, rainfed agro-ecology, crop residue management, agro-biodiversity, climate change and other related concerns are discussed.

The paradigm of food deficiency and growing population that obtained in the 1960s, resulted in adopting the technology popularly known as Green Revolution. While this served the purpose well, and imparted a state of food security to the country, it was unfortunately resource extractive. The implications have been several faces of production unsustainability, some seen and others largely unseen. These are manifest in depleted water table, deficiency of several soil nutrients, land degradation, necessitating increasingly intensive input usage to realise the same yield per unit. In short, the marginal returns on input management has been steadily declining. This serious situation is further aggravated by the climate change that has already begun tos show deleterious impacts.

In light of the above, this Committee, recognised that the agenda of doubling farmers' income, also has to be approached, such that the farmers' realise consistently higher productivity across the agricultural sector, based on efficient use of resources. The two important influencers of farm income are higher gross output, and lower cost of production. Given the certainty of climate change, mitigation, coping and adaptation measures also deserve due importance in the production strategy. The Committee recognises that famers' welfare will be better served if the agricultural eco-system is made more aware of, and is able to counter the existing stresses on soil and water and other aspects of the production system, as also the larger ecology.

This volume of the DFI Report brings to fore the main concerns that need to be thought about, while the agricultural system is progressed on its new growth path. The next Volume-VI, will discuss the specific strategies for developing and promoting sustainability practices in agriculture.

Ashok Dalwai

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Doubling Farmers' Income

Volume V

"Sustainability Concerns in Agriculture"

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Chapter 1

Sustainability Approach in Agriculture

Agriculture in India is facing several challenges which together manifest into sustainability issues. The challenges encountered by Indian agriculture are due to agro-climatic/environmental, social and economic dimensions. The intensification of eco-logical agriculture is now highly required as it has the potential to sustainably feed the growing world and Indian population by bringing "Evergreen revolution based on sustainable thinking".

1.1. Introduction

Agriculture is a primary production system in India that makes a significant contribution to the wealth and quality of life for rural and urban communities. It is apparent that income increases for farm households can be made sustainable, only if agricultural income improvement is driven by approaches and practices, that do not erode the very productive resources on which agriculture is based. Otherwise, the income increases are bound to be short-lived. Green Revolution (GR) has changed the traditional pattern of cropping for higher efficiency & productivity of the production systems. If 1950's was the decade of development and expansion of irrigation and 1960's of intensification of high yielding variety (HYV) in the most favourable environments, 1970's one of exploitative agriculture confined to more favourable ecologies through integration of HYV, fertilizer and pesticide based technology, particularly of wheat and rice. It was only in the late 70's or early 80's that the need for appropriate technology for rainfed, under-invested dry farming and stressed ecologies, was recognized. These were areas that had remained beyond the pale of GR technology.

In the decade of 1990's, the limitations of the exploitative agriculture that was based only on crops, commodities and cropping systems came to be increasingly recognized, and emphasis shifted to alternative and sustainable land use systems, and for improving efficiency of resources and inputs. Degradation of natural resources has direct consequences in terms of productivity but also on the ability of the farm to withstand biotic and abiotic stresses. In the decade of 2000s, and thereafter even with the best possible efforts, the sustainability of productivity is in question in many production systems implying that though the problems was recognised in the earlier decades, total solutions were not found.

It is unfortunate that ever since independence especially after 1960's, the emphasis in Indian agriculture has been more on exploitation of natural resources of land and water and less on improving, restoring, reclaiming and enhancing their productivity and sustainability. Presently, Indian agriculture is facing the critical challenge of feeding an escalating human population under increasingly declining soil quality and changing climatic conditions. It supports18 per cent of the human and 15 per cent of livestock populations of the world on only 2.2 per cent of the world geographical area, 4.2 per cent of freshwater resources, 1 per cent of forest area and 0.5 per cent of pasture land. Further, the extent of arable land is 46 per cent of the country's land mass.

The per capita availability of forest, supplementing livelihood in India is only 0.08 ha, as against the world average of 0.8 ha. The productive farmlands in India are under constant threat from various forms of land degradation and loss of productivity. Various pockets, in almost all the states, are fast turning into "hot spots" reflecting the devastating effects of prolonged, reckless and injudicious use. The utilizable surface water resource is estimated to reduce by 7 per cent due to deforestation and soil erosion while the loss due to water pollution is put at 20 per cent (IEG, 2000). Inefficient use of water in irrigation also leads to environmental degradation through water logging and induced salinity. The productivity of Indian forests is only 0.7 t/ha which is far below its potential of 2 t/ha/yr and the world average. The loss of biodiversity is endangering the livelihood of over 300 million people living in about 2 lakh villages within and on the fringe of forest lands.

Loss of soil organic carbon (SOC) and fertility, soil erosion, dwindling biodiversity, desertification, pesticide pollution and emerging pest resistance, pressing climate change, rising food prices etc are the major consequences of degradation of natural resources. Declining efficiency of agro-ecosystems coupled with the weather instability has worsened the living condition for smallholding and marginal farmers, and agricultural labourers (for whom occupational change is limited) (Srivastava et al., 2016). Given that, agriculture in India is largely rainfed, erratic monsoon precipitation would adversely affect the lives of majority of population. The ability to adapt to the impacts of climate change will have implications for the farming communities in the country.

Now, it is evident that the environmental degradation is closely linked to agricultural modernization. Presently about 60 per cent of the geographical area in Punjab, is reportedly facing soil degradation (e.g. soil infertility, erosion, water-logging, salinity, toxicity and alkalinity) due to extractive farming practices, which is a threat to the nation's food security. Similarly, consequences of green revolution in the form of decline in soil fertility and organic matter, water resources and increasing demand for inputs to sustain the yield levels have also been reported in Haryana. The accumulation of nitrate and pesticides to toxic levels in the ground water is a great cause for concern.

The degradation of inherent soil characteristics and declining nutrient-use efficiency have begun to negatively impact crop productivity.

The accelerated use of natural resources, the degradation of the land resource base with accompanying impacts on biodiversity and agricultural productivity, as also the impending effects of climate change are all posing a serious threat to the survival and welfare of the people. Natural resources need to be managed in a holistic manner as there are direct linkages among the various components.

Sustainable agriculture is the successful management of resources for agriculture to satisfy the changing human needs, while maintaining or enhancing the quality of environment, improving the social and economic conditions of the farmers, their employees and local communities, and safeguards the health and welfare of farmers and conserving renewable natural resources"

Such systems aim to produce food that is both nutritious and without contents that might harm human health. In practice, such systems have tended to avoid the use of synthetically compounded fertilizers, pesticides, growth regulators, and livestock feed additives; and instead rely upon crop rotations, crop residues, animal manures, legumes, green manures, off-farm organic wastes, appropriate mechanical cultivation, and mineral bearing rocks to maintain soil fertility and productivity.

Various agents of degradation of natural resources (land degradation, deterioration of soil health, water scarcity, soil-water -air pollution, deforestation, climate change, loss of biodiversity) and their consequences on food security and sustainability are discussed in details in the subsequent sections that follow.

1.2. Degradation of Natural Resources

1.2.1. Land and its degradation

Land in India suffers from varying degrees and types of degradation stemming mainly from unstable use and inappropriate management practices. Loss of vegetation occurs due to deforestation, cutting beyond the silviculturally permissible limit, unsustainable fuel wood and fodder extraction, shifting cultivation, encroachment into forest lands, forest fires and over-grazing, all of which subject the land to degradation forces.

Other important factors responsible for large-scale degradation are the extension of cultivation to lands of low potential or high natural hazards, non-adoption of adequate soil conservation measures, improper crop rotation, indiscriminate use of agro-chemicals such as fertilizers and pesticides, improper planning and management of irrigation systems, and extraction of ground water in excess of the recharge capacity.

Global studies reveal two big solutions for slowing forest degradation - easing population pressure and improving farming outside forest lands, both of which have nothing to do with forest management. This is especially true in India with more than 300 million people, including 87 million tribals, living in and around forests and deriving sustenance therefrom. The symbiotic relationship has changed over time – the pressures of a burgeoning population being aggravated through increased industrial demand of forest produce and diversion for development imperatives (Bhargava, 2015).

Land use change is a dynamic process in view of the socio-economic developments, market forces and paradigm shifts at national and global levels in the wake of globalization and economic liberalization. This is in addition to the pressure emanating from the requirements of the growing human and animal populations. The land use changes reveal, that the net cultivated area increased significantly by about 11.8 per cent from 119 million ha in 1950-51 to 140 million ha in 1970-71 and since then it is more or less stable at about 140 to 142 million ha. In contrast, the area under culturable wastelands has steadily declined from 8.1 per cent in 1950-51 to 4.3 percent during 2004-05 on account of its diversion for growing additional foodgrains. The total forest and tree cover of the country as per SFR 2015 is 79.4 million ha which is 24.16

per cent of the geographical area of the country. There is an increase of 3,775 sq km in the forest cover as compared to 2013 assessment. The total growing stock is estimated as 5,768 million cum comprising 4,195 million cum inside the forests and 1,573 million cum outside the forests, signifying a increase of 110.34 million cum as compared to ISFR 2013. The total carbon stock in forest is estimated to be 7,044 million tonnes - an increase of 103 million tonnes as compared to the last assessment.

The analysis of changes in land use pattern further reveals that while the net sown area has gone up by merely 19 per cent since 1951, the population has nearly tripled. The cropping intensity has increased from 111 to 135 per cent, while the area under non-agricultural uses has gone up by whopping 164 per cent. Barren and uncultivable land reduced by about 54 per cent, fallow land other than current fallow by 38.5 per cent, while the current fallow has gone up by about 33 per cent. However, since 1980-81, the area under current fallow is almost stable at around 4.8 per cent of the reporting area.

In some of the states, about 70 per cent of irrigation is supported by ground water which has led to over-exploitation of aquifers. The fast disappearance of prime lands especially in the vicinity of big cities and increasing rate of land degradation through various processes is diminishing the cropped area. Moreover, growing competition with industry including Special Economic Zones (SEZ) and urbanization would push agriculture more and more to marginal lands and fragile environments, which were hitherto, left under natural vegetation. Just in a period of 4 years (2000-01 to 2004-05), the area under non-agricultural uses including Special Economic Zones (SEZs) increased by 0.91 m ha. The net irrigated area (58.5 m ha) is only 41 per cent of the net sown area though an irrigation potential of about 102.8 m ha has been created till March, 2007 which is 73.5 per cent of the ultimate irrigation potential of 140 m ha (Planning Commission, 2007). It is ascribed to low overall irrigation efficiency (38 per cent) in the country due to long gestation period in the completion of dam/head works, dilapidated irrigation systems, unlined canal systems, lack of field channels and proper drainage, low rates for water supply, inefficient water application methods and inadequate extension services. The net area under irrigation has by now gone up to 63 million ha.

The burgeoning human population is making the man to land ratio more unfavourable over the years. Per capita total availability of land fell drastically from 0.91 ha in 1951 to about 0.32 ha in 2001 against world average of 2.19 ha. The availability of per capita net sown area similarly reduced from 0.33 ha in 1951 to 0.14 ha in 2001 and is expected to decline further to 0.09 ha by 2050. A minimum economic holding size of 2 ha of unirrigated land and 1 ha of irrigated land has been suggested in India for sustaining a family of 5 or 6 persons (Anonymous, 2007). The average size of a holding came down to 1.1 ha (2011 census). Besides decrease in area per capita which is of major concern, it is the decline in quality of land environment which is of even greater concern for the quality of life in future.

It is well-recognized that land and water form the basis of any sustainable system of agriculture and their improvement should lay the foundation of productive, economically viable, environmentally sound and socially acceptable agricultural system. The future of agriculture depends upon the realization of basic truth that most of the food, fibre, fuel and forage can be produced from the land only with appropriate land use and investment policies.

Since land is a limited and non-renewable resource, the experience has shown that with continuous utilization, even by deploying best technology and skills, its ability to support an activity declines. Hence, it is imperative to not only preserve the land quality but also to enhance it to keep pace with the increasing demand in various sectors. To produce 310 million tonnes of foodgrains and 190 million tonnes of fibres, edible and non-edible oils by 2050 from 150 million ha of net sown area is a big challenge for Indian agriculture. It would require an average productivity of 3.3 t/ha against average productivity of all foodgrains of 1.7 t/ha in 2006-07 (DES, 2007).

Similarly, an average yield of 12.5 t/ha from 120 million ha of land under forests, pastures etc. is needed to produce 1500 million tonnes of biomass, while the mean annual productivity of growing stock of forests is only 0.7 t/ha/yr and of other items such as grass, leaf fodder, fuel wood, non-timber forest products (NTFPs) is 1-2 t/ha/yr. Hence, there is an urgent need to enhance productivity of arable and non-arable lands to meet the requirements of growing population from shrinking land resource. Chemical degradation involving loss of nutrients and/or organic matter, salinization and pollution, and physical degradation in the form of waterlogging, mass movement, landslides, compaction, crusting and sealing are reproduced below:

Table 1.1 Land degradation in India

SN	Type of Degradation	Arable land (m ha)	Open forest (<40 per cent canopy) (m ha)
1.	Water erosion (>10 t/ha/yr)	73.27	9.30
2.	Wind erosion (aeolian)**	12.40	-
	Sub-total	85.67	9.30
3.	Chemical degradation		
	a) Exclusively salt affected soils	5.44	-
	b) Salt-affected and water eroded soils	1.20	0.10
	c) Exclusively acidic soils (pH< 5.5)	5.09	-
	d) Acidic (pH < 5.5) and water eroded soils	5.72	7.13
	Sub-total	17.45	7.23
4.	Physical degradation		
	a) Mining and industrial waste	0.19	
	b) Water logging(permanent) (water table within 2 m depth)	0.88	
	Sub-total	1.07	
	Total	104.19	16.53
	Grand total (Arable land and Open forest)	**120.72**	

Source: Degraded and Wastelands of India: Status and Spatial Distribution. Indian Council of Agricultural Research, New Delhi and National Academy of Agricultural Sciences, New Delhi (2010). 158p.

Degradation of soil and/or vegetative cover is caused by a variety of anthropogenic pressures including development of large hydro-power projects, deforestation, over-grazing, unsustainable agricultural practices and industrial activities. In India, the estimates of land degradation by different agencies vary widely from about 53 million ha to 188 million ha, which is attributed mainly to different approaches and methodologies adopted in defining degraded lands and/or differentiating criteria used. These data sets have now been harmonized to a degraded extent of 120.72 m ha which will actually respond to amendments.

1.2.2. Potential erosion rates

It is estimated that about 5,334 million tonnes of soil is lost annually which works out to 16.35 tonnes/ha (Dhruva Narayana and Ram Babu, 1983) of which 29 per cent is lost permanently into the sea, 10 per cent gets deposited in the reservoirs decreasing their capacity by 1-2 per cent every year and the remaining 61 per cent is displaced from one place to another or re-distributed. Among different land resource regions, highest erosion rate occurs in the Black soil region (23.7–112.5 t/ha) followed by Shiwalik region (80 t/ha), North-Eastern region with Shifting Cultivation (27-40 t/ha) and the least in North Himalayan Forest region (2.1 t/ha).

The analysis revealed that about 39 per cent area in the country is having erosion rates of more than permissible rate of 10 t/ha/yr. About 11 per cent area in the country falls in very severe category with erosion rates of more than 40 t/ha/yr. Some of the States in the North-West and North-East Himalayas are worst affected with more than 1/3rd of their geographical area falling in very severe (40-80 t/ha/yr) category. Land erosion effects agricultural productivity.

1.2.3. Consequences of land degradation

The land degradation has both on-site and off-site effects. On-site effects include the lowering of productive capacity of the land, causing either reduced outputs or need for increased inputs. Off-site effects of water erosion that occur through changes in the water regime encompass decline in water quality, sedimentation of river bodies and reservoirs, loss of biodiversity and natural disasters like floods and droughts. The irrigated agriculture especially through canal systems has resulted in land degradation at many places due to the twin problems of waterlogging and salinization. It is estimated that nearly 8.4 million ha of the irrigated lands are affected by soil salinity and alkalinity, of which about 5.5 million ha is waterlogged (IDNP, 2002).

For example, in case of the command area of Tungbhara irrigation project, land area is found to degrade at the rate of 6,000 ha annually due to salinity and waterlogging. Similarly, in Nagarjuna Sagar Project command area, in a period of 14 years of its commissioning, nearly 25,000 ha of the 140,000 ha under irrigation came to be affected by waterlogging and salinity.

The degree of severity of water erosion is very much linked to the loss of agricultural productivity. The trend on the basis of very limited data available on loss of productivity/crop yields vis-à-vis the erosion class indicates that the productivity may decline by 5-50 per cent under major soil groups of the country (Sehgal and Abrol, 1994).The effect on loss of productivity is more pronounced in red soils followed by black soils and alluvium derived soils.

Studies in the lower Himalayan region revealed, that removal of 1 cm top soil reduced 76 kg/ha of maize grain yield and 236 kg/ha of maize straw yield (Khybri et al., 1988).Maize grain yield, on an average, decreased from 37 q/ha to 13 q/ha with 30 cm removal of top soil (65 per cent reduction over control).Similarly, in the Shiwalik region of Punjab, grain yield reduction of 103 kg/ha has been recorded in maize crop with every cm removal of top soil (Sur et al., 1998).

1.2.4. Soil and deterioration of soil health

Soils provide the basis for life, giving nutrients to plants, which allow animal and human life to exist. Being a tropical country, the organic carbon content of the Indian soils is very low and deficiency of N is almost universal. The status of N is low in about 48 per cent of the area and medium in about 42 per cent. The status of phosphorus and potassium was low in 25 and 27 per cent, and medium for phosphorus and potassium in about 67 and 70 per cent area, respectively.

The high biomass production capacity of Indian soils is being gradually eroded both at farm level and also at ecosystem level. At farm level, factors like (**i**) inability of growers to use modern techniques on small land holdings; (**ii)** maintenance of soil organic matter and nutrients balance at farm; and **(iii)** increased wind and water erosion, are limiting the crop production. At ecosystem level, excessive accumulation of reactive N (Nr), CH_4 and CO_2 are threatening production capacity by altering global heat balance and hydrological cycles.

1.2.5. Threats at farm level

About 29.4 m ha of the nation's soils are experiencing decline in fertility with a net negative balance of 8-10 m tons of nutrients per annum ,which is likely to increase in future. The current estimated average depletion per ha is about 16 kg N, 11 kg P_2O_5 and 42 kg K_2O. Besides, continuous mining of secondary and micro-nutrients has depleted nutrient reserves of soil. With negative nutrient balance, the deficiencies may become more widespread and acute leading to further decline in fertilizer use efficiency. Fertilize N use efficiency seldom exceeds 40 per cent under low land and 60 per cent under upland farming conditions. In case of P and micronutrients, the efficiency hardly exceeds 20 and 2 per cent, respectively even with the best management practices. Thus, rational use of fertilizer and manure for optimum supply of all essential nutrients which simultaneously ensures efficiency of fertilizer use, promotes synergistic interactions and keeps antagonistic interactions out of crop production system would be essential and inevitable for balanced fertilization.

The contributions of soil organic carbon (SOC) on physical, chemical and biological properties of soils in sustaining their productivity are being appreciated since the dawn of human civilization. In most Indian soils, organic matter content is low but it is also dynamic in nature.

Farming practices affect both quantity and quality of organic matter. In general, the SOC content in Indian soils is about 0.5 per cent.

Table 1.2 Soil organic carbon content in 0-30 cm soil depth in different agro climatic zone of India*

Agro climatic zones (ACZ)	**Soil organic carbon (per cent) in 0-30 cm (mean values)**
Western Himalaya Zone (ACZ 1)	0.67
Eastern Himalaya Zone (ACZ 2)	1.88
Lower Gangetic Plains (ACZ 3)	0.47
Middle Gangetic Plains (ACZ 4)	0.18
Upper Gangetic Plains (ACZ 5)	0.78
Trans Gangetic Plains (ACZ 6)	0.27
Eastern plateau and hills regions (ACZ 7)	0.42
Central plateau and hills regions (ACZ 8)	0.52
Western plateau and hills regions (ACZ 9)	0.49
Southern plateau and hills regions (ACZ 10)	1.22
East coast and plains and hills (ACZ 11)	1.15
West coast plains and ghat regions (ACZ 12)	1.77
Gujarat plains and hills (ACZ 13)	0.63
Western dry (ACZ 14)	0.20
Island (ACZ 15)	6.14

**Data compiled from the Bhattacharyya et al., 2013.*

In India, nearly 3.7 m ha is deteriorated due to depletion of organic matter. These areas are widely distributed across the country ranging from cultivated areas of subtropical belt to the areas under shifting cultivation. (The problem of soil health fatigue has been already observed in number of case studies). Particularly, in high intensive cultivated areas of rice-wheat cropping system in Indo–Gangetic Plains (IGP). In the major rice-wheat regions of north-western India, SOC has decreased from 0.5 per cent in 1960s to 0.2 per cent at present (Sinha et al., 1998). The removal or in-situ burning of crop residues, none or minimal addition of organic manures, and intensive cultivation are the major reasons for the depletion of soil organic carbon.

Other factors such as declining livestock population and reduced applications of farm yard manure and green manure crops are also reasons of soil fertility loss. Urgent measures are required to arrest the degradation process and to restore productivity of degraded soils so that more food could be produced to provide livelihood and environmental security to the increasing Indian population.

Erosion affects nutrient cycling and reduces the fertility of the soil by reducing the pool of available nutrients. The details about the extent of land degradation and soil erosion along with their consequences are already presented earlier.

Soil supports broadest variety of living organisms. One gram of soil in good condition can contain upto 600 million bacteria belonging to 15,000 to 20,000 different species. These numbers go down to 1 million and 5,000 to 8,000 species respectively in arid soils. Therefore, soil biodiversity is often used as an overall indicator of the state of soil health as soil organisms themselves serve as reservoir of nutrients, suppress external pathogens and break down pollutants into simpler, often less harmful components. Declines in soil biodiversity make soils more vulnerable to other degradation processes

Problems of water logging and salinity in Indian agriculture are typically associated with canal irrigation. Salinity occurs when the water table rises with percolating irrigation water. When water table is a meter or so below the soil, water flows to the surface, evaporates and leaves the salt deposits. When poor quality groundwater is pumped up, salt is left in soil as it evaporates. About 4.1 m ha of India's land is affected by salinity (Lal, 2004). It is particularly a serious problem in Uttar Pradesh and Gujarat.

Waterlogging occurs when the water table rises to crop's root zone, impeding its ability to absorb oxygen and ultimately compromising yields (except rice crop). About 3.1 m ha of India's agricultural land is waterlogged because of inadequate drainage, improper balance in the groundwater and surface water use, seepage and percolation from unlined channels, over watering, planting crops not suited to specific soils and inadequate preparation of land before irrigation. The problem of waterlogging is most serious in Haryana, Punjab, West Bengal, Andhra Pradesh, and Maharashtra.

1.2.6. Threats at ecosystem level

Stresses due to acidity and alkalinity impair soil's essential ecosystem functions, resilience and ultimately its quality. Non-judicious use of pesticides, dumping of municipal solid wastes, and industrial wastes containing a considerable amount of heavy metals and toxic substances are affecting soil quality and plant growth. As soils of India are fast deteriorating, the likely effect of climate change can further aggravate the problem. Global climate change may affect the soil processes and ultimately its quality and crop growth. Increase in temperature causes greater evapo-transpiration making the soil thirstier with enhanced irrigation demand, lowering of groundwater table, and upward water movement resulting in accumulation of salts in upper soil layers.

Similarly, rise in sea level associated with increased temperature may lead to salt-water ingression in the coastal lands turning them unsuitable for conventional agriculture. Organic matter content, which is already quite low in Indian soils, would get still lower with increasing temperature. The change in rainfall volume and frequency, and wind may alter the severity, frequency, and extent of soil erosion.

Elements like carbon, nitrogen, phosphorus and sulfur are necessary for life and are generally available in global reservoir to sustain life forms from single cell to vertebrates. But, industrialization and industrialization of agriculture have drastically increased the amount of nutrients under circulation, which is leading to their net accumulation either in soil, water or atmosphere leading to adverse consequences.

1.2.6. Impact of soil quality deterioration on ecosystem

Deteriorated soil quality is affecting Indian agriculture adversely through yield loss, low input use efficiency, poor crop quality, reduced farmers' income and profitability, environmental pollution, and climate change.There has been a significant slowdown in the growth rate of production as well as yield of rice and wheat in the IGP after 1990s and the sustainability of this important cropping system is at stake (Ladha et al., 2003). A decline in soil productivity, particularly of organic C and N, deterioration in soil physical characteristics, and decreasing water availability are suggested as the causes of this slowdown in productivity. Diagnostic surveys conducted by the regional universities and international agencies indicated, that in recent years higher amounts of fertilisers need to be applied to get the same yield as in 1970s and early 1980s.

Nearly one-third of rice-wheat farmers apply as much as 180 kg N ha^{-1} to each rice and wheat crop against the local recommendation of 120 kg N ha^{-1}. The N-recovery efficiency, which is already less than 40 per cent in the irrigated rice-wheat system, has declined further. Fertilizer, and N in particular, applied in excess of the crop's demand is lost through various pathways, and this has a negative effect on the environment including eutrophication of surface water, pollution of groundwater, and global warming. The contribution of Indian agriculture to global warming, however, is small i.e., 1.5 Tg methane (Pathak et al., 2005) and 0.08 Tg nitrous oxide (Bhatia et al., 2004).

Pesticides and heavy metals generally reduce soil respiration, microbial activity and soil enzyme activity, inhibit crucial soil processes such as ammonification and nitrification, reduce earthworm population, and suppress algal population. These potentially harmful substances may accumulate in soil and cause long-term effects on crops yields and quality, and may damage soil microflora. Through food and feed, they may also get into human and livestock systems and cause health problems, if the accumulation exceeds the threshold levels.

1.3. Water and its Availability

It is estimated that about 3 million ha of land surface area in the country is covered under ponds, reservoirs, brackish water, lagoons, rivers and canals. India's water wealth is about equal to that of USA although in terms of geographical area it is only 40 per cent. However, water shortages in the near future are sure to be more widespread and acute due to spatial and temporal variations and competing demands among different sectors coupled with climate change impacts. It is, therefore, imperative to closely understand the interaction between 'land cycle' and 'water cycle' for integrated and sustainable management of natural resources and meet our future needs.

The utilizable surface water resource is estimated to reduce by 7 per cent due to deforestation and soil erosion while the loss due to water pollution is put at 20 per cent (IEG, 2000).Hence, there is an urgent need to preserve and maintain the water quality of surface and ground water resources for production and other purposes.

In the past few decades, questions have increasingly arisen over the long-term sustainability of the water infrastructure, and its ability to sustain the future food and water requirements. The public water infrastructure platform is showing signs of crumbling, and is impacting the quality of land, soil and water, which are the natural resource base of agriculture, affecting crop productivities. Indiscreet and over-exploitation of groundwater is shrinking the total resource base itself, as the wells fail because of fall of water tables beyond acceptable depths, leaving farmers in economic distress. This is happening at a time when global changes in climate are affecting the hydrologic cycle that governs the water supplies.

The present situation with respect to water management in India is, therefore, quite turbulent. There is a growing consensus that a 'business as usual' scenario for water development and management is not sustainable, and would result in water scarcity. It is estimated, that by 2050 about 22 per cent of the geographical area and 17 per cent of the population would be under absolute water scarcity (< 500 M^3 per capita per year), and about 70 per cent of the area and 76 per cent of the population will be on the verge of economic scarcity and health risk with water availability less than 1000 M^3 per capita per year (Planning Commission, 2002). Dramatic changes would be required in development and management of water resources to avert such a scenario. The changes would be needed in multiple dimensions– policy, governance, regulation and management, with science and technology underpinning all of these.

1.3.1. National water balance

The principal source of water in the country is precipitation (rainfall and snowfall). The average annual precipitation over India (including snowfall) of about 1,160 mm corresponds to about 4,000 billion cubic meters (BCM) of water. Of this, about 1,869 BCM is the annual runoff that appears as average annual potential flow in rivers. A part of the rainfall is stored as groundwater and the remaining is lost as evaporation and evapotranspiration. On account of various constraints in harnessing water from river flows, only about 1,122 BCM of the potential runoff of 1869 BCM, is considered utilizable, which corresponds to a low per capita availability of water. Even these annual averages are deceptive, as there are significant local variations in time and space.

Temporal variability of water availability further complicates the issues of water management. Competing water demands, climate change and globalization will aggravate the situation for agriculture even more by introducing new uncertainties. A real situation, thus , may arise that can be much worse with respect to water resources availability and use within the next 30-40 years at the local level.

Punjab contributes about 65 per cent of the wheat and 42 per cent of the rice to India's foodgrain pool and is thus regarded as the "food basket of the country." The problem of the falling groundwater table in central Punjab, where rice is a predominant crop, is because of the overdraft of water. The rate of groundwater usage is more than water recharge; of a total of 137 blocks, 103 blocks are over-exploited for water use. A holistic strategy required to overcome the water crisis, which includes crop diversification, delayed transplanting of rice, adoption of water-saving agronomic practices, etc. Agriculture in the state would have to be carefully reoriented to ensure sustainable development with least disturbance to the ecosystem, including water resources.

Since over-exploitation of groundwater through indiscriminate drilling of bore wells and tube wells has reached critical levels in most districts of India, regulation is required to ensure that groundwater supplies are available in sustainable fashion to meet future requirements.

Besides the annually replenishable recharge which constitutes the dynamic fresh groundwater resource, there are deeper aquifers below the active recharge zone (zone of water level fluctuation). These deeper aquifers contain vast quantities of water that has accumulated over many years. This water is called 'static' groundwater. In alluvial areas, these resources also get replenished over a long period. In several cases, for example in Rajasthan, they constitute practically non-renewable 'fossil' water. The tentative estimate of the static groundwater resources in India is 10,800 BCM (nearly 10 times the annual utilizable water resources from surface and groundwater.

1.4. Soil-Water-Air Pollution

Both geogenic and anthropogenic factors affect pollution/contamination of soil and water resources. However, their impact varies with rainfall pattern, and depth and geology of aquifer. There are naturally occurring minerals in aquitards in different regions, which control the concentration of geogenic pollutants, such as arsenic (As), uranium (Ur), fluoride (F), boron (B) and selenium (Se) in alluvial aquifers. Applications of sewage sludge to agricultural soils, and irrigation of field crops with sewage water and untreated industrial effluents alone, or in combination with tube well/canal water, are common practices, especially in the vicinity of large cities, as these are considered reusable sources of essential plant nutrients and organic C. However, some of the elements present in sewage water and untreated industrial effluents, could be toxic to plants and pose health hazards to animals and humans. Large variations in the composition of sewage waters of industrial and non-industrial cities of Punjab have been reported. In general, Led (Pb), Cadmium (Cd) and Nickel (Ni) were in higher concentration in effluents of industries manufacturing metallic products as compared with textile and woollen industries.

In India, water quality has been a serious concern since the 1970s. The Central Pollution Control Board (CPCB) was created in the 1970s to monitor surface and groundwater quality. Levels of fluoride are alarming in several pockets in 200 districts across the country. The occurrence of arsenic in ground water was first reported in 1980 in West Bengal, Bihar, Chhatisgarh and Assam. High concentrations of iron in ground water have been observed in Assam, West Bengal, Odisha, Chhattisgarh, and Karnataka, and in localized pockets in Bihar, UP, Punjab, Rajasthan, Maharashtra, Madhya Pradesh, Jharkhand, Tamil Nadu, Kerala and North Eastern States. Nitrate pollution occurs in intensively irrigated and high agricultural productivity regions, and in urban areas due to improper and inadequate sewage disposal. High concentrations of nitrate (more than 45 mg/l) have been found in many districts of Andhra Pradesh, Bihar, Delhi, Haryana, Himachal Pradesh, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Odisha, Punjab, Tamil Nadu, Rajasthan, West Bengal and Uttar Pradesh. Inland salinity is prevalent mainly in the arid and in semi arid regions of Rajasthan, Haryana, Punjab and Gujarat, and to a lesser extent in Uttar Pradesh, Delhi, Madhya Pradesh Maharashtra, Karnataka, Bihar and Tamil Nadu.

With the introduction of intensive agriculture and adoption of modern farming techniques involving the application of higher volume of water and agricultural chemicals, the problems caused by diffuse agricultural pollution are bound to grow. Nitrate pollution in groundwater is associated with nitrogen loads in the environment. In urban areas, it is associated with sewage and in agriculture areas, with livestock sources and nitrogen fertiliser inputs. Nitrate pollution in drinking water can have serious health impact on humans, especially for babies and children. The most significant potential health effects of drinking water contaminated with nitrate are the blue-baby syndrome (methemoglobinemia) and cancer.

The investigation in three districts of Punjab shows, that 20 per cent of all sampled wells have nitrate levels above the safety limit of 50 mg of nitrate per litre established by the World Health Organisation (WHO). Nitrate pollution levels above the WHO permissible limits also occur at several locations in Gujarat, Maharashtra, and Odisha. The trend in fertilizer consumption in Madhya Pradesh, Andhra Pradesh, West Bengal, Karnataka, etc, points to nitrate pollution becoming a major threat to sustainable water resources development in these states also. **Routine pollution control methods of discharge permits (or consent letters), EIAs (Environment Impact Assessments) or environmental audits, and normal enforcement measures by regulatory agencies are not likely to work for control of such pollution.**

The burning of paddy stubble following the harvest around 20th October of the year, to prepare the land for sowing of wheat by November 25th in Punjab, Haryana and Western Uttar Pradesh leading to smog over large area of Indo-Gangetic Plains (IGPs)and in a highly concentrated form over Delhi-NCR is an another example of pollution. Emergent and comprehensive interventions are called for. Crop residue burning is one among the many sources of air pollution. Burning of farm waste causes severe pollution of land and water at both local as well as regional scale. This also adversely affects the nutrient budget in the soil. Straw carbon, nitrogen and sulphur are completely burnt and lost to the atmosphere in the process of burning. It results in the emission of smoke which if added to the gases present in the air like methane, nitrogen oxide and ammonia, can cause severe atmospheric pollution. These gaseous emissions can result in health risk, aggravating asthma, chronic bronchitis and decrease lung function. Burning of crop residue also contributes indirectly to the increased ozone pollution. It has adverse consequences on the quality of soil. When the crop residue is burnt, the existing minerals present in the soil get destroyed which adversely hampers the cultivation of the next crop.

The on field impact of burning includes removal of a large portion of the organic material. The off field impacts are related to human health due to general air quality degradation resulting in aggravation of respiratory (like cough, asthma, bronchitis), eye and skin diseases.

While on the one hand, there is an urgent need to revitalize the research in agriculture and related activities, an eco-friendly technology will be beneficial to the farmer community and the state by providing them a tool for improving soil health and environment for sustainable agriculture.

1.5. Deforestation

As per the India State of Forest Report (SFR) 2015, of the total geographical area in the country, 24.16 per cent (21.34 per cent under forest cover & 2.82 per cent under tree cover) is under forest/ tree cover as against the target of 33 per cent according to "National Forest Policy - 1988". Since then concerted efforts are being through Government policies, and the adoption of Forest Conservation Act, 1980 has been a milestone in checking degradation. Thanks to both regulatory and developmental interventions, over the decades there has been an increase in the canopy cover in the notified forest areas.

Apart from diversion of forest area to non-forest activities like industries infrastructure and human habitation, other factors like unrestricted exploitation of timber and other wood products for commercial purposes, as also slash and burn method of cultivation in some areas have been responsible for forest degradation. Even today, shifting cultivation is practised in the states of Assam, Manipur, Meghalaya, Mizoram, Nagaland, Tripura and Andaman and Nicobar Islands.

The social consequences of deforestation are many. For indigenous communities, the arrival of civilization usually means the destruction of their traditional life style and the breakdown of their social institutions. Due to deforestation watersheds that once provided drinking water and irrigation water stand affected by extreme fluctuations in water flow. All potential future revenues and future employment opportunities disappear.

Another serious consequence of deforestation is the loss of biodiversity i.e. the extinction of thousands of species and varieties of plants and animals. Global warming is another consequence of deforestation. The impact of deforestation on the soil resource can be severe. The slash and burn farming exposes the soil to the intensity of the tropical sun. This can affect the soil by increasing its compaction and reducing its organic material. In the dry forest zones, deforestation also results in desertification.

Around 80 per cent of India's annual rainfall comes from the summer monsoon, spanning from June to September. But deforestation over the past few decades has caused summer monsoon to weaken, resulting in a considerable decline in rainfall between the years 1980-1990 and 2000-2010.

Consequences of deforestation

- Economic loss
- Loss of biodiversity
- Destruction of the habitats of various species
- Reduction in stream flow; and break in water cycle
- Increase in the rate of global warming
- Disruption of weather patterns and global climate
- Degradation of soil and acceleration of the rate of soil erosion.
- Occurrence of landslides.
- Increases flood frequency and magnitude / severity.
- Break in the nutrient cycle

1.6. Weather Abnormalities and Associated Risks

Extreme weather events and climatic anomalies have major impacts on agriculture. In India, agricultural risks are exacerbated by a variety of factors, ranging from climate variability and change, frequent natural disasters, uncertainties in yields and prices, weak rural infrastructure, imperfect markets and lack of financial services including limited span and design of risk mitigation instruments such as credit and insurance. These factors endanger the farmer's livelihood and incomes but also undermine the viability of the agriculture sector.

The growing incidence and severity of droughts, floods, hailstorms and other extreme weather events are a threat to the livelihood options for small & marginal as also the landless farmers. It is to note that India looses, annually, about 2 per cent of its GDP and around 12 per cent of central government revenues to natural disasters (Lester and Gurenko, 2003). The form, frequency and increasing intensity of extreme weather events are largely attributed to changes in earth's climate. The socio-economic costs of such weather events are very high and debilitating.

1.2.1.7 Loss of biodiversity

Agro-biodiversity is the backbone of a nation's food security and the basis of economic development as a whole. Over the years, this diversity in India has come under pressure due to the massive commercialization of agriculture. The top-down system of agricultural research, where farmers are seen merely as recipients of research rather than as participants in it, has contributed to an increased dependence on a relatively few plant varieties.

Over the years, diversity of various crops of India has been eroded. Replacement of land races (a crop cultivar that evolved with and has been genetically improved by traditional agriculturists, but has not been influenced by modern breeding practices) or traditional varieties (TVs) by modern varieties (MVs) or High Yielding Varieties (HYVs) is one of the most important reasons for compromise of biodiversity.

Over time, the soil quality has depleted because of the indiscriminate use of fertilizers and pesticides, and productivity has begun to suffer, raising a question mark over sustainability. For Example, farmers in the hilly region of Tehri Garhwal district of Uttaralkhand took to high input-intensive techniques of farming to increase productivity. New 'improved' seeds of high yielding varieties were introduced here, along with a range of pesticides, fertilizers and other external inputs. While there has been a substantial increase in productivity, there has been loss of sustainability.

Several indigenous practices and seeds (rice, kidney beans) have already been 'lost' in this area. The challenge today is ensuring an optimal balance between practices that will bring in higher yields and the management approaches that will protect the ecology.

1.7. Indicators of Sustainability

Indicators are a composite set of attributes or measures that embody a particular aspect of agriculture. Indicators are quantified information, which help to explain how things are changing over time. Sustainability indicators examine economic, social and environmental information in an integrated manner.

Many professionals agree that at least three criteria should guide the development of sustainability indicators:

Policy relevance - indicators should address the issues of primary concern to a country or state or district and receive the highest priority. In some cases policy makers may already share concern about an aspect of sustainability (e.g. land degradation) and be ready to use indicator information for addressing the issue.

Predictability - to allow a forward-looking perspective that can promote planning and decisions on issues before they become too severe. Anticipatory decision-making is at least, as important to sustainable agriculture as is recognition of existing problems.

Measurability - to allow planners and analysts the means to assess how the indicator was derived, either qualitatively or quantitatively, and decide how it can best be applied in the planning and decision-making process.

1.8. Annotation

Sustainable Intensification (SI) remains the foremost goal of Indian agriculture in the 21st century. Besides achieving increased crop production per unit area, SI intends to take care of natural resources, ecosystem services, declining soil productivity, and also the evident consequences of 'Green Revolution' technology. Degradation of natural resources remains the primary challenge to the country's growth of Agriculture. Among the other long-term flaws of disrespecting the agro-ecology management are loss of soil organic carbon and fertility, soil erosion, dwindling biodiversity, desertification, pesticide pollution and emerging pest resistance, pressing climate change.

Overuse of agro-chemicals has engendered multiple ecological and environmental concerns, necessitating the need for developing alternative systems, that use less chemicals in agriculture. Immediate attention is warranted to conserve the natural resources & biodiversity, and mitigate weather extremis to minimize the risk of crop & income failures for small and marginal farmers. Afforestation is necessary to combat the issues of global warming, soil erosion, pollution, and the maintenance of biodiversity and ecological balances.

Key Extracts

- The conditions for sustainable agriculture are becoming more favourable and agricultural technology needs to move from production oriented to profit oriented sustainable farming.
- The practice of sustainable agriculture is important as it accelerates the productivity, efficiency and employment; and reduce the practices which affect quality of soil, water resources and other natural resources.
- Policy requires to bring more focus on environmental services such as soil conservation, watershed services, biodiversity and carbon sequestration

Chapter 2

Management of Soil Organic Carbon

Soil organic carbon (SOC) constitutes a significant proportion of terrestrial carbon store and has a pivotal role in physical, chemical and biological soil processes, and contributes to soil productivity and sustainability. It constitutes an important global reservoir of carbon accounting for about two times the amount of carbon tied up in atmospheric CO2 and representing 2/3 of SOC present in terrestrial biosphere.

2.1. Indian Agriculture – Context Today

Despite impressive gains in cereal production from 50 million tonnes in 1947 to about 253 million tonnes in 2017, there remain two serious but inter-related problems. One, expected food demand of 300 million tonnes of cereals by 2030 which must be met from the shrinking land resource base. Two, there are severe problems of degradation of soil and water resources leading to reduction in use efficiency of inputs, pollution of surface and ground waters and emission of greenhouse gases (GHGs) from soil into the atmosphere. Most intensive cereal based production systems are showing declining trend in grain output. A decrease in soil C is one of the causes of yield decline in India (Ladha et al. 2003). In long-term experiments of India, decline in soil organic matter is the major cause of yield decline (Swarup et al. 2000) irrespective of cropping system and soil type. This eventually leads to deterioration of soil quality. The problem is further enhanced by reduced biomass productivity and the low amount of crop residue and roots returned to the soil. Low soil organic carbon content is also attributed to heavy ploughing, removal of crop residue & other bio-solids and indiscreet mining of soil fertility.

The amount of organic carbon in soils of India is relatively low ranging from 0.1 to 1 per cent and typically less than 0.5 per cent. Understanding long term soil organic carbon changes in various ecosystems is of prime importance, because it directly affects soil quality and serves as a major pool of plant nutrients. The biomass produced above ground in agricultural or natural ecosystems is either removed from the system or remains on the soil surface. These changes in SOC, in turn, lead to increasing dependence on in-organic fertilisers, risk of erosion, lower crop yields and ultimately global warming.

2.2. Carbon Stock in different Agro-climatic Regions of India

Each soil has a carbon carrying capacity i.e., an equilibrium carbon content depending upon the nature of vegetation, precipitation and temperature. When the equilibrium is disturbed, as for example by forest clearing, intensive cultivation etc., soil carbon rapidly declines. In the cool and humid climates, soils can have 6-7 per cent SOC content in their surface layers. In contrast, cultivated soils of the arid and semiarid tropics contain a low level of SOC at 0.2-0.3 per cent of those in India. In tropical and sub-tropical areas, decomposition and the turnover of SOC tend to be faster.

The climate in combination with type of soil also influences the SOC content. It has been reported, that SOC in soils ranged from less than 1 per cent in sandy soils to almost 100 per cent in wetland soils. Of course, carbon stores in arid and semi-arid lands show high temporal and spatial variability, some parts acting as carbon sources and others as carbon sinks. In arid and semi-arid zone tropical soils of India, nearly 50 per cent of the carbon is lost. Jenny and Rayachaudhury's classical study on Indian soils showed depletion to be as high as 60-70 per cent in many soils.

The sub-humid region (rainfall 1,000-1,500 mm), covering a major part of the IGP and parts of the southern peninsula, are rich in vegetation, and therefore, SOC content of these soils is relatively high compared to the semi-arid and arid bio-climate. The humid to pre-humid (rainfall 1,200-3,200 mm) bio-climatic system comprising Arunachal Pradesh, Meghalaya, Mizoram, Manipur and the hilly areas of Tripura have cooler winter and higher rainfall months, which are favourable for higher SOC stock. In arid (<550 mm) and semi-arid (550-1000 mm) regions of Rajasthan having shrinking water resources, severe erosion, periodic drought, low biological productivity, summer fallowing have detrimental effect on SOC level.

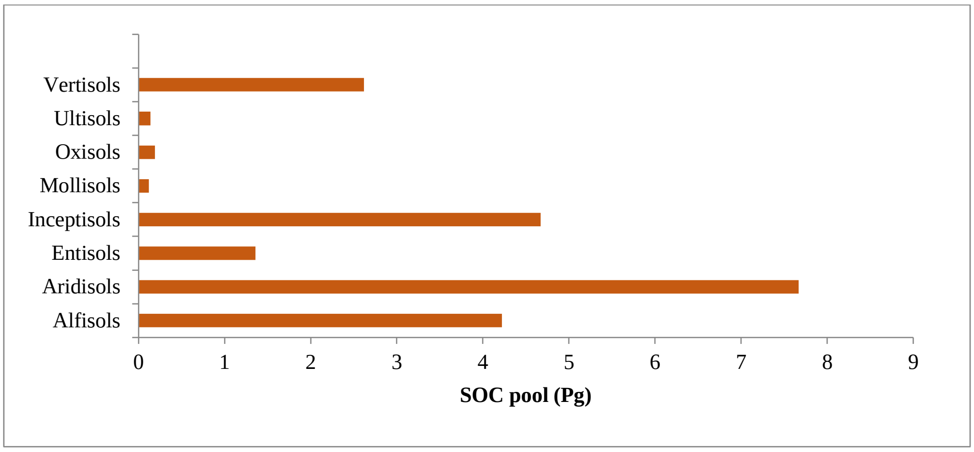
Many of the arid zone soils are affected by high salinity and alkalinity and become barren. Waste lands in India are estimated at over 100 million ha (of which 70 per cent are badly degraded) and are extremely carbon depleted; organic carbon can be as low as 0.2 per cent. Several experiments in India show that extremely carbon depleted sites like salt affected soils have a relatively high potential for accumulating carbon in vegetation and soils if suitable tree and grass species are grown along with proper soil and water conservation measures. The status of present carbon stocks of Indian soils covering 328.5 m ha calculated using organic carbon data of soil profile of 32 bench mark soils and 16 other sites characterised later for 22 agro-ecological regions of India is presented below:

Table 2.1 Status of current and potential stocks of organic carbon in Indian soils.

Soils	Area (m ha)	per cent of total area	Carbon content (kg/m^2)	Carbon stock (Pg)	per cent of total carbon	Carbon carrying capacity (Pg)
Red loamy	50.5	15.3	40.9	4.20	17.3	6.01
Red and laterite soil	20.8	6.3	19.2	1.99	8.2	3.22
Red and yellow soil	13.3	4.0	4.6	0.60	2.5	0.85
Shallow and medium black soil	33.0	10.0	8.2	2.71	11.1	3.57
Medium and deep black soil	26.6	8.1	15.9	2.45	10.0	3.3
Mixed red and black soil	39.2	11.9	34.3	4.75	19.5	6.51
Coastal alluvium derived soil	8.1	2.5	5.3	0.43	1.8	0.70
Alluvium derived soil	66.1	20.1	26.7	3.77	15.5	5.65
Desert saline soil	29.6	9.0	2.8	0.84	3.4	1.30
Brown and red hill soil	8.0	2.4	12.9	1.04	4.3	1.68
Shallow and skeletal soil	15.6	4.7	1.2	0.19	0.8	0.28
Brown forest and podzolic soil	17.7	5.4	7.7	1.36	5.6	1.87

Source: Gupta and Rao, 1994

Figure 2.1 SOC pool (0-30 cm) in different soils types of India.



Source: Velayuthanet al, 2000

The current total stocks are estimated at 24.3 Pg of carbon (Table 1). The potential stocks were also estimated by assuming, that depletion as of now is 50 per cent in surface and sub-surface and 10 per cent in rest of the profile. The potential stock was calculated to be 34.9 Pg and the difference of 10.6 Pg was taken to represent the potential for sequestering additional carbon in soil. Important strategies of soil C sequestration include restoration of degraded soils, and adoption of recommended management practices (RMPs) of agricultural and forestry soils.

Potential of soil C sequestration in India is estimated at 7 to 10 Tg C/year for restoration of degraded soils and ecosystems; 5 to 7 Tg C/year for erosion control; 6 to 7 Tg C/year for adoption of RMPs on agricultural soils; and 22 to 26 Tg C/year for secondary carbonates.

Table 2.2 Depletion of soil organic carbon in cultivated and undisturbed soils

Region	**SOC content**		**Percent reduction**
	Cultivated(g kg^{-1})	Native (g kg^{-1})	
Northwest India			
Indo-Gangetic Plains	4.2 ± 0.9	104. ± 3.6	59.6
Northwest Himalaya	24.3 ± 8.7	34.5 ± 11.6	29.6
Northeast India	23.2 ± 10.4	38.3 ± 23.3	39.4
Southeast India	29.6 ± 30.1	43.7 ± 23.4	32.3
West coast	13.2 ± 8.1	18.6 ± 2.1	29.1
Deccan Plateau	7.7 ± 4.1	17.9 ± 7.6	57.0

Source :Swarupet al., 2000 modified from Jenny and Raychaudhary (1960)

2.3. Carbon Losses

The soil organic carbon pool in 1m depth ranges from 30 t/ha in arid climates to 800t/ha in organic soil of cold regions, with a predominant range of 50-150 t/ha. The soil organic carbon pool represents a dynamic equilibrium of gains and losses. Losses and gains of SOM are influenced by land management practices such as cropping frequency, reduced tillage, and fertiliser/manure application and also by cultivation of perennial legumes and grasses. The depletion is exacerbated when the output of carbon exceeds the input and when soil degradation is severe.

A decline in SOC content is a common phenomenon when land use changes from natural vegetation to cropping, reasons being reduction in total organic carbon inputs, increased rate of decomposition due to mechanical disturbance of the soil, higher soil temperatures due to exposure of the soil surface, more frequent wetting and drying cycles and increased loss of surface soil rich in organic matter through erosion.

Low external input of chemical fertilizers and organic amendment causes depletion of SOC pool, because nutrients harvested in agricultural products are not replaced, and are made available through mineralization of soil organic matter (SOM).

Maintenance of soil structure in any soil type strongly influences soil C residence times, and thus management and disturbance can lead to substantial losses of soil C. Frequent disturbance to the soil (i.e., tillage) exposes protected organic matter and increases the rate of decomposition, decreased aggregate stability resulting in lower steady-state SOC storage. Excessive tillage and intensive cultivation in semi-arid region reduced soil organic carbon density from 60 kg km^{-2} under single cropping to 10.5 kg km^{-2} under double cropping.

Decrease in soil organic carbon pool may be caused by three, often simultaneous processes viz., mineralization, erosion, and leaching.

Mineralization: Most of the biomass produced in the natural ecosystem is returned into the soil. However, the rate of mineralization in agriculture ecosystem often exceeds the rate of carbon accretion occurring through addition of roots and biomass. Higher soil temperature increases the rate of mineralization of SOC pool (Jenny and Raychaudhury, 1960). Due to high temperature, soils of tropical, subtropical, arid and semi-arid regions are expected to be contributing more oxidative products. Long-term cultivation reduced SOC storage, but losses varied depending on the climate in the order: tropical moist>tropical dry>temperate moist>temperate dry.

Soil erosion: Conversion of natural ecosystem to agricultural use generally leads to significant increase in the rates of soil erosion by both water and wind. In general, the ratio of C content of water and wind-borne sediments to that of contributing soil (C enrichment ratio) is always greater than one. Thus, the detachment of aggregates and redistribution of carbon rich sediments over the landscape may accentuate loss of carbon from soil to the atmosphere.

Leaching: The soluble fraction of SOC pool, called dissolved organic carbon (DOC), can be leached out of the soil profile with seepage water (Moore, 1998). While a component fraction of the DOC transported into the ground water may be precipitated and sequestered, a large portion may be mineralized and released into atmosphere as CO_2. Some soils have lost as much as 20-80 t C/ha mostly emitted into atmosphere. Crop cultivation is known to adversely affect distribution and stability of aggregates and reduces organic carbon stock in soil. In other words, the low SOC pool in soils of India is partly due to the severe problem of soil degradation.

2.4. Management of Soil Organic Carbon (SOC)

The amount of SOC depends on soil texture, climate, vegetation and historical and current land use/ management practices. Mean annual rainfall, tillage, period of canopy cover, available water capacity (AWC), silt and clays also have pronounced effects on carbon dynamics. The SOC is sensitive to impact of human activities, viz. deforestation, biomass burning, land use changes, soil disturbances and environmental pollution.

Table 2.3 Land will be a sink or source of atmospheric CO_2

Item factors	Soil as a source of CO_2	Soil as a sink of CO_2
Soil properties	Coarse textured soil, excessive drainage, high susceptibility to erosion	Clayey soil, poorly drained ecosystems, depositional sites, including foot slopes
Land use	Seasonal crops, simple ecosystem, shallow roots and low root-shoot ratio	Perennial crops, diverse ecosystem, deep roots and high root-shoot ratio
Soil management	Intensive tillage based on plough, negative nutrient balance, residue removal and/or burning, continuous cropping, loss of soil and water by runoff and erosion	No tillage, positive nutrient balance, mulch farming, cover crops in rotation cycle, soil and water conservation

Source: adapted from Lal (2005)

2.4.1. Carbon sequestration

Soils are the largest carbon reservoir of the terrestrial carbon cycle. It is estimated that the buildup of each tonne of soil organic matter removes 3.667 tonnes of CO_2 from the atmosphere (Kumar et al., 2006). Soils can regain lost carbon by re-absorbing it from the atmosphere. Restoration of soil organic carbon (SOC) in arable lands represents potential sink for atmospheric CO_2 (Lal and Kimble 1997). Carbon sequestration implies transferring atmospheric CO_2 into long-lived pools and storing it securely so that it is not immediately remitted. Promoting soil C sequestration is an effective strategy for reducing atmospheric CO_2 and improving soil quality. Indeed, quantification of SOC in relation to various crop management practices is of importance in identifying sustainable systems for C-sequestration in soils and increasing crop productivity in semi-arid and sub-tropical environments. Various crop management practices like tillage, cropping system and fertilisation influence potential C-sequestration and storage in soil.

2.4.2. Options for sequestering carbon in soils

In agricultural cropping systems, the large part of the carbon is stored in soil. Input of carbon to soil is determined by the net primary production and the fraction of it remaining on the field. Evaluation of current and new management practices for carbon sequestration will focus on the input and output of soil organic carbon. Increasing the soil carbon content means increasing the carbon input, decreasing output or a combination of the two through improved management. Carbon sequestration can also occur through a reduction in soil disturbance because more carbon is lost from tilled soils than from soils that are less disturbed. Measures for reducing soil disturbance include reduced or zero tillage systems, set aside land and the growth of perennial crops. Measures to increase carbon inputs to soil include preferential use of animal manure, crop residues, sewage sludge and compost on crop land instead of grassland, improved rotations with high carbon input to soil and in some cases fertilisation/irrigation/livestock management to increase productivity. Switching from conventional arable agriculture to other land uses with higher carbon inputs or reduced disturbance (eg. Bio-energy crop production, conversion to grass land, natural regeneration) will increase soil carbon stocks.

The SOC density can be enhanced by planting deep-rooted species with high below- ground biomass production. These strategies can be achieved through a wide range of land use and soil/vegetation management options. Restoration of degraded soils and ecosystems, erosion control and conversion of agriculturally marginal soils to a restorative land use are important options of SOC sequestration. Restoring eroded soils can enhance biomass production and improve SOC concentration. Similarly, restoration of salt-affected soils can lead to a drastic increase in SOC pool. A similar potential exists in restoring vast tracts of wastelands throughout India (Gupta and Rao, 1994). Even at modest rates of 40 to 150 kg/ha/year, the potential of SOC sequestration is 2.6 to 3.9 Tg C/year for restoring soils prone to water erosion, 0.4 to 0.7 Tg C/year for wind erosion, 3.5 to 4.4 Tg C/year for soil fertility decline, 0.1 to 0.2 Tg C/year for waterlogged soils, and 0.5 to 0.6 Tg C/year for salinized soils. The total potential of restoring degraded soils in India is 7 to 10 Tg C/year. There are three principal components of soil and water management in relation to C sequestration in soil. **Soil surface management involves**: (**i**) seedbed preparation through varying frequency, intensity, and type of tillage operations; (**ii**) crop residue management and return of organic by-products to the soil surface; and **iii**) efficient use of resources.

2.4.3. Conservation tillage and cycling

Soil tillage affects SOC through its influence on both aggrading and degrading processes. Seedbed preparation, based on mechanical soil manipulation, is a principal factor responsible for exacerbating soil processes that accentuate C mineralization and decomposition. Several experiments have shown that ploughing decreases SOC content both in temperate (Carter, 1993) and tropical ecosystems (Lal et al. 1989). In contrast to ploughing, conservation tillage practices reduce frequency and intensity of tillage, retain crop residues as mulch on the soil surface, reduce risks of runoff and soil erosion, and increase SOC content of the surface soil.

The SOC content also depends on the type of conservation tillage and amount of crop residues returned to the soil surface, and may be linearly related to crop residue returned to the soil. Even a fraction of these residues returned to the soil through conservation tillage can increase SOC content and lead to C sequestration.

Several experiments conducted in temperate and tropical regions have demonstrated the beneficial effects of conservation tillage on SOC. Conservation tillage usually has a positive impact on activity and species diversity of soil fauna. Also earthworm activity is notably improved by conservation tillage. Activity of soil fauna usually has beneficial effect on SOC because of mixing and deep placement. Burrowing activity of soil fauna facilitates translocation of SOC from surface to the sub-soil.

2.4.4. Nutrient management and cropping systems

Fertility maintenance may involve use of organic wastes and other by products; supplemental use of inorganic fertilizers to balance soil nutrient reserves; and biological nitrogen (N) fixation. Beneficial effects that application of organic materials bring on SOC are well known from several long-term experiments. Long-term fertilizer experiments conducted in the tropics have also shown beneficial effects of organic as well as inorganic fertilizers on SOC. It is important to realize, that low input agricultural systems deplete SOC and accentuate risks of the greenhouse effect.

Long-term intensive rice based cropping systems caused a net depletion of SOC that was inversely proportional to the amount of residue carbon inputs. However, balanced fertilisation (with NPK) improved the SOC level even under otherwise unfavourable condition (high summer temperature) in this sub-tropical region. Such build-up was more with the system having double rice crop or single rice crop with companion crops like wheat, sesame / mustard, etc. producing lower quality (low N content) of crop residues. Organic amendments like FYM (Farm Yard Manure) or compost *per se* could not appreciably improve SOC stock (10.7 per cent), but encouraged the rate of stabilisation of crop residue C to SOC by about 1.6 times more than that in its absence. The system with double rice crop in a year showed remarkable efficiency in stabilisation of greater amount of applied C into SOC as compared with the other tested cropping systems. Attempts are required to be made to curb such huge amount of escaping of C from cropped soil in order to maintain the soil health and to restrain the global warming (Mandal et al. 2007).

An absolute quantity of SOC within a natural ecosystem depends on many ecological factors. Important among these are annual precipitation, mean annual temperature, and soil texture. Conversion from natural to an agricultural land use often results in loss of SOC.Over and above the effect of climate and soil, the rate of decline of SOC also depends on soil and crop management. Agricultural practices with a profound positive effect on SOC content are cover crops and fallowing, agro-forestry and agro-pastoral systems, rotations with deep-rooted crops, and crop residue management or mulching.

Cultural **practices with proven positive effect on SOC are of two categories:** (**a**) those that increase biomass production; and (**b**) those that increase humification. Management practices such as application of fertiliser and manure play an important role in soil C sequestration and thereby greenhouse gas mitigation. NPK + FYM treatment resulted in significantly higher SOC content while lowest values were found in conventional tillage treatment with intermediate values in fertiliser and fallow treatment in Eastern India (Ghosh et al 2010).

2.4.5. Cover crops and fallowing

Growing aggressive cover crops and managed fallow systems enhance SOC content. Growing grasses and leguminous cover crops continuously also increase SOC content of a degraded Alfisol . Fallow based system restored more SOC compared to intensive cropping system but had low total system productivity (Ghosh et al. 2006).

2.4.6. Plant roots and carbon sequestration

Plant root acts as a medium for transfer of atmospheric carbon into the soil in the form of carbon containing compounds, viz., organic acid, phenolic acid, amino acid etc. Root lysis and root exudates contribute significant quantities of carbon deposited in subsurface soil. These deposits have potential for greater contribution for long-term carbon sequestration due to slow oxidation than surface soil.

The exact amount of sequestration depends on land management practices, edaphic factors, climate and the amount and quality of plant and microbial inputs. Studies on carbon transfer via roots will generate a whole new idea that will allow better decisions on specific use of crop rotation, fertilisation and other method of soil amelioration. These approaches provide valuable tools for addressing many problems in natural and agricultural soils.

2.4.7. Agro-forestry and agro-pastoral systems

The value of forests and trees in sequestering carbon and reducing carbon dioxide emission to atmosphere is increasingly being recognised worldwide. Agro-forestry has importance as a C sequestration strategy because of carbon storage potential in its multiple plant species and soil as well as its applicability in agricultural lands and in reforestation. Proper design and management of agro-forestry systems can make them effective carbon sinks.

Average carbon storage by agro-forestry systems has been estimated to be 9, 21, 50 and 63 Mg C/ha in semiarid, sub humid, humid and temperate regions (Montagnini and Nair 2004). Agro-forestry can also have an indirect effect on C sequestration when it helps decrease pressure on natural forests which are the largest sink of terrestrial carbon.

Deep-rooted crops with capacity to produce biomass in large quantities may enhance SOC content of the sub-soil horizons, where it is not easily mineralized and decomposed. Ley farming systems, with controlled grazing and low stocking rate, are effective in reducing losses and improving SOC pool. Pastures significantly improve soil hydro-physical characteristics and biological activity particularly increasing SOC by 30 per cent and decreasing erosion ration by 33 per cent. Such improvements in soil properties had a direct bearing on long term sustainability, soil erosion and soil quality in a complex divesrse risk prone fragile hilly ecosystem (Ghosh et al 2009).

2.4.8. Residue management and mulching

Farming systems that produce a large quantity of biomass and return it to the soil support more SOC pool than those that produce less. Improving the humus content is an important strategy to enhance the SOC pool. Management practices to enhance humification include none or controlled burning, returning crop residue mulch and other biomass to the soil, and preventing losses through conservation- effective measures. Benefits of these programs in improving SOC contents are well documented.

Deep incorporation of humus or non-labile fraction beneath the plough layer is another effective strategy for C sequestration. Carbon placed beneath the plough layer is not easily decomposed because it is not exposed to climatic elements. Practices that lead to deep placement of SOC include activity of soil fauna, vertical mulching, and growing deep-rooted annuals and perennials. Vertical mulching, practised regularly with substantial quantity of crop residue, can also facilitate increase in SOC in the sub-soil horizons (Lal, 1986).

2.4.9. Water management

Soil water management also affects SOC content by optimizing the soil moisture regime for plant growth. Three aspects of water management in relation to SOC content are in-situ conservation, water harvesting and supplemental irrigation, and drainage. Both in-situ conservation and supplemental irrigation are important for improving biomass production and increasing SOC in arid and semi-arid eco-regions. In contrast to irrigation, drainage of excessively wet soils may decrease SOC content by increasing soil temperature and increasing the rate of mineralization. Sub-surface drainage decreased SOC and soil aggregation. Soil fertility management is equally important in maintenance of SOC at high level.

2.4.10. Cropping systems and crop diversification

The input-output relationships of carbon storage with linear kinetic model under different cropping systems are presented in Annexure II. Carbon storage equilibrium depends upon types of soil, cropping systems and nutrient management.

Pulses are known to play an important role in maintaining soil health and enhancing soil organic carbon though leaf drop and root biomass. Legumes in the crop rotation restore SOC due to the combined impact of C and nitrogen (N) on SOC pool. It is very difficult to increase the soil organic matter content of the cultivated soil, unless legumes or hay crops are included in the rotation or organic matter is added from external sources.

Under current situation, there is a stiff competition for organic matter from other sectors as well. Pulses add significant amount of organic residue to soil in the form of root biomass and leaf litter. There are reports that the organic carbon content of the soil increase over the initial level in all the pulse based cropping systems, but the maximum benefit was found in rotation involving pigeon pea. In central India, the gross C input is relatively higher when soybean + sorghum-wheat system or soybean-wheat system that follows. The least C input is reported from cereal-cereal system (soybean-wheat).

A simple inclusion of pulse crop itself acts as a component of INM and benefits arising out of this are very much comparable with the benefits obtained from any other organic manure. Therefore, pulse crops has dual benefits – they constitute an economically viable component of the system; and also conserve the natural resources. Several long term fertilizer experiments (LTFE) conducted under AICRP in different agro-ecological zones of India also indicate the declining trends in the productivity of cereal-cereal system, underlining the positive role of farmyard manure in arresting these trends. Application of FYM in all places and under all conditions is not practically possible because of large scale consumption of dung for fuel purpose. Hence, growing of pulses can serve as an alternative options and must be included in intensive cereal-cereal systems.

2.5. Strategies for Enhancing C- sequestration

- Land use and soil management systems, which enhance the amount of biomass returned to the soil, also accentuate the terrestrial C pool. Different technological options for biotic and soil C sequestration include afforestation, and restoration of degraded ecosystem.
- It is useful establishment bio-energy plantations with a large potential for biomass production; opting for perennials with a deep and prolific root system; growing species containing high cellulose; and developing land use systems etc.
- Adoption of conservation tillage and mulch farming techniques, maintenance of soil fertility, soil and water conservation, and adoption of complex rotations have greater C-sequestration potential. The total potential of SOC sequestration through restoration of degraded and decertified soils in India is 10-14 Tg C yr^{-1}.
- Major changes in land use occurred in the forests and grassland with 39.9 and 37.5 per cent of total land use change in India, respectively. Such land use changes that lead to reduction of forests and grasslands should be discouraged.
- Returning crop residues, animal waste, and other biomass to soils is important to SOC sequestration, but not a practical option because of alternate uses for these by-products as fodder, fuel, construction material and numerous other economic uses.
- Adoption of appropriate farming systems and use of cover crops provide another option of C-sequestration within terrestrial ecosystems. Mixed crop rotations and use of cover crops improve SOC contents and enhance aggregation.

2.6. Long Term Carbon Management Strategy and Mitigation of Climate Change

Enhancing soil quality is important to increasing the use efficiency of inputs (e.g., fertilizers, irrigation), increasing biomass/agronomic yields, and improving the environment. Improving the concentration of quality and quantity of SOC is important for enhancing soil quality. In fact, there is a strong linkage between low SOC concentration in soils of India and the widespread problem of soil degradation. Therefore, reversing soil degradation trends necessitates increasing SOC concentration through adoption of no-till farming, use of crop residue mulch and compost on soil, and legume-based rotations.

A major constraint in adopting conservation tillage and mulch farming in the country is the non-availability of crop residue for returning to the soil. Most of the crop residues are removed from the fields for use as fodder and fuel and burnt in some cases. Dung is also used as fuel for cooking. Thus, adoption of mulch farming techniques is possible only if economic sources of fuel and alternative sources of fodder are identified. The expanding footprints of LPG cylinders under government's flagship scheme – UJWAL is expected to minimise the use of dung, crop residues etc as fuel and save it to return to the soil. Emissions from fossil fuel combustion in India are increasing. The soil C sequestration potential of 39.3 to 49.3 Tg C/y (mean of 43.3 Tg C/y) can be significant towards reducing the net emission from fossil fuel combustion.

This potential is considerable in terms of the negotiation under the provision of Clean Development Mechanisms (CDMs) under Inter-Government Panel on Climate Change (IPCC), and for trading C in the national and international markets. **Bio-sequestration of C, both by soil and biota, is a truly win-win situation.** While improving agronomic/biomass productivity, these options also improve water quality and mitigate climate change by decreasing the rate of enrichment of atmospheric CO2. Realization of this vast potential, which is of priority in the country, requires adoption of recommended management practices including the use of mulch farming and conservation tillage, integrated nutrient management and manuring, agro-forestry systems, restoration of eroded and salinized soils, and conversion of agriculturally marginal lands into restorative land uses.

Carbon sequestration will definitely help in reducing atmospheric CO_2 concentration and will mitigate drought, salinity stress and desertification. It is certainly one of the most viable approach towards sustainable agriculture. Thus sequestered carbon may be used for agriculture, forestry and will be a potential option to mitigate global change.

2.7. Annotation

The soils are important reservoirs of active C and play a major role in the global carbon cycle. As such, soil can be either a source or sink for atmospheric CO_2 depending on land use and the management of soil and vegetation.

The conversion of native ecosystems (e.g. forests, grasslands and wetlands) to agricultural uses, and the continuous harvesting of plant materials, has led to significant losses of plant biomass and carbon.

Carbon sequestration in managed soils occurs when there is a net removal of atmospheric $CO_{2,}$ because C inputs (crop residues, litter, etc.) exceed C outputs (harvested materials, soil respiration, C emissions from fuel and the manufacture of fertilizers, etc.).

Management practices that increase soil C are reduced tillage, erosion control, diversified cropping system, balanced fertilization, etc. The crop residue and maintenance of large root and crop biomass in the soil would enhance the organic carbon stock in the profile even under continuous cropping like rice-fallow. As the soil disturbances have considerable impact on the soil properties and SOC storage, conservation agriculture may be introduced for favouring environmental benefits.

Key Extracts

- Research on C sequestration should concentrate on: development of silivi-pstoral, horti-pastoral, agri-pastoral and silvi-cultural models for all kind of waste lands in different agro-climatic regions of the country and estimation of carbon sequestration potential of different land use systems viz., arable farming, forest plantations an agro-forestry in pilot scale studies may be initiated.
- Identifying sustainable systems for carbon sequestration and increased productivity in semi-arid and sub-tropical environment is important.
- There are 3 potential ways to increase SOC storage rate: i) by increasing carbon inputs; ii) by decreasing decomposition rate of organics; and iii) by reducing the amount of CO_2 produced per unit of organic matter decomposition. Intensive research on these process should be evaluated by management.

Chapter 3

Agro-ecological Based Agriculture

Agro-ecologists study a variety of agro-ecosystems, and the field of agro-ecology is not associated with any one particular method of farming, whether it be organic, inorganic, conventional, intensive or extensive. It is not defined by certain management practices, such as the use of natural enemies in place of insecticides, or polyculture in place of monoculture. The basic approach in this branch is derived mostly from agronomy, including the traditional agricultural production sciences.

3.1. Introduction

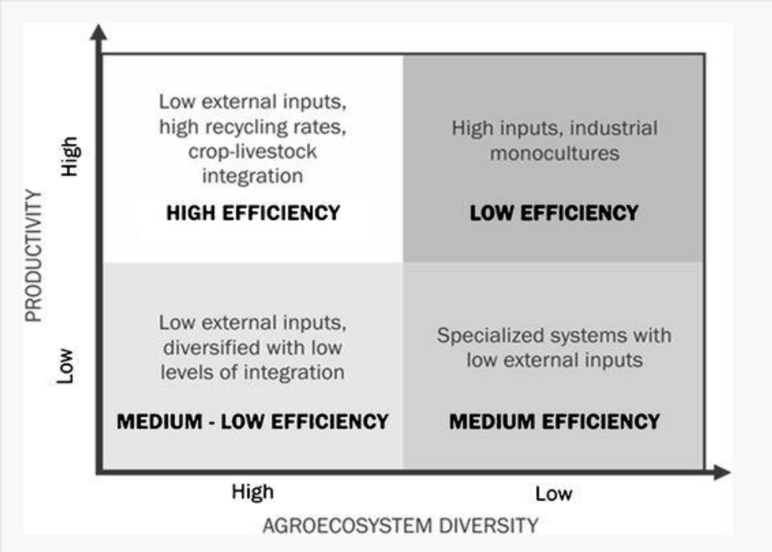
The realization of the contribution of peasant agriculture to food security amidst the challenging context of climate change, economic and energy crisis, led to the concepts of food sovereignty and agro-ecologically based production systems gaining much attention in the developing world in the last two decades. New approaches and technologies involving application of blended modern agricultural science and indigenous knowledge systems and spearheaded by thousands of farmers, NGOs, and some government and academic institutions are proving useful in enhancing food security while conserving agro-biodiversity soil and water resources across the developing world.

The agro-ecology based development involves revitalization of small farms which emphasizes diversity, synergy, recycling and integration; as also social processes that value community participation and empowerment. It is an option that balances economic needs and ecological challenges related to agriculture. Given the present and predicted near future climate, energy and economic scenarios, agro-ecology has emerged as one of the most robust pathways towards designing bio-diverse, productive, and resilient agro-ecosystems.

Most traditional agro-ecosystems exhibit five similar and remarkable features:

- High levels of biodiversity that play a key role in regulating ecosystem functioning and also in providing ecosystem services of local and global significance
- Ingenious systems and technologies of landscape, land, and water resource management and conservation that can be used to improve management of agro-ecosystems
- Diversified agricultural systems that contribute to local and national food and livelihood security;
- Agro-ecosystems that exhibit resilience and robustness to cope with disturbance and change (human and environmental) minimizing risk in the midst of variability
- Agroecosystems nurtured by traditional knowledge systems and farmers innovations and technologies
- Socio-cultural dimension, regulated by strong cultural values and collective forms of social organization including customary institutions for agro-ecological management, normative arrangements for resource access and benefit sharing, value systems, rituals, etc.

Figure 3.1 Features of green agro-ecosystems of the future: productivity, diversity, integration, and efficiency



(Funes-Monzote 2009).

Proponents of the Green Revolution technology and other modernization schemes assume that transformation progress and of traditional agro-ecosystems requires the replacement of local crop varieties by improved ones; and that the economic and technological integration of traditional farming systems into the global system enables increased production, income, and well-being. The conventional wisdom is, that small family farms are backward and unproductive, and that peasant agriculture generally lacks the potential of producing meaningful marketable surplus, and ensuring food security. Many scientists believe that traditional systems do not produce more because hand tools and draft animals put a ceiling on productivity. This may not be totally correct. Productivity may be low but the causes appear to be more social, not technical.

Following sections will discuss options across the major Agro-Ecological Systems (AES) in India

3.2. Irrigated Eco-system

Irrigated system in India occupies a unique place in its agriculture helping achieve impressive output of several agri-commodities. Around 48 per cent of the cultivated area is under assured irrigation. With advancement in irrigation facilities in northern India, wheat (*Triticumaestivum* L.), rice (*Oryzasativa* L.), and maize (*Zea mays* L.) crops are predominating. In other parts of the country too, dependable irrigation has come to support intensive production system. However, irrigated productions systems in the country are mainly cereal dominated. Recent evidences show that continuous cereal–cereal production systems have come under stress. Irrigated systems of irrigation has resulted in overuse, and large extents have come to suffer from soil health deterioration. The extent of problematic soils – acidic and alkaline is as high as 24 million ha in the country. The fast declining ground water table and factor productivity in rice–wheat cropping system of Indo-Gangetic Plains (IGP) indicate the situation of over-exploitation of natural resources.

What is most critical is the necessity of adopting crop alignment once an irrigation source is created. The farmers exhibit greater productivity to take up high water duty crops, irrespective of the ability of the available water to support. Irrigation management, that includes enforcing strict crop alignment based on water budget, nature of soil and other agro-climatic factors, deserves priority attention. In case of soils, that have already been affected they need to be nursed back into health, by practising soil amendments and leguminous crops like pulses.

3.2.1. Challenges in irrigated areas

In the post-green revolution era, resource conservation issues have begun to demand attention in view of the widespread land and water degradation problems linked to mechanized intensive tillage in rice-wheat cropping system. There is a need for shifting cropping systems and/or production practices in accordance to the resource availability, particularly in respect of soil characterization and water availability. More than 80 per cent of the water available in the country is already being used in agriculture, of which two-thirds is allocated to rice cultivation. Ironically, rice requires about 4,000–5,000 litres of water for production of 1 kg grain with conventional puddled planting method. This is unaffordable, given the situation of water deficiency in India.

Climate change is another challenge likely to have impact on agricultural land use and production. This may be due to less availability of irrigation water, higher frequency and intensity of inter and intra-seasonal droughts and floods, low soil organic matter, soil erosion and constraints of energy. Therefore, rice crop cultivation should be discouraged in IGPs with light texture soils, like loamy sand and sandy loam. These soils have low water retention capacity. Diversification by replacing the rice crop or by inclusion of suitable crops in the cropping systems is a matter of urgency. The diversified cropping systems including pigeon pea-wheat, maize-wheat, and inclusion of pulses in the rice-based cropping systems is the need of the hour.

Considering the increasing population and stress on natural resources, new technologies that will support higher productivity with lower intensity of resource use and on a sustainable basis, are a must. It is therefore, imperative to adopt a perspective plan that takes care of sustainability and anticipated impact of climate. This will need re-orientation of R&D, technology package and extension emphasis.

According to the National Action plan on climate change, the key priorities for coping against climate in IGPs of India under "National Mission on Sustainable Agriculture" are **(i)** diversification of cropping systems;**(ii)** promotion of carbon sequestration in agricultural practices and building resilience in soil;**(iii)** sustainable soil management practices;**(iv)** popularization of aerobic rice cultivation methods;**(v)** water saving technologies; and **(vi)** climate responsive research programmes.

Planned adaptation is essential to increase the resilience of agricultural production to climate change. Several improved agricultural practices evolved over time for diverse agro-ecological regions in India have the potential to enhance climate change adaptation, if deployed prudently. Management practices that increase agricultural production under adverse climatic conditions also tend to support climate change adaptation, because they increase resilience and reduce yield variability under variable climate and extreme events.

3.2.2. Improved agro-techniques for irrigated systems

a) Laser land levelling

Laser land leveling alters fields having a constant slope of 0 to 0.2 per cent using laser equipped drag buckets and gives a smooth land surface (± 2 cm). Large horsepower tractors and soil movers equipped with global positioning systems (GPS) and/or laser-guided instrumentation help to move soil either by cutting or filling to create the desired slope. Laser leveling provides a very accurate, smooth and graded field, which helps in saving of irrigation water up to 20 per cent and improves the use-efficiency of applied N.

b) Conservation tillage (zero/minimal tillage)

Conservation tillage is the collective umbrella term, commonly given to no-tillage, direct-drilling, minimum-tillage and/or ridge-tillage, to denote that the specific practice has a conservation goal of some nature. Usually, the retention of 30 per cent surface cover by residues characterizes the lower limit of classification for conservation tillage, but other conservation objectives for the practice include conservation of time, fuel, earthworms, soil water, soil structure and nutrients.

c) Bed planting (narrow/broad beds)

In bed planting crops are grown on the raised beds alternated by furrows. Beds are usually made of a width at 0.6-1.0 m, and 2-3 rows of crops are sown on the beds. The furrow irrigated raised-bed system (FIRBS) of wheat cultivation has been shown to result in a saving percentage of seed by 25-40, water by 25-40 and nutrients by 25 without affecting the grain yield**.**

d) Direct-seeded rice

Direct dry seeding of rice with subsequent aerobic soil conditions reduces overall water demand, saves labour, fuel and time, and gives similar yield to transplanted rice, if weeds are effectively controlled. The technology does not affect rice quality and can be practised in different ecologies such as upland, medium and low land, deep water and irrigated areas. Soil health is maintained or improved, and fertilizer and water use efficiencies increase. Therefore, it can be a feasible and preferable alternative to conventional puddled transplanted rice.

e) Furrow irrigated raised bed system of planting

Furrow Irrigated Raised Bed (FIRB) system of planting is an agronomic intervention, where crops are sown on raised beds of different sizes. Bed size depends on crop type, soil, objectives of making bed and machineries available for making bed. The concept of raised bed planting is very advantageous in both water logged and limited water area. The system of planting crops on raised bed alters crop geometry and land configuration, imposes effective control over irrigation and drainage. Water logged situation is a common feature of rainy season pulses in eastern and central Uttar Pradesh. However *rabi* pulses are normally grown under limited water condition or under rainfed environment, such as in Bundelkhand region of Uttar Pradesh. Further, 40-50 per cent reduction in incidence of complex *Phytophthora* wilt is observed in pigeonpea under heavy rains. Furrows can be used to drain out the excesses amount of water from water logged fields. Further, 40-50 per cent saving in irrigation water was recorded when irrigation was applied through furrows. The problem of over-irrigation or ponding in field can also be avoided. In addition, 40-45 per cent saving of irrigation water and 25 per cent saving of fertilizers and seeds were also recorded under FIRB planting.

3.3. Rainfed agro-ecology

With limited access to dependable sources of irrigation, rainfed agriculture is as high as 54 per cent of the net cultivated area. Rainfed agriculture is as old as agriculture itself. Growing of crops entirely under rainfed conditions particularly where quantum of precipitation is low, is known as dryland agriculture. Depending on the amount of rainfall received, dryland agriculture can be grouped into three categories:

a) **Dry farming:** is cultivation of crops in regions with annual rainfall less than 750 mm. Crop failures are most common due to prolonged dry spells during the crop period. These are arid regions with a growing season (period of adequate soil moisture) less than 75 days. Moisture conservation practices are necessary for crop production.
b) **Dry land farming:** is cultivation of crops in regions with annual rainfall more than 750 mm. In spite of prolonged dry spells, crop failure is relatively less frequent. These are semi arid tracts with a growing period between 75 and 120 days. Moisture conservation practices are necessary for crop production. However, adequate drainage is required especially for vertisols or black soils.
c) **Rainfed farming:** is crop production in regions with annual rainfall of more than 1150 mm. Crops are not subjected to soil moisture stress during the crop period. Emphasis is often on disposal of excess water. These are humid regions with growing period of more than 120 days.

3.3.1. Area under dry lands

Majority of the districts in India are dry farming districts and cover more than 50 per cent of the total cultivated area. Most of this area is covered by crops like millets, pulses, oilseeds, cotton etc. These areas spread throughout the country.

- The area under dryland agriculture is the highest in India (54 per cent of total cultivable area)
- Areas of low rainfall (below 750 mm) constitute more than 30 per cent of total geographical area
- About 84 districts in India fall in the category of low rainfall area

- Providing assured irrigation to all the drylands is expensive and time taking, besides being infeasible many a time
- Even after harvesting the full irrigation potential of the country, major percentage of area will continue to depend upon monsoon

3.3.2. Principal dry farming zones in India

Almost all the states have some area under rainfed culture depending upon topography and irrigation facilities. Only the major dry farming areas are discussed hereunder.

3.3.2.1. Indo-Gangetic Plains (IGP) of North India

This zone is the youngest in terms of geological formation, and includes districts in the states of Rajasthan, Punjab, Haryana, North- western M.P., and U.P. The zone is characterized by two major soil types, namely, light loam and heavy loam. The land is nearly level with a modest slope of 2 ft/mile length. The soils are very deep and situated at about 700 to 800 ft. above main sea level. On account of heavy sand and silt fractions in the soil, it has large pore spaces. The soils are rich in essential nutrients like nitrogen, phosphorus, potash, calcium etc. and, therefore, well suited for raising various crops, excepting a few with high water duty. The cropping intensity, in this zone, stands around 120 per cent and the major crops which are grown in this zone are millets, cereals, oilseeds and pulses.

As regards rainfall pattern, it is observed that about 60 per cent or more of the total rainfall is received between the end of July and the end of August, and the spread in remaining months is quite poor. Thus, due to very high intensity of rainfall, floods are of frequent occurrence during the first week of September followed by a long spell of drought.

3.3.2.2. Trapian Plateau of Peninsular India

This zone comprises the states of Maharashtra, Karnataka and Andhra Pradesh. The soil of this zone has been derived from the Deccan trap .The tract is undulating and consists of low ridges and valleys due to erosion, which results in rapid run-off. About 40 per cent of the land of this zone is not fit for cultivation. The soil may be grouped into three types based on its depth as deep, medium deep and shallow soils. Leaching of lime has resulted in the formation of lime nodules or kanker on the surface soil. The soil is quite rich in total and available nitrogen, phosphorus and potash which favour production of crops if moisture is efficiently conserved.

In this zone, two high peaks of rain are observed, because the area benefits from both south-west as well as northeast monsoons. About 40-55 per cent of the total annual rainfall is obtained from south-west monsoon and the rest from north-east monsoon. Mostly, millets and some oilseeds like groundnut are grown in this zone.

3.3.2.3. Plateau of granite formation

The soils of this zone are grouped as red soils and black cotton soils. Red soils are shallow, while black cotton soils are very deep like clayey soils. The topography is of gentle undulations which favour run-off and soil erosion. The high pore space and high swelling of soil obstruct the permeability of rain water into the lower layers of soil and its shrinkage results in hardening and clod formation on the surface which is unfavourable for plant growth. The red laterite and black cotton soils are deficient in nitrogen and phosphoric acids.

This zone also gets rain from both south-west and north-east monsoon, and the distribution pattern is more or less like that of the peninsular group. Upland rice, millets and ragi are the main crops of this zone, but yield levels are low.

3.4. Constraints in Dryland farming

3.4.1. Inadequate and uneven distribution of rainfall

In general, the rainfall is low and highly variable which results in uncertain crop yields. Besides its uncertainty, the distribution of rainfall during the crop period is uneven, receiving high amount of rain when it is not needed, and lack of it when crop needs it.

3.4.2. Late onset and early cessation of rains

Due to late onset of monsoon, the sowing of crop is delayed resulting in poor yields. Sometimes the rain may cease very early in the season exposing the crop to drought during flowering and maturity stages which reduces the crop yields considerably.

3.4.3. Prolonged dry spells during the crop period

Long breaks in the rainy season are an important feature of Indian monsoon. These intervening dry spells when prolonged during crop period reduces crop growth and yield and when unduly prolonged crops fail.

3.4.4. Low moisture retention capacity

The crops raised on red soils, and coarse textured soil suffer due to lack of moisture whenever prolonged dry spells occur due to their low moisture holding capacity. Loss of rain occurs as runoff due to undulating and sloppy soils.

3.4.5. Low fertility of soils

Drylands are not only thirsty, but also hungry too. Soil fertility has to be increased, but there is limited scope for extensive use of chemical fertilizers due to lack of adequate soil moisture. Hence, more of organic based manuring is the option.

3.5. Negotiating dryland agriculture – key elements

- Capturing and conservation of moisture
- Effective use of available moisture
- Soil conservation
- Optimal use of inputs and rationalisation of costs

3.6. Sustaining Dryland Agriculture

3.6.1. Agricultural diversification

Though the green revolution technology shortened the growing period of irrigated crops, facilitating two or more harvests a year, similar progress has been relatively slower in the dry regions. However, growth rates in agricultural production and total factor productivity have been moderate, if not high. Modern technologies such as high-yielding varieties (HYVs) are increasingly being used. Agricultural research scientists are combining a medley of measures to allow farmers to reap more than one harvest a year, e.g., quicker growing plants that mature before the summer heat and water-harvesting techniques that allow concentration of available water where it is most needed. Better water management methods have helped farmers optimize the use of water. As a result, cropping pattern shifts are taking place and nutri-cereals (known more as coarse cereals) are being replaced by soybean, pigeon pea and lentil, and in some places maize. Significant dietary changes are also occurring across all income baskets.

3.6.2. Livestock management

Population growth, urbanization and increasing per capita incomes are fuelling a rapid growth in demand for animal-based foods in developing countries, especially in the dryland regions. This is true for India too. Hence, in addition to improving crop production, it is important to seek ways to improve dryland livestock production and crop-livestock systems.

Vast tracts of arid and semi-arid lands are unsuitable for crop production but are livestock supportive, especially of small ruminants (sheep and goats). Livestock is not only a vital source of protein but also constitutes an important sector of the economy which makes use of land that would otherwise remain unproductive. They provide livelihood to around 300 million pastoralists worldwide. Livestock support farming by providing it with manure and draft power.

In India, as discussed in DFI Report Vol II, the livestock and small ruminants hold great potential in contributing to farmer's income. These are well suited in rainfed system as an important component of integrated farming.

3.6.3. Residues retention for mulch

Cropland offers a huge potential for sequestering C, especially when crop residues are managed properly. Permanent or semi-permanent crop/plant residues cover on soil, which can be a growing crop or dead mulch, has a role to protect soil physically from sun, rain and wind; and to feed soil biota/micro-organisms that take over the tillage function and soil nutrient balancing. Crop residues significantly influence physical, chemical and biological properties of the soil. It helps in water conservation through enhanced water infiltration, and reducing evaporation, wind and water erosion.

3.6.4. Micro-irrigation

Micro-irrigation systems use precision technologies for efficient management of both water and nutrient, by directing these precious resources, near the root zone of the crop plant where actually required.

The major advantages in terms of water application include three factors that directly enhance both conveyance and water use efficiency, viz., **i)** water is applied directly to the root zone of plants; **ii)** water is applied in frequent intervals in precise quantities as per the crop water requirement; **iii)** water is applied through a low-pressure pipe network comprising Mains, Sub mains, Laterals and Emitting devices. There are perceptible advantages such as application of water at field capacity and near root zone, use of saline water upto 8-10 m mhos/ cm and combining fertilizer with drip-water. Such precision application of water results in lesser weeds & pests and greater pod retention, besides realization of efficiency in nutrient uptake due to fertigation.

3.7. Coastal Agro-ecology

The coastal zone represents the transition from terrestrial to marine influences and vice versa. It comprises not only shoreline ecosystems, but also the upland watersheds draining into coastal waters, and the near shore sub-littoral ecosystems influenced by land-based activities.

Functionally, it is a broad interface between land and sea that is strongly influenced by both. India has an 8,129 km long coastline. Its peninsular region is bounded by the Arabian Sea on the west, the Bay of Bengal on the east and Indian Ocean to its south. It has two distinct major island ecosystems, the Andaman and Nicobar group of Islands in the Bay of Bengal and the Lakshadweep Islands in the Arabian Sea. The coastal ecosystem in India occupies an area of about 10.78 million hectares (1,07,833km^2), and covers a long strip along the east coast (West Bengal, Odisha, Andhra Pradesh, Pudicherry and Tamil Nadu) and west coast (Gujarat, Maharashtra, Karnataka and Kerala). It also occupies considerable area under Lakshadweep and Andaman and Nicobar group of Islands.

3.7.1. Constraints in coastal agriculture

Low productivity of this ecosystem is attributed to its unfavourable agro-climatic conditions. Coastal soils encounter several abiotic stresses viz., salinity, acidity, waterlogging and sandy texture. Most of the coastal areas have problematic soils, such as saline, alkaline, acid sulphate, marshy and waterlogged, as they are situated in low-lying areas, mainly along the deltas. Salinity is the main factor responsible for poor yield of crops growing an area of about 3.1 million hectares. The estimate on the extent of acid sulphate soils in the coastal areas reveals that about 0.26 million hectares area in Kerala and the Andaman and Nicobar group of islands are occupied by this type of soil.

The presence of acid sulphate soils has also been reported in the coastal areas of Sundarbans, West Bengal. Coastal soils exhibit a great deal of diversity due to difference in parent material, wide variation of climate, physiography, differentially active geomorphic processes, hydro-chemical characteristics of shallow underground water and differential inundation by tidal marine/lacustrine waters. Therefore, proper understanding about the nature, properties and prevailing constraints related to diverse group of coastal soils is necessary to adopt better management practices and improve the productivity and quality of such low productive soils.

3.7.2. Management approaches for coastal soils

3.7.2.1. Leaching the soil

The salinity level of salt-affected coastal soils can be reduced by leaching the soils with good quality water. This can be a good option to reclaim the cyclone affected soils of the coastal area also. In the low-lying coastal areas where water table remains shallow for most part of the year and the quality of ground water is poor, installation of sub-soil drainage system is more useful.

3.7.2.2. Avoidance of summer fallow

Most of the coastal areas suffer from excess water in monsoon season with attendant problem of prolonged deep water submergence, leaving an adverse effect on crop growth. Whereas in winter and summer months, the capillary rise of the saline ground water impel the farmers to take only one rice crop in a year during the monsoon season. If good quality water is available, second crop of rice cultivation can be undertaken during the fallow period which will reduce the salinity level, besides increasing the cropping intensity. The high salinity is due to the high evaporation rate from soil during winter and summer months, when ground water is at shallow depth and rich in salt content. In coastal areas, the availability of good quality irrigation water is one of the major problems. However, if sufficient irrigation water of good quality is not available, a crop like chilli, barley, linseed, sugar beet can be grown whose crop canopy will reduce evaporation as well as soil salinity.

3.7.2.3. Application of soil amendments

Field experiments conducted at Coastal Saline Research Centre, Tamil Nadu Agricultural University, Ramanathapuram, Tamil Nadu revealed that application of organic waste materials such as pressmud @ 12.5 t ha^{-1} is beneficial in improving soil quality due to increased soil organic carbon and nutrient availability and substantial reduction in the electrical conductivity of coastal saline soils. Application of lime and alkaline flyash in proper combination to the coastal acid sulphate soils is effective for amelioration to some extent. Rice husk bio-char could be used as a substitute for liming materials to improve the quality of acid sulphate soils. Increase in the pH of acid sulphate soil due to application of rice husk bio-char is well documented. Amending coastal sandy soils with polyacrylamide @ 100-120 mg kg^{-1} is useful for increasing the aggregation of soil, which in turn increases the water holding capacity of coastal sandy soil. This plays an important role in highly permeable coastal sandy soils during dry summer months.

3.7.2.4. Growing of suitable crops

In coastal areas, rice is the most preferable crop, as it is highly salt tolerant and can be grown under submerged condition. Rice cultivation promotes the leaching of salts from coastal saline soils. Adoption of rice crop in acid sulphate soils of coastal areas increases the pH of soil and thus reduces the iron and aluminium toxicity. Selection of suitable rice variety depending upon the salinity level and depth of water regime is highly appreciable. A large number of promising rice varieties have been developed/identified by Central Soil Salinity Research Institute, Karnal, Haryana and its regional research station at Canning, West Bengal for various waterlogging and salinity levels in kharif season. Crops other than rice identified as salt tolerance are chilli, guava and sapota; and for coastal saline soils, vegetables 7 fruits are seen as appropriate. Growing of cashew in the coastal belt with proper irrigation and management practices may be beneficial.

3.7.2.5. Nutrient management

Most of the coastal soils are deficient in nitrogen due to heavy loss through volatilization, leaching and run-off. Phosphorus deficiency is also a common phenomenon in coastal acid sulphate or acid saline soils. Use of nitrogenous fertilizers is very much essential to obtain higher yield of crop in coastal saline soils. Application of rock phosphate as phosphorus source is highly beneficial for coastal acid saline soils (locally known as kari or kayal or karappadom in Kerala). Long term fertilizer experiment showed significant response of rice crop due to application of nitrogenous fertilizers on coastal saline soils of West Bengal under rice-fallow cropping system. Integrated use of chemical fertilizers and farmyard manure (FYM) @15 t ha^{-1} is also a recommended practice for better use of fertilizer nutrients in coastal soils.

3.7.2.6. Rice-Fish based agro-ecology

Rainfed lowlands with water stagnation and flooding occupy 41 per cent (17.3mha) of the rice area in the country, and 52 per cent (14.9 mha) of the rice area in eastern India. The productivity of this mega system is very low (less than 1.5 tha^{-1}) because of mono-crop of rice. Among the farming system options available in rainfed low land ecologies, rice-fish farming system is one of the best acceptable choices considering the resources, food habits and socio-economic cultures of the country in general and eastern India in particular. The water stored in the deep part of the system is utilized for life saving irrigation. Rice-fish farming venture is a better bargain than a single rainfed low land rice-cultivation, under the risk of vagaries of climate.

3.7.3. Components of rice-fish farming system

Crop husbandry: In the centre of the pond area, rice is grown in the Kharif season; followed by vegetables like brinjal, gourds, chilli etc. in the summer season. Fruits like banana and papaya are grown on the dykes of the pond. In the deep area of the pond rice-rice crop sequence may be followed. Rice varieties like Jaladhi-1, Jaladhi-2, Jalmagna, UtkalPrabha, Manika, Mahalaxmi, Panidhan, FR-13A, Jal Lahri, Jal Nidhi, Jal Priya etc. are found suitable. Rice varieties capable of growing vigorously in hypoxic environment, that is oxygen deficient conditions alleviate the constraints of poor seedling stand establishment and also accrue the weed suppressing advantage of early flooding.

To supplement the nitrogen requirement, Azolla is grown along with paddy. Azolla (*Azollamicrophylla*) is inoculated to the rice field @ $500gm^{-2}$ at 9 days after transplanting. With quantification of nitrogen fixation rates in water and sediment media of fish ponds under different management practices, biofertilization with Azolla has been standardised at 40 tonnes $hectare^{-1}$ $year^{-1}$, providing 100 kg nitrogen, 25 kg phosphorus, 90 kg potassium and 1,500 kg organic matter (Ayyappan, 2000). Rice seedlings are transplanted in June/July at a distance of 20 cm x 20 cm. Fish species which thrive in shallow water, tolerate high turbidity, high temperature and grow fast are selected. The fishes like catla (*Catlacatla*) ,rohu (*Labeorohita*), mrigal (*Cirrmnusmrigala*), common carp (*Cyprinus carpi~* and exotic carp like grass carp (*Ctenopharyngodonidella)* can be best suited for rice-fish-culture. The stocking density is maintained at 5,000 to 6,000 fingerlings per hectare (Singh, 2000).

A perimeter trench of 2 m wide and 1.5-2.0 m deep is dug around the' rice field to enable fish to move to- and-fro from the pond. The flow of water is must for the 'fish population and grow. Water hyacinth (*Eichorniacrassipes*) is grown in a portion of the canal, which provides shade and shelter for the fish, besides being an excellent feed to the fishes. It is grown as an added commodity in a rice-fish farm. Practically, whole plant of water hyacinth can be consumed (tubers, stalk and leaves) by the fishes. It is also utilized as food by the ducks. The fishes are fed with rice-bran or rice polish and mustard cake/ groundnut cake or soybean meal (1: 1) in dough-like balls at 2-3 per cent of the average body weight of the fish as supplementary feed to help them grow to a bigger marketable size.

3.8. Shifting Cultivation in India

Shifting cultivation in India is known as *jhum* in Assam; *punamkrishi* is Kerala; *podu* in Andhra Pradesh and Odisha; *bewar, mashan, penda and beera* in different parts of Madhya Pradesh.

Shifting cultivation is practised by tribal people. About 20 lakh hectares of forests are cleared every year by felling and burning the trees and shrubs. These clearings are cultivated under very crude and extravagant methods for 2-3 years and then abandoned when fertility dwindles or soil erosion makes it unfit or forests reappear. Paddy, buck wheat, maize, millets, tobacco, some vegetables and banana are grown on the burnt over clearings and the products shared jointly by the clan. Dry deciduous forests are especially suited to jhuming.

This wasteful practice in difficult terrain obviously supports a very sparse population. By the time of the sowing season the earth is covered with a layer of ashes. Then seeds are scattered/broadcast, and rarely sown in these ashes. After some time the seeds take root and grow, nourished by an occasional shower of rain. The crops are scarce and of inferior quality. In a few years' time the spoil becomes impoverished in the absence of ploughing and manuring, and a new stretch of the forest is brought under the axe.

There have however been several initiatives to stop this unsustainable practice and orient the practitioners into a more settled form of agriculture, also supported by other non-farm activities. It is always a challenge in these areas to marry the demands of ecology and livelihood, set in apparent contradiction to each other.

Disadvantages

- It has been characterized as inefficient, uneconomic and wasteful.
- It has caused deforestation and as a consequence thereof, erosion and floods.
- Valuable timber has been wastefully lost.
- Farmers do not produce enough even for their own consumption.

- It is an unsustainable system of cultivation.
- The practitioners' are having to live with unsteady employment and poor livelihood options.

3.9. Rice-fallows Ecosystem

Rice-fallows (~14 m ha) a mono-crop rice based production system of south Asia is mainly concentrated in India, Nepal, Pakistan and Bangladesh (Subbarao et al., 2001). In India, an extent of around 11.7 m ha (30 per cent of the area under rice production) remains fallow in the subsequent rabi (winter) season. Rice-fallows are widely distributed in the rainfed ecosystem across the country, but as per recent estimate, almost 82 per cent of the rice-fallows are concentrated in seven states viz. Chhattisgarh, Jharkhand, Madhya Pradesh, Assam, Bihar, Odisha, and West Bengal.

However, based on the agro-climatic conditions and edaphic characteristics, rice fallows can be categorized into three major zones i.e. *rice fallows of north-eastern zone; rice-fallows of central zone;* and *rice fallows of coastal peninsular zone*.

The rice fallows of north-eastern zone include eastern Uttar Pradesh, Bihar, Odisha, West Bengal and Assam. Soils are mainly deep alluvial and neutral to acidic in nature. Lentil, lathyrus and chickpea are potential crop in this zone. Lentil and lathyrus are mostly grown in relay system (utera, paira) before harvest of rice for effective utilization of residual soil moisture in parts of Bihar and West Bengal.

The rice-fallows of central region cover Chhattisgarh, Madhya Pradesh and Maharashtra. Soils are generally clay in nature (vertisols), become hard and develop deep cracks on drying and poor in soil nutrients (Ali et al., 2014). Soil constraints are major challenges in this zone. Lathyrus and chickpea are the primary candidate crops in this zone.

Rice-fallows in areas of Andhra Pradesh, Tamil Nadu and Karnataka are covered under coastal peninsular zone. The region receives bi-modal rains. Excessive soil moisture and mild winter are the main characteristics of the region favouring blackgram (urdbean) and greengram (mungbean) cultivation.

These vast stretches of post kharif rice fallows with their residual moisture are well suited to raising of pulses, oilseeds and millets, all of which are important from production perspective. This will also increase the cropping intensity of the country.

3.10. Annotation

Agriculture and food production are the basis of life and economy, and have multiple functions in creating healthy societies. They are at the centre of a strategy in addressing challenges like hunger and poverty, climate change and environment, women's wellbeing and community health, income and employment.

A transition to greener, more productive, sustainable agro-ecological farming allows local people to lead in creating solutions. The proper management and utilization of ecosystem-based soil resources are the need of the hour for maintaining and/or improving the quality and productivity of soil in order to meet the ever increasing demand of food, fibre, fuel and fodder triggered by ever increasing population in a more sustainable manner.

So as to increase the productivity and cropping intensity, location specific and appropriate management practices are needed depending on the existing problem.

It is an urgent need to develop low-cost irrigation technology with higher efficiency to support the cultivation of more than one crop in a year. Despite the positive gains that agro-ecological movements have had over time, there are many other factors that have limited or constrained the diffusion and implementation of agro-ecological initiatives more comprehensively.

Major reforms must be made in policies, institutions, and research and development agendas to make sure that agro-ecological alternatives are adopted as a solution & strategy, made equitably and broadly accessible, and multiplied so that their full benefit for sustainable food and income security can be realized.

It must be recognized, that a major constraint to the spread of agro-ecology has been inadequacy of attention to the need for research and development related to agro-ecology and sustainable approaches.

Key Extracts

- Knowledge about biologically diverse farming practices in different agro-ecology is necessary to enhance farm profitability and sustainability.
- Research must be targeted to generate improved germplasm, harness bio-technology, protect crops against major pests and diseases, develop watersheds, enhance crop-livestock interactions and innovate approaches for linking farmers to markets (input and output markets).
- System diversification comprising diversification of income-generation activities at the farm level, value addition, changing market trends, new opportunities, and information technology use in agriculture, and enhanced food processing and food supply chains and marketing are the key for sustainability.
- Degrading natural resources, severe pest and disease infestation, drought, resistance to new breeds (such as GM crops), low productivity caused by poor varieties and inadequate local seed systems are major constraints to agricultural development. Hence, a need to provide sustainable solutions to these pressing problems is a real challenge.

Chapter 4

Conservation Agriculture and Residue Management

Interest in sustainable crop production systems at the global level has grown ever since the sustainability of industrial agricultural systems came to be questioned in the 1940's. In respect of India, the challenges faced by the increasing unsustainability of the rice–wheat system, in the Indo-Gangetic Plain (1GP) brought attention to conservation agriculture (CA) to meet the present and future challenges in agricultural intensification.

4.1. Introduction

Today, Conservation Agriculture (CA) is practised globally on an estimated 155 million hectares in all continents and agricultural ecologies. USA, Brazil, Argentina, Canada and Australia account for about 90 per cent of the area under conservation agriculture in the world (100mha). The conservation agriculture, which is advocated as an alternative to the conventional production system, has been adopted by the Food and Agriculture Organization (FAO) of the United Nations as a lead model for improving productivity and sustainability. Recent estimates have revealed, that conservation agriculture-based resource conserving technologies (RCTs) that include laser assisted precision land levelling, zero/reduced tillage, direct drilling of seeds, direct seeding of rice, unpuddled mechanical transplantation of rice, raised bed planting and crop diversification are being practised over 3 mha in South Asia.

In India, there are divergent views on the extent of area under CA. Derpsch*et al.*, 2010 estimated that CA is practised on about 1.5 m ha in IGP, and is otherwise known through resource conservation technologies (RCTs). The spread of CA is largely concentrated in the rice–wheat system in the IGP of the country. Indian IGP comprises of Trans (GP), Upper (GP), Middle (GP) and the Lower (GP). The IGP of South Asia includes India, Nepal, Bangladesh and Pakistan.

The aggregate of no-till and reduced till wheat area in the IGP is estimated at about 2 million hectares in 2004–2005. Recent assessments of CA in the IGP across India, Pakistan Bangladesh, and Nepal and in the rice–wheat cropping system with large adoption of no-till wheat is about 5 million ha, but it includes only marginal adoption of permanent no-till systems and full CA (Friedrich *et al*., 2012).The CA based cropping system practised in the IGP is rarely a full conservation agriculture, but rather a step-wise adoption or periodic CA which involves reduced or minimum tillage including crop residue and rotation in one season i.e., in wheat crop but not in rice crop, grown in the succeeding season.

4.2. Genesis of Conservation Agriculture

Concerns about stagnating productivity, burning of crop residues, increasing costs of management of crop residues, declining resource quality, declining water tables and increasing environmental problems are the major factors forcing a look at alternative technologies, particularly in the northwest region encompassing Punjab, Haryana, western Uttar Pradesh (UP) and Uttarakhand. In the eastern region covering eastern UP, Bihar and West Bengal, developing and promoting strategies to overcome constraints for continued low cropping system productivity have been the chief concern.

The CA is one of the major drivers of sustainable agricultural intensification in the IGP vis-à-vis the increasing soil carbon depletion, declining groundwater table, increasing air pollution and the stagnating or low yields of the rice–wheat system. The zero-till(ZT) wheat after rice is the most widely adopted resource conserving technology in the Indian IGP. Thus it has become the predominant CA based cropping system. Zero-till wheat is aided by significant costs savings and potential yield increases (Erenstein and Laxmi, 2008).

In these systems, ZT is only applied to the wheat crop–and does not essentially involve the retention of crop residue as mulch or the use of crop rotations. Also, the subsequent rice crops are continuously puddled and transplanted. This anomaly in CA practices (in one season and not in the other) present a serious inadequacy from the ecologically-sustainable intensification outlook, as the benefits accumulated in the wheat season are lost in the subsequent puddled and transplanted rice.

Even in zero tillage wheat, farmers usually do not intentionally retain mulch and often burn the preceding rice straw–although the anchoring straw retained in the soil after burning may be enough to satisfy the requirements of residue mulch in CA. Moving towards a full conservation agriculture calls for an improved management of crop residue and its retention and the shift towards direct-seed aerobic rice and crop diversification. Regional inequality in terms of agricultural productivity seems to favour the less intensified eastern IGP areas than the highly intensified north-western (NW-IGP), in terms of yield gains and cost savings from ZT practice.

Table 4.1 Key elements of transformation

Conventional agriculture	Conservation agriculture
Cultivating land, using science and technology to dominate nature	Least interference with natural processes
Excessive mechanical tillage and soil erosion	No till / drastically reduced tillage (Biological tillage)
Residue burning or incorporation	Surface retention of residues
Use of e*x-situ* FYM/composts	Use of *in-situ* organics/ composts
Green manuring (incorporated)	Brown manuring (surface drying)
Free-wheeling of farm machinery	Controlled traffic
Crop-based management	Cropping system-based management
Single or sole crops	Intercropping / relay cropping
Uneven field levels	Precision laser land levelling

Socio-economic and system benefits of ZT in India are not a function of farm size. Smallholders have taken the advantage of ZT-drill in contract services. The use of ZT in wheat unwraps the opportunity for the adoption of a full CA cropping system, and to other crops (pulses and vegetables) in the IGP. It also opens the scope for triple cropping in rice–wheat systems, thereby increasing cropping intensity and diversity. For the expansion and scaling up of CA, it will have to deal with the impeding trade-offs or short falls associated with this anomaly.

4.3. Managing Crop Residues through Conservation Agriculture

The primary focus of developing and promoting CA practices in India has been the development and adoption of zero tillage cum fertilizer drill for sowing wheat crop in rice–wheat system. Other interventions being tested and promoted in the IGP include raised-bed planting system, laser-aided land-levelling equipment, residue management alternatives, and alternatives to rice–wheat cropping system in relation to CA technologies. The area planted with wheat by adopting zero-tillage drill has been rapidly increasing in last few years. It is estimated that over the past few years, adoption of zero-tillage has expanded to cover about 2 m ha. The rapid adoption and spread of zero tillage is attributed to benefits resulting from reduction in cost of production, reduced incidence of weeds and therefore savings on account of herbicide costs, savings in water and nutrients and environmental benefits. Adopting CA systems further offers opportunities for achieving greater crop diversification. Crop sequences/rotations and agroforestry systems, when adopted in appropriate spatial and temporal patterns, can further enhance natural ecological processes which contribute to system resilience and reduced vulnerability to yield, thus reducing disease and pest problems. Zero-tillage when combined with appropriate surface-managed crop residues sets in processes, whereby, slow decomposition of residues results in structural improvement of soil and increased recycling and availability of plant nutrients. Surface residues are also expected to improve soil moisture regime, improve biological activity and provide a more favourable environment for growth. These processes, however, are slow and results are expected only with time.

In northwest (NW) India, rice-wheat cropping system generates huge quantities of crop residues (CRs). Majority of rice and wheat in NW India is harvested by combine leaving residues in the field. While about 75 per cent of wheat straw is collected as fodder for animals with the help of special cutting machine, (though this requires additional operation and investment), rice straw is considered poor feed for animals due to its high silica content. Rice straw stems are more digestible than leaves because their silica content is lower; therefore, the rice crop should be cut as close to the ground as possible if the straw is to be fed to livestock.

Management of rice straw compared to wheat straw is a serious problem, because there is very little turn-around time between rice harvest and wheat sowing and proper technology for recycling is not available. Among options available to farmers for the crop residue management (including burning), important ones are baling/removal for use as feed and bedding for animals, *in situ* incorporation in the soil with tillage, and complete/partial retention on the surface as mulch using zero or reduced tillage systems. After bailing, CRs can also be used for paper and ethanol production, bio-conversion, and engineering applications. Since rice straw has no economic value and there is a scarcity of labour, farmers hesitate to invest in cleaning the field by using a chopper. This practice also requires another operation and increases cost. Farmers in NW India have discovered burning as the cheapest and easiest way of removing large loads of residues produced by rice to establish the wheat crop rapidly after rice. Presently, more than 80 per cent of total rice straw produced annually is being burnt by the famers in 3-4 weeks during October-November. It is estimated, that the total rice straw production is as high as---34 m tonnes.

There are several technologies in India for managing crop residues. However, there are a few constraints, which limit large-scale adoption of these technologies. One major handicap in using large amounts of straw is the high cost and labour requirement for its collection and transportation. Some countries have developed strategies for successful management of crop residues to avoid on-farm burning. In China, where about 700 mt crop residues are generated annually, 31 per cent of crop residues are left in the field, 31 per cent are used for animal feed, 19 per cent are used for bio-energy generation and 15 per cent are used as fertilizer (Jiang et al., 2012).

In USA, on-farm burning has been regulated in some of the states. For example, in California farmers require a permit for crop residues burning, which can be carried out only on 'burn-days' determined by the local authorities in consultation with the California Air Resource Board. The crop residues are also required to be shredded and piled where possible. The crop residues are used as a source of energy in some countries like Indonesia, Nepal, Thailand, Malaysia, Philippines, Indonesia and Nigeria; for composting in Philippines, Israel and China; as animal feed in Lebanon, Pakistan, Syria, Iraq, Israel, Tanzania, China and countries in Africa; for mushroom cultivation in Vietnam and even burnt on-farm in China, USA, Philippines and Indonesia

India too requires a comprehensive policy to scientific use of crop residues that also includes, in situ incorporation into the soil, and ex-situ composting. In order to use it for activities like bio-energy aggregation of crop residues should grow up as an enterprise. This needs to be promoted.

4.4. Principles of Conservation Agriculture

Soil disturbance regulation, surface residue management and crop rotation are the fundamentals (core pillars) of CA. Controlled traffic or minimum physical soil disturbance on cropland– zero or reduced tillage enhances soil natural processes and recycling. This ensures that soil life, aggregates and structural quality is preserved, which promotes ecosystems sustainability. Permanent soil cover regulates erosion and temperature effect on surface soil, provides substrate for microorganism existence. Soils under diverse cropping systems by and large have a higher SOC pool than monocultures.

Exclusion of summer fallow and growing a winter cover crop augments soil quality through soil organic carbon (SOC) sequestration. Crop diversification through rotations, cover- and inter-crops contributes to recycling nutrients, disrupt weed, pest and disease cycles, enhance biological nitrogen fixation (BNF) when legumes are included and ensure diversify food diets.

Agro-ecosystems sustainability can be enhanced by changing from monoculture to rotation cropping. The CA integrated with best management practices can give higher yield, lower irrigation use, increase in irrigation water productivity; and reduction in energy use than conventional tillage. Also, net returns can be increased with reduction in production cost in CA with best management based systems.

These principles can be integrated into most of the rainfed and irrigated production systems, including horticulture, agro-forestry, organic farming, rotational farming and integrated crop-livestock systems to strengthen ecological sustainability.

Permanent crop cover with recycling of crop residues is a pre-requisite and an integral part of conservation agriculture. However, sowing of a crop in the presence of residues of preceding crop is a problem. But new variants of zero-till seed-cum-fertilizer drill/planters such as Happy seeder, Turbo seeder and Rotary-disc drill have been developed for direct drilling of seeds even in the presence of surface residues (loose and anchored up to 10 t ha^{-1}). These machines are very useful for managing crop residues with a view to conserving moisture and nutrients, as well as controlling weeds in addition to moderating soil temperature. However, one needs to develop and fine-tune appropriate farm machinery to facilitate collection, volume reduction, transportation and application of residues, and sowing of succeeding crop under a layer of residues on soil surface. Besides this, there is a need to modify combine harvester to collect and remove crop residues from field. Twin cutter bar type combine harvester for harvesting of top portion of crop for grain recovery and a lower cutter bar for straw harvesting at a suitable height and wind-rowing should be developed for proper management of straw and developing straw spreaders for uniform distribution of the crop residues.

4.5. Weed Management for Conservation Agriculture system

Increasing concern about weed interference in CA systems has necessitated the inclusion of weed management as one of the basic principles of CA. Globally, weeds proliferation within CA based systems is a challenging management problem (Lafond*et al*., 2009; Nath*et al*., 2017), particularly with the increase development of herbicides resistance weeds. Importantly, soil cover with residue retention and crop rotation, which are fundamental principles of CA are in themselves methods of weed control, yet CA systems rely on herbicides for weed management. Minimum soil disturbance over a long term practice also reduces the weed populations from the absence of practices that creates favourable germinating conditions and encourages dormant weed seeds at the surface through tillage. Crop rotation is an effective practice for weed control. Rotating crops with different life cycles is very effective in controlling problematic weed like *Phalaris minor* inwheat. The retention of crop residue in suppressing weeds is well documented. Thus, CA can go a long way in reducing weeds and its seedbanks over time.

4.6. Utilization of Crop Residues in Conservation Agriculture

India produces more than 500 million tons of crop residues annually. Besides using as animal feed, for thatching of homes, and as a source of domestic and industrial fuel, a large portion of unused crop residues is burnt in the fields primarily to clear the left-over straw and stubbles after the harvest. Non-availability of labour, high cost of residue removal from the field and increasing use of combines in harvesting the crops are main reasons behind burning of crop residues in the fields. A package of intervention is needed to resolve the economic and ecological issues.

4.6.1. Crop residues as source of plant nutrients

Crop residues are good sources of plant nutrients, are the primary source of organic matter (as C constitutes about 40 per cent of the total dry biomass) added to the soil, and are important components for the stability of agricultural ecosystems. About 40 per cent of the N, 30-35 per cent of the P, 80-85 per cent of the K, and 40-50 per cent of the S absorbed by rice remain in the vegetative parts at maturity. Similarly, about 25-30 per cent of N and P, 35-40 per cent of S, and 70-75 per cent of K uptake are retained in wheat residue. One ton of wheat residue contains 4-5 kg N, 0.7-0.9 kg P, and 9-11kg K. Based on several observations, it was reported mean N, P and K amounts in rice straw as 6.2 kg N, 1.1 kg P and 18.9 kg K per ton of straw.

Considering that 90 per cent of rice straw and 30 per cent of wheat straw are surplus in Punjab, the amount of NPK recycled annually would be about 0.54 MT. Besides NPK, one ton of rice and wheat residues contain about 9-11 kg S, 100 g Zn, 777 g Fe and 745 g Mn. CRs still play an important role in the cycling of nutrients despite the dominant role of chemical fertilizers in crop production. **Continuous removal and burning of crop residues can lead to net losses of nutrients under standard fertilization practices, which ultimately will lead to higher nutrient input cost in the short term, and reduction in soil quality and productivity in the long- term.**

4.6.2. Consequences of on-farm burning of crop residues

Burning of crop residues leads to release of soot particles and smoke causing human and animal health problems. It also leads to emission of greenhouse gases (GHGs), namely, carbon dioxide, methane and nitrous oxide, causing global warming and loss of plant nutrients like N, P, K and S. The burning of crop residues is a wastage of valuable resources which could be a source of carbon, bio-active compounds, feed and energy forrural households and small industries. Heat generated from the burning of crop residues elevates soil temperature causing death of active beneficial microbial population, though the effect is temporary, as the microbes regenerate after a few days.

Repeated burnings in a field, however, diminishe the microbial population permanently. The burning of crop residues immediately increases the exchangeable NH_4^+-N and bicarbonate-extractable P content, but there is no build-up of nutrients in the profile. Long-term burning reduces total N and C, and potentially mineralizable N in the upper soil layer(IARI, 2012).The burning of agricultural residues leads to significant emissions of chemically and radioactively important trace gases such as methane (CH_4), carbon monoxide (CO), nitrous oxide(N_2O), oxides of nitrogen (NO_X) and sulphur (SO_X) and other hydro carbons to the atmosphere. About 70 per cent, 7 per cent and 0.7 per cent of C present in rice straw is emitted as carbon dioxide, carbon monoxide and methane, respectively, while 2 per cent of N in straw is emitted as nitrous oxide upon burning. It also emits a large amount of particulates that are composed of a wide variety of organic and inorganic species. One ton of rice straw on burning releases about 3 kg particulate matter, 60 kg CO, 1460 kg CO_2,199 kg ash and 2 kg SO_2 (Gadi, 2003).

4.6.3. Use of crop residues in conservation agriculture- viable strategy for sustainability

It is a paradox that burning of crop residues and scarcity of fodder co-exists in this country, when fodder prices have surged significantly in recent years. Much of the paradox owes it to non-availability and easy access of the quality crop planters which can seed into loose and anchored residues. There are several options such as animal feed, composting, energy generation, biofuel production and recycling in soil to manage the residues in a productive and profitable manner. Use of crop residues as soil organic amendment in the system of agriculture is a viable and valuable option. Management of crop residues in combination with zero tillage is a proven strategy for soil and water conservation and enhancement of soil biological processes. Residue application through soil incorporation has been found beneficial to soil health, crop productivity, nutrient-use efficiency. Therefore, appropriate management of crop residues assumes a great significance.

Surface residue management is one of the fundamental principles of CA. Permanent soil cover regulates erosion and temperature effect on surface soil, provides substrate for microorganism existence .For efficient sowing of wheat using Turbo Happy Seeder, the loose rice residue can be uniformly spread across the field, but the traditional combine harvesters put the loose residues in narrow swath. Manual spreading of in small holder farmers is also possible. Surface retention, incorporation (in-situ) and composting (ex-situ) are the promising on-farm management options to address the issue of burning as well as maintaining soil health and long-term sustainability of rice- wheat system.

Permanent crop cover with recycling of crop residues is a pre-requisite and integral part of conservation agriculture. However, sowing of a crop in the presence of residues of preceding crop is a problem. But new variants of zero-till seed-cum-fertilizer drill/planters such as Happy Seeder, Turbo Seeder and rotary-disc drill have been developed for direct drilling of seeds even in the presence of surface residues (loose and anchored up to 10 t ha^{-1}). These machines are very useful for managing crop residues for conserving moisture and nutrients as well as controlling weeds in addition to moderating soil temperature.

4.7. Impact of Conservation Agriculture

To be widely adopted, all new technologies have to prove their benefits and advantages, to a broad group of farmers to understand the differences between what is being practised and what needs to change. In the case of CA these benefits can be grouped as:

- **Economic benefits** that improve production efficiency.
- **Agronomic benefits** that improve soil productivity.

- **Environmental and social benefits** that protect the soil and make agriculture more sustainable.

4.7.1. Economic benefits

Three major economic benefits that can result from CA adoption are, **(a)** time saving and thus reduction in labour requirement; **(b)** reduction of costs, e.g. fuel, machinery operating costs and maintenance, as well as a reduced labour cost; and **(c)** higher efficiency by way of more output for a lower input. The positive impact of CA on the distribution of labour during the production cycle and, even more important, the reduction in labour requirement are the main reasons for farmers to adopt CA. Manual labour for soil preparation is back-breaking and unnecessary.

4.7.2. Agronomic benefits

Adopting CA leads to improvement of soil productivity through organic matter increase, *in-situ* soil water conservation, improvement of soil structure, and thus rooting zone. The constant addition of crop residues leads to an increase in the organic matter content of the soil. In the beginning this is limited to the top layer of the soil, but with time this will extend to deeper soil layers. Organic matter plays an important role in the soil by improving: fertilizer use efficiency, water holding capacity, soil aggregation, rooting environment and nutrient retention.

4.7.3. Environmental benefits

The CA reduces the soil erosion, improves water and air quality, increase bio-diversity and carbon sequestration. Residues on the soil surface reduce the splash-effect of the raindrops, and once the energy of the raindrops has dissipated the drops proceed to the soil without any harmful effect. This results in higher infiltration and reduced run-off, leading to less erosion. The residues also form a physical barrier that reduces the speed of water and wind over the surface. Reduction of wind speed reduces evaporation of soil moisture. Soil erosion is reduced close to the regeneration rate of the soil or even adding to the system due to the accumulation of organic matter.

Maintaining soil cover reduces erosion with the consequent loss of soil fertility, soil compaction, and, eventually, landscape change. One aspect of conventional agriculture is its ability to change the landscape. The destruction of the vegetative cover affects the plants, animals and micro-organisms. Some few profit from the change and turn into pests. However, most organisms are negatively affected and either they disappear completely or their numbers are drastically reduced.

With the conservation of soil cover in conservation agriculture a habitat is created for a number of species that feed on pests, which in turn attracts more insects, birds and other animals. The rotation of crops and cover crops restrain the loss of genetic biodiversity, which is favoured with mono-cropping. Systems that are based on high crop residue addition and no tillage, accumulate more carbon in the soil, compared to the loss into the atmosphere resulting from plough-based tillage.

During the first years of adopting conservation agriculture, the organic matter content of the soil increases through the decomposition of roots and the contribution of vegetative residues on the surface. This organic material is decomposed slowly, and much of it is incorporated into the soil profile, thus triggering slow release of carbon into the atmosphere.

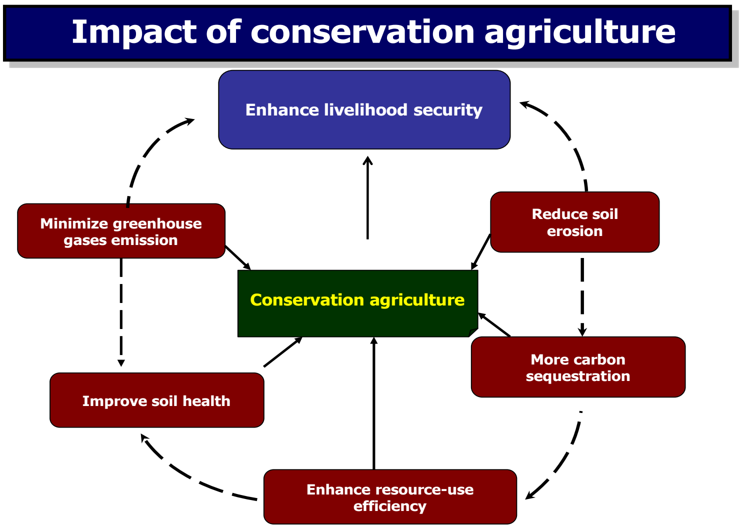


Figure 4.1 Multi-pronged benefit of conservation agriculture

In total balance, carbon is sequestered in the soil, and turns the soil into a net sink of carbon. This could have profound consequences in the fight to reduce greenhouse gas emissions into the atmosphere, and thereby help to forestall the calamitous impacts of global warming.

4.8. Using Crop Residues in Conservation Agriculture - Constraints

A series of challenges exist in using crop residues in conservation agriculture. These include difficulties in sowing and application of fertilizer and pesticides, and problems of pest infestation. The conservation agriculture with higher levels of crop residues usually requires more attention on timings and placement of nutrients, pesticides and irrigation. Lot of improvement has been done in the zero-till seed-cum fertilizer drill system to give farmers a hassle-free technology. Weed control is the other bottle-neck, especially in the rice-wheat system. Excessive use of chemical herbicides may not be desirable for a healthy environment. Nutrient management may become complex because of higher levels of residues and reduced options for application of nutrients, particularly through manure.

Application of fertilizers, especially N entirely as basal dose at the time of seeding may result in a loss in its efficiency and environmental pollution. Sometimes, increased application of specific nutrients may be necessary and specialized equipments are required for proper fertilizer placement, which will add to the costs. No-till in particular can complicate manure application and may also contribute to nutrient stratification within soil profile from repeated surface applications without any mechanical incorporation. Similarly, increased use of herbicides may become necessary for adopting conservation agriculture. Countries that use relatively higher amounts of herbicides are already facing such problems of pollution and environmental hazards. Further limiting factor in adoption of residues incorporation systems in conservation agriculture by farmers include additional management skills, apprehension of lower crop yields and/or economic returns, negative attitudes or perceptions, and institutional constraints. In addition, farmers have strong preferences for clean and good looking tilled fields vis-a-vis untilled shabby looking fields.

4.9. Annotation

One of the options available to ensure sustainable production system is conservation agriculture (CA). It is of particular relevance in rice-wheat cropping system in the NW-IGPs where soil & water health is under stress. Management of crop residues with conservation agriculture is vital for long-term sustainability of Indian agriculture. Hence, burning of residues must be discouraged and utilized gainfully for conservation agriculture in improving soil health and reducing environmental pollution. Both in-situ (incorporation into the soil) and ex-situ (composting) methods of residue management are useful.

Regions where crop residues are used for animal feed and other beneficial purposes, some amount of residues should still be recycled into the soil. Development and promotion of appropriate farm machinery are needed to facilitate collection, volume reduction, transportation and application of crop residues, and sowing of the succeeding crop under a layer of residues on soil surface under conservation agriculture practices.

Key Extracts

- Zero-tillage can achieve the same or even higher yield than conventional tillage, particularly in less endowed areas, where water based agriculture is not feasible.
- Retention of crop residues on soil surface is needed for success of CA in the long-run.
- Zero-tillage along with residue has beneficial effects on soil moisture, temperature moderation and weed control.
- Conservation agriculture helps in build-up of organic carbon and arrest of decline in factor productivity.
- Conservation agriculture has immense potential to revolutionize crop production in many regions including eastern India. However, R&D needs to work on priority to develop and release suitable varieties, so that total overall output is not affected.
- Zero-till systems cause shift in weed flora, and may result in emergence of perennial weeds like *Cyperusrotundus* and *Cynodondactylon*.
- Integrated weed management involving chemical and non-chemical methods (residue, cover crops, varieties etc.) is essential for success of CA systems in the long-run.

Chapter 5

Climate Change

Climate change refers to a significant variation in either the mean state of the climate or in its variability persisting for an extended period (typically decades or longer). Climate change has gained significant international attention over the past decade due to concerns of deleterious long-term impacts on agriculture, water supply and human welfare. The implementation of effective land use and management practices helps in increasing above ground carbon sequestration and reverse the pace of changing climate.

5.1. Introduction

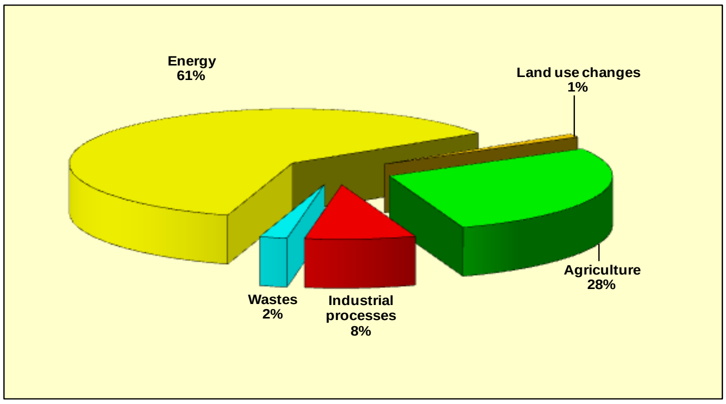
Climate change is the dominant environmental challenge of the current time facing decision makers and planners. Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures. Eleven years from 1995-2006 rank among the twelve warmest years in the instrumental record of global surface temperature (since 1850). The 100-year linear trend (1906-2005) of 0.74 [0.56 to 0.92] °C is larger than the corresponding trend of 0.6 [0.4 to 0.8]°C (1901-2000) and over the 21st century average temperature of earth surface is likely to go up by an additional of 1.8-4^{o}C (IPCC, 2007). This temperature increase can be attributed to the altered energy balance of the climate system resulting from changes in atmospheric concentrations of the greenhouse gases (GHGs).

Among the principal components of radiative forcing of climate change, CO_2 has the highest positive forcing leading to warming of climate. CO_2 has the least global warming potential among the major greenhouse gases but due to its much higher concentration in the atmosphere, it is the major contributor towards global warming and climate change. Agriculture sector in India contributes 28 per cent of the total GHG emissions (NATCOM, 2004). The global average from agriculture is only 13.5 per cent (IPCC, 2007). In future, the percentage emissions from agriculture in India are likely to be smaller due to relatively much higher growth in emissions in energy-use transport and industrial sectors.

The emissions from agriculture are primarily due to methane emissions from rice fields, enteric fermentation in ruminant animals and nitrous oxides from application of manures and fertilizers to agricultural soils (NATCOM, 2004). The per capita release of GHG emission is 1.02 tonnes/year in India, whereas developed countries like USA release 20.01 tonnes/year.

To reduce the CO_2 concentration in atmosphere, C-sequestration has a critical role and it can be defined as the long term capturing and secure storage of carbon that would, otherwise, be emitted or remain in the atmosphere.Carbon dioxide is absorbed by plants through photosynthesis and stored as carbon in biomass in tree trunks, branches, foliage and roots and soils. Increasing soil carbon by 1 Pg through carbon sequestration is equivalent to reducing atmospheric CO_2 concentration by 0.47 ppm.

Figure 5.1 Contribution of different sector to the total GHG emissions in India (NATCOM, 2004)



5.2. Climate Change Scenarios for India

The warming trend in India over the past 100 years has indicated an increase of 0.60°C. The projected impacts are likely to further aggravate field fluctuations of many crops, thus impacting food security. There are already evidences of negative impacts on yield of wheat and paddy in parts of India due to increased temperature, water stress and reduction in number of rainy days. Significant negative impacts have been projected with medium-term (2010-2039) climate change, for example, yield reduction by 4.5 to 9 per cent, depending on the magnitude and distribution of warming. Since, agriculture makes up roughly 15 per cent of India's GDP/ GVA, a 4.5 to 9.0 per cent negative impact on production implies the cost of climate change to be roughly at 1.5 per cent of GDP/GVA per year.

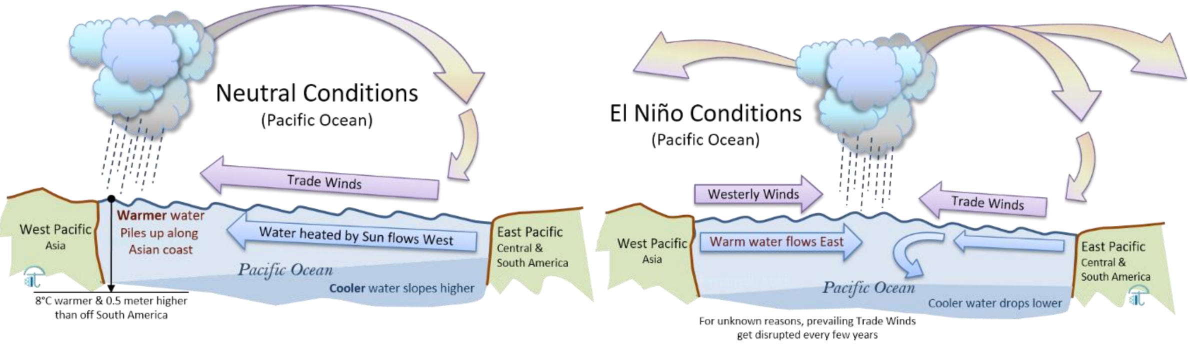
India has a highly seasonal rainfall pattern with about 75 per cent of the long term average annual rainfall occurring during the southwest monsoon (rainy) season. This period is spread over the months of June to September. The year to year variability in monsoon rainfall leads to extreme hydrological events, such as drought and floods in different parts of the country, affecting agricultural production. Analysis of the historical trends in yields of rice and wheat crops in the IGP has shown decline in grain yields of rice and wheat and this could partly be related to the gradual change in weather conditions (Aggarwal *et al*. 2004).The anticipated climate change and variability with changes in air temperature and precipitation pattern will have reflective effect on regional water availability, and would further exacerbate the current situation of water scarcity.

5.3. Causes of Climate Change

There is nothing new about climate change. For hundreds of millions of years the Earth's temperature has been influenced by continental shifts, which have triggered volcanic eruptions among other things. Sometimes these shifts released large volumes of CO_2 which heated up the Earth. Today, it is understood that natural phenomena, even though occurring in faraway geographies, make a deep impression on the climate across the globe.

An example is El Niño, which occurs at intervals of three to seven years. The phenomena occurs when the easterly trade winds get disrupted every few years. In neutral conditions, the trade winds blowing normally from the west coast of south America, pile up warm water along the eastern shores of Asia. Along the shores of Indonesia, the sea level is about 8°C warmer and almost half a metre higher than that off South America. In El Niño conditions, the easing up of the trade winds results in the warm water from the Western Pacific (Indonesia, Philippines), to flow eastwards and cause a rise in sea temperature in the eastern pacific ocean.

Figure 5.2 El Niño effect on global weather



Source: Issue 12, NCCD newsletter

A persistent westerly wind is also set off, which results in shift in the jet stream, causing other deviations in cloud patterns, precipitation and temperature, disrupting the weather patterns worldwide. This phenomena creates worldwide. In India this can result in droughts, followed by a rise in the Indian Ocean temperature, which thereafter has consequences in the form of heavier than normal rains (NCCD 2015). The causes of climatic changes are many and varied and the effects on the earlier climate system are complex, and still to be fully understood.

5.3.1. Influence of humans activities

Humans have been influencing the climate since the start of the Industrial Revolution. Since then, the average world temperature has risen by approximately 0.8 degrees Celsius. Upto 1950, the influence of nature was more vigorous than that of humans. After that, the pattern in the average world temperature can only be explained by factoring in the human influence. Even so, a slight decline in temperature did appear from the mid-1940s to the mid-1970s. It was linked to a dramatic increase in cooling aerosols from the post-war industrialisation in the western world. It was also caused by a mild decline in solar activity and some major volcanic eruptions in the second half of this period. According to the latest IPCC report, it is more than likely (more than 90 per cent probability) that most of the global warming in recent decades is attributable to the observed increase in greenhouse gases.

5.3.2. CO2 and climate change

The most well-known and the most important greenhouse gas is CO_2. The concentration of CO_2 in the atmosphere is subject to variation even without human intervention. The carbon cycle causes an exchange of CO_2 between the biosphere and the oceans on the one hand, and the atmosphere on the other. Vast amounts of CO_2 are also released by the burning of fossil fuels. The trend suggests that CO_2 emissions will continue to rise globally, although the economic crisis did prevent a rise in 2009. The Netherlands (per head of population) is high on the list of CO_2 emitters in the world. Besides CO_2, methane (CH_4), nitrous oxide (N_2O), fluorinated gases, ozone (O_3) and water vapour are important greenhouse gases. Water vapour plays a unique role as it strengthens the heat-trapping effect caused by other greenhouse gas emissions. This is because, a warmer atmosphere retains more water. The amount of water vapour cannot be artificially increased or decreased.

5.3.3. Aerosols

Aerosols are less well-known than greenhouse gases. Aerosols are dust particles which, in addition to CO_2, are released into the atmosphere in large quantities when wood and fossil fuels are burned. Some aerosols have a cooling effect on the climate, while others have a warming effect. On balance they have a cooling rather than a warming effect, but no-one can say with certainty about of the magnitude, because it is not yet clear as to how aerosols influence the occurrence and characteristics of clouds. Natural phenomena, greenhouse gases and aerosols create an imbalance in the incoming and outgoing radiation in the atmosphere. **This process is known as radiative forcing.** When the Earth heats up, the short-wave radiation from the sun that enters the atmosphere is greater than the long-wave radiation that exits the atmosphere. The temperature changes on Earth will not stop until the radiation balance is restored. Given the immense capacity of oceans to absorb heat, it will take a long time to strike a new balance.

5.3.4. Uncertainty

The extent of global warming in the future is swathed in uncertainty; first, because there is no idea of how much of an increase to expect in greenhouse gases (depending on economic growth), and secondly, because it is not known exactly as to how the climate system will respond (climate sensitivity).

5.4. The Greenhouse Gases

The most important greenhouse gases (GHGs) directly emitted by humans include CO_2, CH_4, nitrous N_2O, and several others.

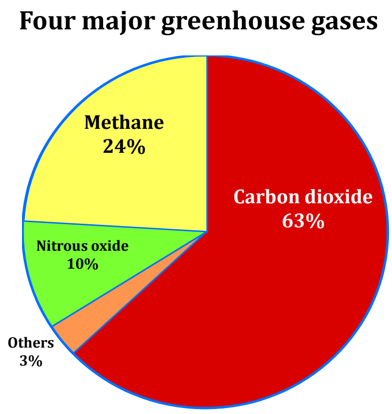


Figure 5.3 Contribution of different GHGs

The sources and recent trends of these gases are detailed in following sections.

5.4.1. Carbon dioxide

Carbon dioxide (CO_2) is the primary greenhouse gas that is contributing to recent climate change. CO_2 is absorbed and emitted naturally as part of the carbon cycle, through plant and animal respiration, volcanic eruptions, and ocean-atmosphere exchange. Human activities, such as the burning of fossil fuels and changes in land use, release large amounts of CO_2, causing concentrations in the atmosphere to rise. Atmospheric CO_2 concentrations have increased by more than 40 per cent since pre-industrial times, from approximately 280 parts per million by volume (ppmv) in the 18th century to over 400 ppmv in 2015. In agriculture, excessive ploughing, burning of residue and intensive cropping systems primarily emits CO_2.

5.4.2. Methane

Methane is produced through both natural and human activities. For example, natural wetlands, agricultural activities, and fossil fuel extraction and transport all emit methane (CH_4). Methane is more abundant in Earth's atmosphere now than at any time in at least the past 800,000 years. Due to human activities, CH_4 concentrations increased sharply during most of the 20th century and are now more than two-and-a-half time's pre-industrial levels.

In recent decades, the rate of increase has slowed down considerably. The agricultural activities that emit methane are:

- Ruminants
- Rice fields
- Manure management
- Residue burning

5.4.3. Nitrous oxide

Nitrous oxide is produced through natural and human activities, mainly through agricultural activities and natural biological processes. Fuel burning and some other processes also create N_2O. Concentrations of N_2O have risen approximately 20 per cent since the start of the Industrial Revolution, with a relatively rapid increase toward the end of the 20th century.

5.4.4. Other greenhouse gases

Water vapour is the most abundant greenhouse gas and also the most important in terms of its contribution to the natural greenhouse effect, despite having a short atmospheric lifetime. Some human activities can influence local water vapour levels. However, on a global scale, the concentration of water vapour is controlled by temperature, which influences overall rates of evaporation and precipitation. Therefore, the global concentration of water vapour is not substantially affected by direct human emissions.

5.5. Impact of Climate Change on Agriculture

Agriculture and fisheries are highly dependent on the climate. Interestingly, increases in temperature and CO_2 can increase some crop yields in some places. But to realize these benefits, nutrient levels, soil moisture, water availability, and other conditions must also be met. However, rise in temperature has a deleterious impact on water and seasonal crops like wheat which is an important cereal in the Indian food basket. Changes in the frequency and severity of droughts and floods could pose challenges for farmers threaten food safety. Meanwhile, warmer water temperatures are likely to cause the habitat change of many fish and shellfish species to shift and also damage ecosystem. Overall, climate change could make it more difficult to grow crops, raise animals, and catch fish in the same ways and same places as done in the past. The effects of climate change also need to be considered along with other evolving factors that affect agricultural production, such as changes in farming practices and technology.

5.5.1. Impacts on crops

Agricultural productivity is sensitive to two broad classes of climate-induced effects. The first one is its direct effect due to changes in temperature, precipitation and carbon dioxide concentrations; and the other is the indirect effect through changes in soil moisture and the distribution and frequency of infestation by pests and diseases (Mendelsohn 2014). The main direct effect is generally seen on the duration of the crop. An increase in temperature will speed up crop development. In the case of an annual crop, the duration between sowing and harvesting will shorten. For example, the duration in harvest of a maize crop could shorten between one and four weeks. The shortening of such a cycle could have an adverse effect on productivity because senescence would occur sooner. In India, impact of 1-2^0C increase in mean air temperature is expected to decrease rice yield by about 0.75 t/ha in efficient zones and 0.06 t/ha in coastal regions; and impact of 0.5^0C increase in winter temperature is projected to reduce wheat yields by 0.45 t/ha. Furthermore, crops may experience both low and high weather extremes like drought and flood, heat and chilling etc. in a single cropping season and such changes will have varying and complex impacts on agricultural production.

Reductions in yields as a result of climate change are predicted to be more pronounced for rainfed crops in comparison with irrigated crop and under limited water supply situations, because there are no coping mechanisms for rainfall variability (Dasgupta et al 2013).

Additional challenge to temperature increase stems from the fact, that higher temperatures will increase the rate at which plants lose moisture resulting in increased transpiration and water loss. Agricultural production in India will be adversely affected not only by an increase or decrease in the overall amount of rainfall, but also by shifts in the timing of the rainfall. In general, climate change may affect the agricultural production system by intensifying abiotic and biotic stresses which influence germination, growth, reproduction, pollination, fertilization and maturity processes of crops besides crop durations and incidence of diseases and pests, enhanced photosynthesis and water use efficiency, limiting water availability for irrigation, and enhancing frequency of extreme weather events.

Studies conducted under the National Network Project on Climate Change (2004-13) to assess the impact of medium term (2010-2039) changes in climate on Indian agriculture indicated an average reduction in productivity by 4-6 per cent in rice, 6 per cent in wheat, 18 per cent in maize, 2.5 per cent in sorghum, 2 per cent in mustard and 2.5 per cent in potato besides significant regional variability (Naresh Kumar *et al.*, 2012). **However, the study also demonstrated that appropriate adaptation measures could greatly negate the impact of climate change.**

Many weeds, pests, and fungi thrive under warmer temperatures, wetter climates, and increased CO_2 levels. The ranges and distribution of weeds and pests are likely to increase with climate change. This could cause new problems for farmers' crops previously unexposed to these species.

Though rising CO_2 can stimulate plant growth, it also reduces the nutritional value of most food crops, another threat to the country's effort to achieve nutritional security for its people. Rising levels of atmospheric carbon dioxide reduce the concentrations of protein and essential minerals in most plant species, including wheat, soybeans, and rice. This direct effect of rising CO_2 on the nutritional value of crops represents a potential threat to human health. Human health is also threatened by increased pesticide use due to increased pest pressures and reductions in the efficacy of pesticides. In fact, a vicious cycle is triggered by climate change.

5.5.2. Impacts on livestock

Heat waves, which are projected to increase under climate change, could directly threaten livestock. Exposure to high temperature events can cause heat-related losses to livestock farmers. Heat stress affects animals both directly and indirectly. Over time, heat stress can increase vulnerability to disease, reduce fertility, and reduce milk production.

Drought may threaten pasture and feed supplies. Drought reduces the amount of quality forage available to grazing livestock. Some areas could experience longer, more intense droughts, resulting from higher summer temperatures and reduced precipitation. For animals that rely on grain, changes in crop production due to drought could also become a problem.

Climate change may increase the prevalence of parasites and diseases that affect livestock. The earlier onset of spring and warmer winters could allow some parasites and pathogens to survive more easily. In areas with increased rainfall, moisture-reliant pathogens could thrive.

Potential changes in veterinary practices, including an increase in the use of parasiticides and other animal health treatments, are likely to be adopted to maintain livestock health in response to climate-induced changes in pests, parasites, and microbes. This could increase the risk of pesticides entering the food chain or lead to evolution of pesticide resistance, with subsequent implications for the safety, distribution, and consumption of livestock and aquaculture products.

Similar to the effect on human food, increases in CO_2 may increase the productivity of pastures, but may also decrease their quality. Increases in atmospheric CO_2 can increase the productivity of plants on which livestock feed. However, the quality of some of the forage found in pasturelands decreases with higher CO_2. As a result, cattle would need to eat more to get the same nutritional benefits.

5.5.3. Impacts on fisheries

Some marine disease outbreaks have been linked with changing climate. Changes in temperature and seasons can affect the timing of reproduction and migration. Many steps within an aquatic animal's lifecycle are controlled by temperature and the changing of the seasons.

Future agriculture will be more challenging with more population pressure, declined natural resources, decline in factor productivity, and deterioration of soil health as these are already evident from present agricultural scenario (Ladha et al., 2003). Enhancing agricultural productivity and resource-use efficiency, therefore, is critical for ensuring food and nutritional security for all, particularly the resource poor small and marginal farmers who would be affected the most. In the absence of planned adaptation, the consequences of long-term climate change could be severe on the livelihood security of the poor (NICRA, 2012). Identifying and scaling up sustainable agricultural practices in different agro-climatic zones is vital to address the food security and for tackling climate change (NAPCC, 2012). **In order to develop and target appropriate adaptation and mitigation measures, it is important to identify regions that are relatively more affected by climate change.** This 'identification process involves assessment of vulnerability of different regions'.

In India, the Indo-Gangetic Plains (IGPs) including Uttar Pradesh (UP), Punjab, Haryana, Bihar, and West Bengal exhibit very high vulnerability to climate change (Vulnerability Atlas, 2013). Further, climate change will have an adverse impact on food security. Disadvantaged regions and socially and economically backward people will be affected more as food cost will increase due to its less availability. Available trends indicate that agricultural productivity will decline upto 25 per cent in irrigated areas, and could be as much as 50 per cent in rainfed areas. Dominance of small and marginal farmers (about 92 per cent) with small land holdings will make Uttar Pradesh more vulnerable to climate change in future also. The present and future vulnerability index of the IGP including U.P. ranges from very high to high indicating higher level of vulnerability of agriculture in these regions.

In nutshell, climate change can impact agriculture in following ways:

- Soil: Drier, reduced productivity
- Irrigation: Increased demand, reduced supply
- Pests: Increased ranges and populations
- Production: Reduced crop yield
- Livestock: Increased diseases and heat stress
- Fishery: Affected abundance and spawning

- Economic impact: Reduced agricultural output
- Agricultural productivity in India was estimated to decrease by 2.5 to 10 per cent by 2020 to 5 to 30 per cent by 2050 (IPCC assessment).

5.6. Issues around Climate Change

5.6.1. Disturbed C-cycle

Plant produces carbohydrate by using the natural resources and maintains the ecosystem. When civilization was at initial stage or later when human population was small, there was integrity between human society and environment. The modern agriculture with the robust pace of output has disturbed the ecosystems.

5.6.2. Removal of carbon from the fields

By harvesting the crop, one is removing the biomass from field and it is responsible for carbon removal from soil. Residue burning (Figure 5.3) is a major violater of ecology as discussed in earlier secton. It also emits large amount of particulates that are composed of wide variety of organic and inorganic species. Burning of crop residue increase the nutrient loss.Pedology is the basis for agricultural and rural sustainability. The heat from burning cereal straw can penetrate into soil upto 1 (one) cm elevating the temperature to as high as 33.8-42.2^{O}c. About 32-76 per cent of the straw weight and 27-73 per cent N are lost in burning. Bacterial and fungal populations decrease immediately and substantially only on top 2.5 cm upon burning. Repeated burning in the field permanently diminishes the bacterial population by more than 50 per cent. Burning immediately increased the exchangeable NH_4-N and bicarbonate extractable-Phosphorus content but there is no build up of nutrients in the profile. Long term burning reduces total N and C and potentially mineralized N in the 0-15 cm soil layer. One of the recognized threats to rice-wheat system sustainability is the loss of soil organic matter as a result of burning.

Figure 5.4 Residue burning adds to emission of GHGs in atmosphere

5.6.3. Methane recovery

- Animal waste methane recovery & utilization.
- Installing an anaerobic digester & utilizing methane to produce energy.

- Coal mine methane recovery.
- Collection & utilization of fugitive methane from coal mining.
- Capture of biogas.
- Landfill methane recovery and utilization.
- Capture & utilization of fugitive gas from gas pipelines.
- Methane collection and utilization from sewage/industrial waste treatment facilities.

5.6.4. Agricultural sector

- Energy efficiency improvements or switching to less carbon intensive energy sources for water pumps (irrigation).
- Methane reductions in rice cultivation.
- Reducing animal waste or using produced animal waste for energy generation.
- Any other changes in an agricultural practices resulting in reduction of any category of greenhouse gas emissions.

5.7. Measures for Reducing the Pace of Climate Changes

5.7.1. Adaptation measures

Enhancing the resilience of agriculture to cope with the climate change and the climate variability is imperative to sustain production and improve the livelihood security of farmers through various adaptation and mitigation strategies. The climate mitigation is an anthropogenic intervention to reduce the sources or enhance the sinks of Green House Gases (GHGs), while climate adaptation is an adjustment in natural or man-made system to a new or changing environment. Adaptation is an anticipatory and planned process, managed through policies, technologies and developmental activities. Though, mitigation strategies are important to reduce the drivers of climate change, it is adaptation strategies that are more essential to minimize its impacts. Mitigating and bringing a halt to climate change is not within the capability of one section of people or state or country alone. Hence adaptation strategies are more likely to save livelihoods and ensure food security than mitigation strategies. The adaptation options include (i) technological developments; (ii) government programs and insurance products; (iii) farm production practices; and (iv) farm financial management.

Crop substitution: Traditional crops/varieties, which are inefficient in utilization of soil moisture, less responsive to production input and potentially low producers should be substituted by more efficient ones.

More use of inter-cropping: Inter-cropping has a higher biological efficiency than sole cropping (usually at least 30 per cent, if farmers intercrop), because of: better buffering against climatic extremes; more efficient use of resources (light, nutrients, water); and Less problems with pests and diseases.

5.8. Water – central to Climate Change Adaptation

As water is one of the medium through which most of the climate change impacts will be felt and mitigated, water management will be at the centre of climate change adaptation strategies, especially for agriculture. As climate change is expected to produce water stresses in several parts of the country, substantial adaptation efforts will be needed to ensure adequate supply and efficient utilization of available water resource. **The supply and demand management measures aimed at conserving or enhancing or improving the water supply may be capable of alleviating such impacts to a limited extent.** There is ample opportunity to enhance net water availability through increased surface water storage, ground water development and reduced conveyance losses.

The options for enhancing supply include**:** increased access to water resources using modern irrigation methods; changes in design of irrigation infrastructure (reservoirs/dams, canal network); rain water harvesting and it's recycling; improved reservoir/dam operations; re-use of drainage water and wastewater; and transfer of water between river basins etc. **The greatest potential for short-term adaptation is in demand management and more efficient and integrated management of surface and groundwater supplies. Adoption of drip/micro-irrigation, rainwater harvesting, groundwater recharge, encouraging water-saving techniques such as water recycling, reducing losses in canal systems could form some of the adaptation options.**

In the context of climate change, the micro-irrigation options are not only important for saving water but also relevant for saving energy and reducing carbon emission. In view of the impending threats caused by climate change, regulating the unrestrained exploitation of groundwater and aggressive pursuit of water conservation should become a national priority.

The successful production of rainfed crops largely depends on how efficiently soil moisture is conserved *in situ* or the surplus runoff is harvested, stored and recycled for supplemental irrigation. Storage of water in the soil and in natural or man-made structures and efficient utilization of given quantity of water are important aspects of water conservation.

Watershed management is one of best adaptation measures in case of climate change, especially for rainfed agriculture. It offers the scope to practise integrated water resource management program at a local level with participation of communities. Thus, upgrading rainfed agriculture through integrated rainwater harvesting systems and complementary technologies such as low-cost pumps and efficient water application methods, that include drip/micro irrigation methods is the most viable management strategy to cope with water scarcity situation under the climate change scenarios.

Several soil and crop management practices viz. conservation tillage, reduced tillage, no-till, contour bunding, terracing and mulching etc. control soil erosion and soil water losses, and simultaneously enhance soil infiltration rate and soil water capacity. Such practices could be adopted as effective water management options. Different resource conserving technologies (RCTs) like zero or minimum tillage (with or without crop residues), bed planting of crops and direct-seeded rice have a substantial scope in improving irrigation efficiency and saving energy for groundwater withdrawal and thereby reducing greenhouse gas emissions. The use of crops or varieties with better resilience to dry spell, changing planting or sowing dates, increased agricultural diversification, including better integration of fish, livestock and horticultural crop are some other adaptation measures to increase the resilience of farming systems.

As occurrence of flood and droughts is likely to increase in many parts of India, there is a need for better systems for detection and forecasting of floods and droughts. Use of seasonal climate forecast in crop planning and management could possibly reduce crop losses due to weather variability and provide opportunities for employing contingency measures including crop diversification. Improved weather forecast, hydrological monitoring, improved information and communication technology (ICT) **for people's preparedness may help to alleviate the effects of these extreme events and** could greatly help in decision making.

5.9. Mitigation Strategies

These are the actions to reduce greenhouse gas emission and sequestration or storage of carbon in the short-term and developmental choices that will be lead to low emission in the long-term.

a) Reducing emissions of carbon dioxide, methane and nitrous oxide: reduction in the emission of greenhouse gases by changing the practice of transplanting rice with the direct seeded rice/ aerobic rice which require less water and due to aerobic conditions the emission of CH_4 and CO_2 gases will be less.

b) Sequestering carbon: sequestering atmospheric carbon is very important as without reducing the atmospheric level of carbon, it is not possible to mitigate the climate change. The switch over to carbon sequestering practices is recommended.

c) Resource conservation technologies: any method, material or tool which enhances the input use efficiency, crop productivity and farm gate income is termed as resource conservation technology. It includes:

- crop establishment system (zero tillage, minimum tillage or reduced tillage etc.);
- water management (adoption of laser land leveller technique); and
- nutrient management (use of SPAD or SSNM or slow release fertilizers etc.)

d) Enriching soil organic matter: by applying FYM, compost or by practising organic farming we can improve the soil organic matter which can help in improvement of soil health.

5.9.1. Carbon finance

Integration of carbon finance and thereby improving both farming and silvicultural practices would be a win-win situation for both the small farmer as well as the environment. An example is drawn from The Kenya Agriculture Carbon Project (KACP)[1] supported by the World Bank's Bio-Carbon Fund and in partnership with a Swedish NGO - Vi Agroforestry (ViA), is an attempt to use carbon finance to enhance adoption of its sustainable agricultural production

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[1] Source: FCPF, World Bank

model. The Sustainable Agricultural Land Management (SALM) developed by the Bio-Carbon Fund, consists of practices such as use of residues for mulching and composting, manure application, fertilizer use, water harvesting, terracing and tree planting to restore soil fertility and enhance soil carbon sequestration. Verified Carbon Standards (VCS) approved the project in December, 2011 spelling out how carbon sequestration is measured in soils. The project targets 3000 farmer groups composed of about 60,000 farmers covering 45,000 hectares of land and the purchase of a part of the carbon credits (150,000) estimated at USD600,000, to be generated from 2009-2016. The first ever batch of carbon credits generated by improved agricultural practices, issued in October 2013, amounted to a reduction of 24,788 metric tons of carbon dioxide, equivalent to taking 5,164 cars off the road for one year and accrual of USD 65,000 to the Kenyan farmers till date.

The project beneficiaries are farmers who own an average of half hectare of land with a family size of five or more. Due to land degradation they have been unable to produce enough food for their own consumption. In Kisumu, upto 46 per cent of the farmers are food insecure for half a year. However, just three years into the program and with the experience of 1505 farmer groups, the integration of carbon finance with SALM has been amply illustrated. Early analysis of maize and beans showed that productivity increased by as much as 15-20 per cent, as also their resilience to climate change through enhanced soil fertility. The farmers have been engaged in the monitoring process to measure the impact of agricultural practices on crop yields. The carbon revenue distribution reflects the relative carbon sequestration performance among farmer groups based on practices adopted and sustained during the project monitoring period. There is a well-structured process for revenue flow from the World Bank (Bio-Carbon Fund) to the communities. The farmers have the options of investing in Farmer Enterprises and other developmental investments, micro financial saving instruments, rural infrastructure or other uses for collective common good of the farmers.

5.10. Annotation

Improving the water-use efficiency of crop plants, their drought and pest resistance and also the agronomic practices will improve the adaptability for the changing scenario. There are several mitigation and adaptation practices that can be effectively put to use to overcome the adverse impacts of climate change with desirable results.

These methods fall into the broad categories of crop/cropping system-based technologies, resource conservation-based technologies and socio-economic and policy interventions. Therefore, soil carbon sequestration is an important cost-effective tool in climate change mitigation programme.

Conservation agriculture, organic farming, agroforestry, biochar application can easily be adopted, and these practices have positive impact on soil carbon sequestration and crop productivity.

For successful carbon sequestration in major production system in India, the requirements are knowledge, thorough understanding, proper channel to disseminate the technology, financial back up and government efforts. The Kyoto Protocol, Japan came into force on 16 February 2005 and 187 states have signed and ratified the protocol on November 2009. Countries with commitments under the Kyoto Protocol to limit or reduce greenhouse gas emissions must meet their targets primarily through national measures. As an additional means of meeting these targets, the Kyoto Protocol introduced three market-based mechanisms, thereby creating what is now known as the "carbon market.

Key Extracts

- Climate is changing and this reality is being felt in the agricultural sector. Indian agriculture is equally susceptible in the long run due to higher temperatures, erratic weather, and decreased or random availability of irrigation.
- Adaptation strategies can help minimize negative impacts to some extent whereas mitigation options can help in long run.
- Adaptation research is aimed at developing technologies and systems to help "cope" with global climate change. The farmers, foresters and other land managers need to have appropriate strategies at hand as the nature of global change becomes clearer for given regions.
- The implementation of effective land use and management practices, such as the conservation reserve programme, forestry incentive programme, integrated nutrient management and conservation tillage, crop diversification help in increasing above ground carbon sequestration and mitigate climate change.

Chapter 6

Agro-biodiversity for Smart Ecological Services

Agro-biodiversity is the variety and variability of bio-resources in a region at a point of time. The diversity includes plants, animals, soil micro-organisms and of course the human being. This is directly or indirectly related to food and agriculture- crop and animal husbandry, forestry and fisheries. The conservation of bio-diversity requires a significant commitment by governments, industry sectors and the wider community to ensure a long-term balance between sustainable land management and bio-diversity conservation.

6.1. Introduction

Since the dawn of civilization, natural resources of land, soil, water, bio-diversity and climate form the very basis for supporting and sustaining life of human beings, plants and animals on the earth. However, in recent times, intensive use and over-exploitation of these pristine resources have robbed them of their legendry resilience. To effectively tackle the complex problems of livelihood and food security, poverty, unemployment, equity and environmental services, efficient and judicious utilization of natural resources and ecological intensification for enhanced and sustained productivity, is a matter of serious concern for policy makers, planners, scientists, conservationists and environmentalists. The strategy need for building the national food security and the circumstances that obtained in the 1960's led to adoption of technology that warranted intensive use of natural resources of land and water. The emphasis was not so much on improving, restoring, reclaiming and enhancing their productivity and sustainability of land race, and also safeguarding the bio-diversity.

Agro-biodiversity is the variety and variability of bio-resources in a region at a point of time. The diversity includes plants, animals, soil micro-organisms and of course the human being. This is directly or indirectly related to food and agriculture- crop and animal husbandry, forestry and fisheries. The genetic resources i.e., varieties, breeds and species have existed and are used for food, fodder, fiber, fuel and also pharmaceutical production. The degree or the extent of agro-biodiversity may change over time due to natural and continuous man-made activities. There may be resurgence of new bio-resources due to natural or artificial genetic modification. The inherent productivity of agro-ecosystem largely depends on the agro-biodiversity of a region. The interaction, very complex and varied, is the most important phenomenon among different components of bio-resources and also with climate in sustenance and functioning of the agro-biodiversity of a region. Local knowledge and culture among people can be considered as a part of agro-biodiversity, because it is the human activity towards agriculture that shapes and conserves this bio-diversity.

India is one of the most diverse countries in the world. It occupies only about 2.4 per cent the world's land area, and yet it harbors 7-8 per cent all recorded species, including about 45,000 species of plants and 91,000 species of animals. The country has the primary, secondary or regional centers of diversity of at least 167 crop species and 320 wild relatives of crops. Indigenous knowledge is associated with it to nurture and use the agro-biodiversity. Appropriate dependence on bio-diversity are multiple benefits for the agricultural system, These include: making farming systems more stable and sustainable; sound management of pest and diseases; conserving soil and increased natural soil fertility and health; reduced risks of disasters; reduced dependency on external inputs; improve human nutrition etc. Besides its ecological and intrinsic value, bio-diversity has a considerable socio-economic and monetary value as well. Such values attached to bio-diversity can be classified as:

Productive use value: It is the value assigned to products that are commercially harvested for exchange in formal market. Such products are fuelwood, timber, fish, animal skin, musk, fodder, fruits, cereals and medicinal plants.

Consumptive use value: The value of biological resources that is reflected on natural products that are consumed directly. These goods do not enter the normal channel of trade .A significant number of non-timber forest product (minor forest products) as soft broom grass and cane fall under this category.

Indirect values: The values are related to intangible benefits with the functions of ecosystems which do not normally appear in national accounting systems. Maintenance of ecological balance and prevention of soil erosion are examples of such indirect values.

India's contribution to agro-biodiversity has been impressive and ranks seventh in the world in terms of contribution of number of species are concerned.

6.2. Major Concerns

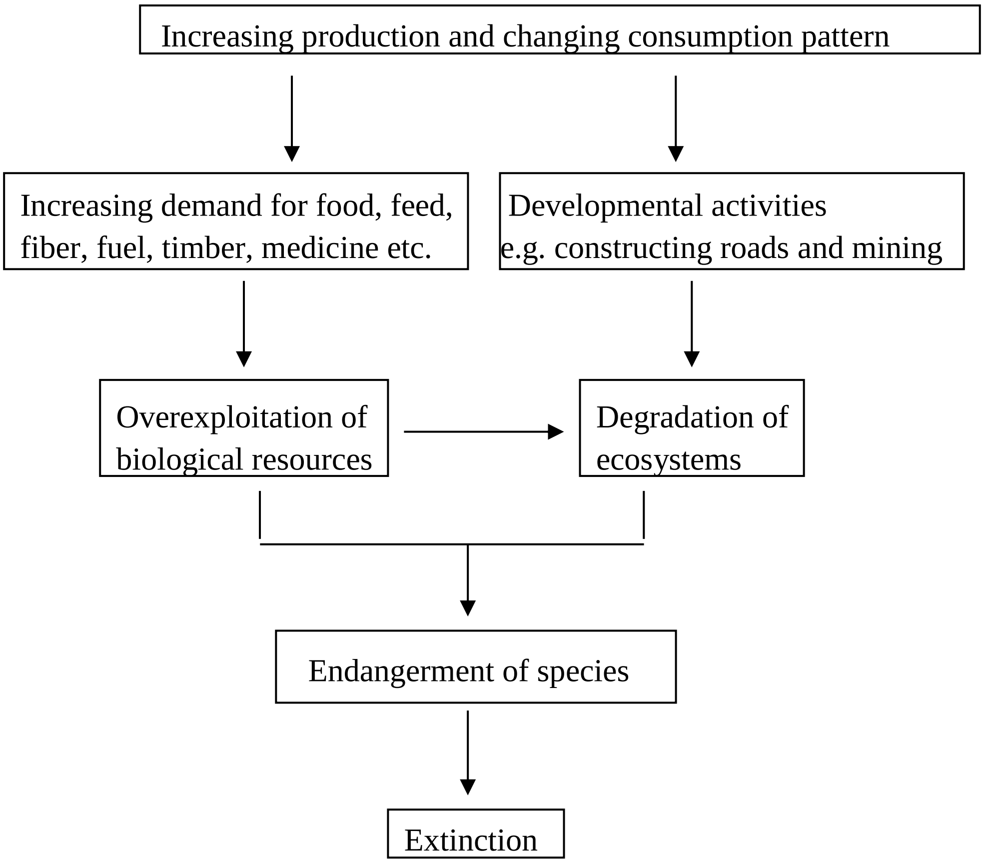
The loss of bio-diversity is likely to be further aggravated by the increasingly rapid, large scale global extinction of species. It occurred in the 20th century at a rate that was thousands of times higher than the average rate during the preceding 65 million years. This is likely to destabilize various ecosystems including agricultural systems. India is endowed with diverse ecosystems such as tropical rain forests, temperate forests, alpine vegetation, wetlands and mangroves. However, over-exploitation, habitat destruction, pollution and species extinction are major causes of bio-diversity loss in India (Fig.).Other factors include fires, which adversely affect regeneration in some cases.

According to the National Forest Policy, at least 60 per cent of the reporting area in the hills should be under forests. The States of Arunachal Pradesh, Himachal Pradesh., Manipur, Meghalaya, Mizoram, Nagaland, Sikkim, Tripura and Uttarakhand fulfill this criterion, whereas in other hilly states, such as Assam and Jammu and Kashmir (J&K), the area under forests is much lesser than the recommended one. Overall,124 districts of the country have forest cover of 38.85 per cent of their total geographical area (FSI, 2005).

For maintaining the long-term services of the hill and mountain ecosystems as a valuable store-house of water resources in the country, protection and management of upper catchments is of paramount importance.

Bio-diversity of various ecosystems needs to be preserved to generate multiple and wide-ranging on-site and off-site economic benefits.

Figure 6.1 Causes of bio-diversity loss



Demographic pressure, coupled with unplanned and inappropriate increase in infrastructure facilities, have caused major damages to hill slopes, fields, forests, grasslands, local flora and fauna, soil and water. The major concerns would be:

6.2.1. Genetic erosion and loss

Genetic resources which provide food security are in distress due to several factors especially the anthropogenic. As per the National Biodiversity Action Plan, 41 per cent of India's forest cover is at different levels of degradation. Traditional varieties of a wide range of crops with specifically adapted gene complexes to local environments such as rice, small millets, pseudo cereals etc have disappeared from several agro-ecosystems. It is believed that around 5,000 landraces of rice collected from North East region of India are no more under cultivation in that region. Loss of breeds and genetic diversity within breeds due to universal use of very few improved breeds, limiting number of certain superior individuals, often from exotic sources to dominate as parents of future generations has become a threat to native livestock diversity. The aquatic bio-diversity faces threats with wide ranging causes including over-exploitation, habitat alterations, constructions and reduced flow of water in rivers. Indian major carps face threat from exotic introductions that escaped into native eco-systems. Genetic erosion in soil microbial community structure is mainly due to changes in the soil physio-chemical properties, biotic factors such as changing plant diversity and abiotic factors such as application of industrial effluents, pesticides, amendment with chitin, compost or manure, and agriculture intensification including introduction of genetically modified microorganisms.

6.2.2. Genetic pollution

The release of transgenic plants at commercial scale has evoked a number of bio-safety issues in relation to bio-diversity, human and animal health. The genetic resources have to be protected from the contamination of transgenes. The movement of unwanted genes into the environment may pose more of a management dilemma than unwanted chemicals; as such alleles have the opportunity to multiply themselves. The impacts and costs of invasive species include crop losses, rangeland value decline, water resource depletion, livestock disease, genetic contamination and management and eradication costs. Many introduced pests such as insects, seed-borne virus and fungi, and invasive species such as *Prosopisjuliflora, Acacia auriculiformis, Lantana camara* and alien fish species in aquatic ecosystem have led to significant changes in native eco-systems. Further, the recent case of the deadly H5N1 strain of avian influenza virus on poultry which is reported from about dozen countries and is spreading in India at an alarming rate is well known. Besides, the economically important Ug99 strain of wheat rust which is spreading globally since its detection in Uganda in 1999, and not yet reported from India, is an example of the potential threat to the country's wheat genetic resources, since the rust spores are air-borne. The ICAR, in collaboration with International Wheat and Maize Research Centre (CIMMYT), Mexico has started a testing program of wheat at Njoro in Kenya. The Indian wheat varieties, viz; GW 273, GW 322, HI 1500, HD 2781, MP 4010, HUW 510, MACS 2846(durum), HI 8498 (durum), UP 2338, DL 153-2 and HW 1085 have so far shown resistance to Ug99.

6.2.3. Impact of global climate change

Agricultural bio-diversity is at risk from climate change (IPCC, 2007). Species and communities at particular and possibly critical risk include those with limited climatic ranges, limited dispersal ability and those with specialized habitat requirements. Besides, some indigenous pests that were earlier not causing much damage are emerging as serious pests such as foliar blight in wheat, necrosis in sunflower, bract mosaic in banana, sheath blight in maize and paddy, Pyrilla in sugarcane etc. Increase in physiological reactions at high temperatures will elevate heat loads of animals resulting into a decline in productivity of meat, wool, milk and draught power (Upadhyay et al., 2008). Temperature increase is likely to cause a rise in animal diseases that are spread by insects and vectors. Incidences of mastitis and foot diseases will increase due to the rise in temperature and humidity. Besides, introduction of naturally occurring or genetically modified pests/ diseases into weaponry, livestock, crops and medicine is a possibility, which if not adequately anticipated and controlled, may threaten entire populations and ecosystems (Padamkumar, 2008).

It is predicted that by the year 2050, the challenge of providing food security to around 9.6 billion world population will be acute. In a rapidly changing climate scenario, there will be increase in frequency and intensity of stresses, particularly drought, indicating likely shift of vast arable land further to the kitty of already existing 40 per cent of global land under arid and semi-arid areas. The extent of salinity affected area is also likely to increase further from the existing 20 per cent of irrigated lands of the world. As salinity tolerance is almost synonymous to drought tolerance, clues can be obtained from strains of extreme halophilic bacilli and their derived genera, archaea, and fungi that survive the extremities of salinity as prevalent in the otherwise undisturbed ecosystem of the Rann of Kutch in Gujarat with the history of stable evolutionary lineages. While studying the diversity of the extreme halophiles, these groups of organisms were found to possess survival potential and perpetuate their races at upto saturated levels of NaCl concentration, the most inhospitable level of possible salinity.

It is estimated that just a few decades ago, Indian farmers grew more than 30,000 different varieties of rice before green revolution. Unfortunately, this enormous diversity has reduced over years post-green revolution. There has been a loss of several thousand rice varieties. This is a risk in itself.

6.3. Status of Agro-biodiversity

6.3.1. Plant genetic resources

Presently as many as 3,58,571 accessions of 1,134 species in seed gene bank; 1,973 accessions of 158 vegetatively propagated crops under *in vitro;* and 8,493 accessions of 720 species have been *cryo* preserved (www.nbpgr.ernet.in). New protocols have been developed for micro-propagation and *in-vitro* conservation of vegetative propagated species and also for cryo-preservation of vegetative propagated and non-orthodox seed species like tea, black pepper, almond, neem, etc.

The initiatives for on-farm conservation of landraces and crops of local importance have been recently undertaken in Western Himalayan region and Bastar area of Chattisgarh. Several civil society organizations have also taken initiative to conserve many precious landraces and crop species. The Union Ministry of Environment and Forests has facilitated conservation of natural flora, through its field organizations. The entire spectrum of this component of plant biodiversity is distributed over 10 bio-geographical zones and is being conserved *in situ* in 92 National Parks, 504 Sanctuaries and 15 Biosphere Reserves spread over 16.00 million ha (MoEF 2008). There are about 1,00,000 to 1,50,000 sacred groves and micro-eco-systems, and 309 forest preservation plots that provide home to a large number of agriculturally important plants that disappeared from of the surrounding landscapes. About 245 botanical gardens, arboreta, herbal gardens and other field repositories also conserve number of species, particularly of threatened and rare nature. The establishment of sanctuaries in Tura range in Garo Hills of Meghalaya for conservation of rich native diversity of wild *Citrus* and *Musa* species, and for *Rhododendron* and orchids in Sikkim is also helping *in-situ* conservation of economically important species.

6.2.2. Animal genetic resources

A total of about 48,000 cryo-preserved semen doses representing economically important and fast genetically eroded breeds are being maintained in the Animal Gene Bank. Somatic Cell

Nuclear Transfer (SCNT) technique has been standardized.

6.3.2. Fish genetic resources

A database on Fish Diversity of India covering 2,225 indigenous fish species including 79 threatened fish species has been developed (Lakra et al., 2007).

6.3.3. Microbial genetic resources

India shares a significant diversity in microbial diversity. Indian collection has more than 1.18 lakh cultures and accounts for about 14 per cent of the world collection.

6.4. Bio-diversity Management

Bio-diversity management is done at ecosystem, species and gene levels. *In situ* approach is appropriate at ecosystem, while *ex situ* approach is adopted for study, conservation and exploitation purposes.

Agro-biodiversity builds the foundation of sustainable agricultural development and is an essential natural resource to ensure current and future food and nutrition security. The effective and efficient management of agro-biodiversity is essential through management of gene banks, science-led innovations; livelihood, food and nutrition security though crop diversification, use of lesser known crops and wild relatives in crop improvement; dealing appropriately the quarantine, bio-safety and bio-security. Wisdom of farmers should be maintained as they have bred thousands of varieties of thousands of species over thousands of years. Paradoxically, the more the seeds are used, the more they are shared and multiplied better are they conserved. To make the best use of agro-biodiversity, and for it to fulfill the needs of the nations food and nutritional security on as sustainable basis, a combination of on-farm, in-situ and ex-situ conservation approaches are required.

The importance of agricultural bio-diversity in food security and agriculture has been widely recognized with respect to its functions in climate change adaptation within the agriculture sector. In-*situ* conservation of agricultural bio-diversity must be made an integral part of agricultural development and be supplemented by *ex-situ* conservation.Gene sources from traditional varieties and breeds are to be tapped using techniques like allele mining and development of genomic resources for specific traits of interest for high temperature, photo-insensitivity, low respiration and higher photosynthetic rate, drought, flood, salinity, pests etc.

The conservation and use of genetic resources will remain essential for improving productivity in agriculture, and sustaining human existence and wellbeing. Given that global food security depends significantly on production in more industrial agriculture, it is relevant to note the important contribution of agricultural biodiversity to global food production as well as to sustainable livelihoods is in traditional agricultural systems. **It is, therefore, inappropriate to promote large-scale abandonment of bio-diverse agriculture and to marginalize it in intensive industrial production systems.** The demand for uniformity in the modern world is in a way legislative to low-cost natural management that the nature contains in its order and warrants its maintenance. The challenge is to create a new enabling environment that helps sustainable maintenance of genetic resources and reflects their true value to the livelihoods of different stakeholders. Building complementarities among agriculture, bio-diversity and conservation of genetic resources will also require changes in agricultural research and development, land use, and breeding approaches. The natural populations of many species of crop wild relatives, wild economic species and wild fauna are threatened by habitat loss and by increasing destruction of natural environment.

6.4.1. Utilisation of bio-diversity

The utilization of indigenous bio-diversity for various purposes, particularly for transferring genes from wild relatives is not very encouraging except for a few crops such as rice, brinjal, cucumber, banana etc. Nevertheless, considerable amount of genetic resources has been used through direct selection and it constitutes about 60-65 per cent of the total varieties released so far in the indigenous crops. Indian gene center despite rich in crop wild relatives has used only about 2-3 per cent of it for gene transfers into their cultivated allies. The situation is far low in case of animal and aquatic genetic resources.

The importance of indigenous genetic resources has increased manifold under the new regime of Intellectual Property Rights (IPRs). The sole dependence on exotic sources for germplasm particularly in wheat, maize, and temperate horticultural crops is a matter of concern and invites attention towards increasing use of indigenous bio-diversity. Micro-organisms are endowed with the ability to degrade and/or detoxify chemical substances such as petroleum products, xenobiotics, pesticides and heavy metals, and are, thus utilized in bioremediation and cleaning environmental pollution. There is a need to evaluate available genetic resources and come out with genes alone or in combination for their direct immediate use.

6.4.2. Diversified agro-ecological farming

In contrast to industrial agriculture, diversified agro-ecological farming can deliver simultaneous and mutually-reinforcing benefits for productivity, the environment and society. These alternative systems deliver strong and stable yields over time by building healthy eco-systems, where different species interact in ways that improve soil fertility and water retention. They perform particularly strongly under environmental stress and deliver production increases in the places where additional food is most needed. These systems have major potential to keep carbon in the ground, increase resource efficiency and restore degraded land, turning agriculture from a major contributor to climate change to one of the key solutions. Diversified agriculture also holds to key to increasing dietary diversity at the local level, as well as reducing the multiple health risks from industrial agriculture (e.g. pesticide exposure, antibiotic resistance).

6.4.3. Bio-technology and bio-diversity

The use of bio-technology is made as a tool for acquiring in-depth knowledge on bio-diversity and to directly intervene in breeding, in particular to transfer genetic information from one sort of organism to a particular crop, or to a farm animal to make it transgenic. Transgenic crops need to be used to benefit humans, maintain native bio-diversity and the environment rather than to endanger it. Bio-technology is effective in the field of bio-systematic especially to resolve the issues related to species identification and also to segregate some taxa treated as species complex, for instance, *Vigna*, *Amaranthus*, *Chenopodium*, *Prunus*, *Pyrus*etc. There are many other emerging areas, where bio-technology can be employed for harnessing the benefits and valuation of bio-diversity.

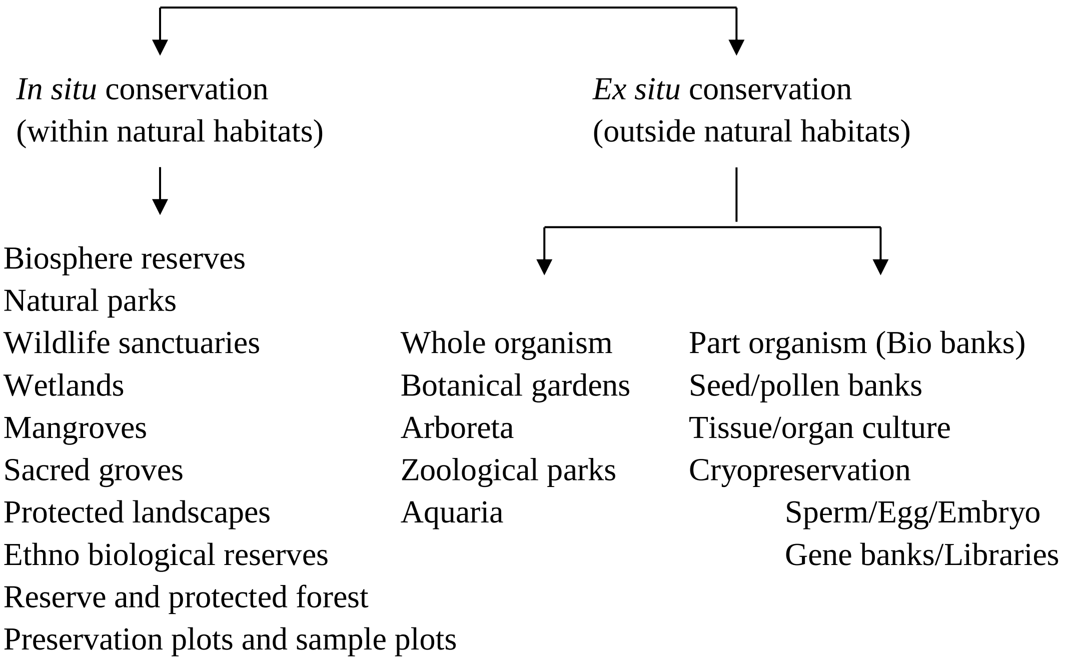
6.4.4. Bio-informatics

The complex and voluminous data of bio-diversity can be digitalized for easy access, analysis and interpretation. It makes for easy survey, documentation and measurement of bio-diversity data. Based on the available data, future bio-diversity of a particular area can be predicted and model formulated by computational methods, and thereby takes appropriate measures for its conservation and sustainable utilization. The electronic information may serve as the raw material for augmenting future developments in other areas of biology including phylogenetic relationship among the species/individuals, and bio-diversity extinction rate. Establishment of a repository for gene constructs and large insert DNA fragments hasten the utilization of diverse genomic resources of plants, animals, fisheries and microbes.

6.5. Sustainable Management of Bio-diversity

The increasing population, pollution and degradation of environment have already had a negative bearing on the plant, animal, fish and microbial genetic resources and their productivity. This is bound to increase due to changes in the land use pattern and climate.

Figure 6.2 Approaches to bio-diversity conservation



Bio-diversity conservation is to help countries maintain and manage the variety of species, genetic resources, and ecosystems, where they exist such as forests, grasslands, wetlands and coastal habitats. If the current trend of loss of bio-diversity is allowed to continue, the world would not only be deprived of some plant and animal species of economic importance but it will also lead to ecological imbalance. Therefore, it is imperative to conserve our natural heritage through a careful blend of *in situ* and *ex-situ* methods for protection and restoration of organisms.

Some strategies to achieve this target are listed below:

a) National Biodiversity Authority was established in 2003 by the Central Government to implement India's Biological Diversity Act, 2002. The NBA is a statutory body and that performs facilitative, regulatory and advisory function for Government of India on issue of conservation, sustainable use of biological resource and fair equitable sharing of benefits of use. The State Biodiversity Board (SBBs) focus on advising the state governments, subject to any guidelines issued by the central government, on matters relating to the conservation of biodiversity, sustainable use of its components and equitable sharing of the benefits arising out of the utilization of biological resources. The NBA considers requests by granting approval or otherwise for undertaking ant activity referred to in Sections 3, 4 and 6 of the Act. The SBBs also regulate by granting of approvals or otherwise upon requests for commercial utilization or bio-survey and bio-utilization of any biological resource by the Indians.

The Local Level Biodiversity Management Committees (BMCs) are responsible for promoting conservation, sustainable use and documentation of biological diversity including preservation of habitats, conservation of land races, folk varieties and cultivators, domesticated stocks and breeds of animals and microorganisms besides chronicling of knowledge relating to biological diversity. T**he main function of the BMC is to prepare People's Biodiversity Register in consultation with local people. The Register shall contain comprehensive information on availability and knowledge of local biological resources, their medicinal or any other use or any other traditional knowledge associated with them.***"* Preparation of "*People's Biodiversity Registers (PBR)"*

b) Sustaining Bio-diversity – Need for Harmonization of Policies: There is a growing need to enhance national networking on acquisition, conservation, evaluation and utilization of crop germplasm, strengthening database on plant genetic resources (PGR) information and monitoring national and international regulations in PGR policy, to suitably ensure efficient PGR management. Germplasm management being a gigantic task can be efficiently done in a network mode where Bureaux has to play a pivotal role in harmonizing the policies for implementation through various departments of Ministries of Agriculture, Environment and Forests, Science and Technology, Commerce, Health and Family Welfare, Defense and Home.

c) Traditional Farming System: Deployment of greater genetic diversity in traditional production systems is expected to take care of both their sustainable use and conservation. Multi-disciplinary research linking traditional crop varieties, indigenous animal and fish resources and policy support are needed to evolve farming systems, which can provide enough quality food and economic security to the local people. This 'grass root breeding' can build upon existing knowledge and skills of farmers and link farmers and scientists from different regions through the exchange of information and genetic resources to face the challenges of increasing agricultural production in decades ahead.

c) Community Rights and IPR: IPRs regime includes plant variety protection, geographical appellations, patents and trademarks. Research in frontier areas of biotechnology like genetic engineering, allele mining, genomics and proteomics can lead to patent protection and their commercialization, thereby promoting economic benefits and incentives to the scientists/creators of such technology. The inter-phase of agriculture, bio-technology, pharmaceuticals and nutraceuticals is an area where patents have much scope. In August 2008, the Ministry of Environment and Forests notified guidelines on biological diversity heritage site under section 37 of the Biological Diversity Act, 2002.

d) Public-Private Partnership: The conservation of bio-diversity requires a significant commitment by governments, industry sectors and the wider community to ensure a long-term balance between sustainable land management and bio-diversity conservation. The establishment of statutory protected areas, a range of off-park conservation management measures and ecologically sustainable land management at the landscape scale need emphasis. It calls for working out modalities for benefit sharing between the private and public sectors to ensure continuity of germplasm exchange, conservation and utilization bringing about synergy between the two sectors.

6.6. Annotation

The management of bio-diversity requires coordinated approach by several agencies/organizations and stakeholders. Appropriate policy and institutional changes are, thus, needed for developing a national action plan for its management. Several institutions are already actively involved, and coordination work is needed at all levels to ensure effective reforms and genetic resources conservation policies that benefit the public, especially the poor.

Policy changes that attack the roots of problems and ensure peoples' rights are needed. Issues needing further attention include ensuring public participation in the development of agricultural and resource use policies, policy support and incentives for effective agro-ecological methods that make sustainable intensification possible.

Building complementarities between agriculture and bio-diversity will also require changes in agricultural research and development, land use, and breeding approaches. There is a need to have integrated conservation of genomic resources to collect, validate and facilitate the use of useful genes and gene constructs generated in the country. This venture is expected to enhance the utilization of genomic resources and their availability to researchers across the country.

Current economic decisions are largely based on direct use values, although the other uses may be of equal or greater importance. By focusing exclusively on direct use values, biodiversity and genetic resource are likely to be consistently undervalued, thus resulting in a bias towards overexploitation through activities that are incompatible with their sustainability.

Key Extracts

- Bio-diversity is the basis of agriculture. It has enabled farming systems to evolve ever since agriculture was first developed some 10,000 years ago. Bio-diversity is the origin of all species of crops and domesticated livestock and the variety within them.
- Bio-diversity and agriculture are strongly interrelated while biodiversity is critical for agriculture, agriculture can also contribute to conservation and sustainable use of biodiversity.
- Indeed, sustainable agriculture both promotes and is enhanced by bio-diversity. Maintenance of this bio-diversity is essential for the sustainable production of food and other agricultural products and the benefits these provide to humanity, including food security, nutrition and livelihoods.
- The Earth's biodiversity is being lost at an alarming rate, putting in jeopardy the sustainability of agriculture and ecosystem services and their ability to adapt to changing conditions, threatening food and livelihoods security.
- To maintain agro-biodiversity, assessing the status and trends of the world's agricultural bio-diversity, the underlying causes of change, and knowledge of management practices is needed.
- Also, identifying adaptive management techniques, practices and policies; building capacity, increasing awareness and promoting responsible action; and mainstreaming national plans and strategies for the conservation and sustainable use of agricultural biodiversity into relevant agriculture sectors.

Chapter 7
Policy Approach and Recommendations

7.1. The Approach

The sustainability of cereal-cereal production systems of the IGP is critical to the country's food and livelihood security. Among the cereal based systems, rice-wheat cropping system of IGP is one such extensively deployed agro-production system, not just in India, but in South Asia too. A number of problems have cropped up with the cultivation of rice and wheat in system mode, threatening the sustainability of the system. The systems has had several bad consequences in soil health and on the ecosystem. As a result, productivity growth has also been negatively impacted. The deterioration relate to soil and water in particular.

The major factors that have caused yield stagnation of the major production systems are (**i**) declining soil organic carbon (SOC) and increasing multiple deficiencies of major nutrients (N, P, K, and S), as also micronutrients (Zn, Fe, and Mn); (**ii**) poor management of crop residues, including their burning; (**iii**) loss of bio-diversity, specially deterioration of soil microbial load; (**iv**) over-exploitation of groundwater resources leading to a decline in the groundwater table; and **(v)** degradation of cultivable land leading to more run-off and soil loss.

In order to arrest the deterioration of and ameliorate the status of scarce natural resources and biodiversity, and also to bring long-term sustainability of agricultural productivity (both crops and soil productivity), a holistic approach is required which will essentially involve a targeted approach to scientific intervention, participation of various stakeholders, policy direction and strengthening of the on-going schemes of the government.

Land as the base, with soil and water as necessary ecological mediums, need special attention and policy support to enable sustainable agricultural growth. A sustainable approach will also allow the agricultural system to convert inputs into output in a more efficient manner. Unsustainable practices lead to decrease in productivity, added cost of cultivation, raise the risk level and ecological stress.

7.2. Land Related Recommendation

Since land forms the base of land-water-forests/plants complex, it is necessary to maintain a balance between the available land and projected demands from various sectors.

i. Harmonise land resources databases at the national level to address the key issues of land degradation, land reclamation, land evaluation and land use planning.

ii. Evaluate the degree, type, extent and severity of soil erosion and its effect on production and nutrient losses. The information will lead to a targeted action plan, focussed on preventing land degradation and bring erosion within permissible limits for sustained productivity. Suitable technologies, conservation measures and strong research support will be needed. Special focus on reclamation of degraded/wastelands is recommended.

iii. Prepare judicious land use planning based on local agro-climatic as well as techno-economic potentials specific for each region, as the land and locations are not equally suitable for same kind of crops.

iv. Prepare a perspective plan for treating the degraded lands following the concept of participatory watershed management after prioritising the issues and vulnerable areas. This may include studying the long-term implications of changing land use patterns.

v. The Common Guidelines of Government of India (2008), may be amended to assign a larger share for watershed development works, including contribution from beneficiaries.

vi. Ensure effective implementation of the watershed programme with equal partnership of the community with minimal desirable subsidy for sustainability of various production systems in the long-run. Greater involvement of the watershed community at both planning & implementation levels, including making contributions (financial or/and kind) will add to long term sustainability ability of the watersheds.

vii. Use remote sensing and geographic information system-based decision support system with database on climate, soil, land use and crop yields for assessing, mapping, and monitoring land use performance under given technological conditions.

7.3. Soil and Soil Health Related Recommendations

There is greater recognition of the "role and place of soil" in national development for its various production, environmental and hydrological functions, that aim at development and conservation of natural resources, and maintaining soil health. There is a need to increase awareness about the 'exhaustiveness' of soil resources among various stakeholders - farmers, organizations, private sectors, and policy makers.

i. The universal Soil Health Card (SHC) scheme is very appropriate. There is need to connect SHC Portal with Integrated Fertiliser Management System (I-FMS) of Department of Fertilisers, to ensure that SHC based fertiliser alone is supplied to all the farmers. It is equally important to educate the farmers on use of the recommendations. The farmer should be enabled to receive electronic SHC (eSHC), anytime for any crop, based on the sample test already carried out.

ii. Farmers may be facilitated to get their soil samples tested at reasonable price in advance to the next planned cycle of testing is rolled out. There is also scope to spectrometry sensor based technology for soil testing and nutrient recommendation.

iii. Prepare a district level nutrient map to promote district-and-crop-specific customized fertilisers based on the soil health card data. Once nutrient mapping is completed for all districts, and crop-specific fertilizer prescription is made, this will not only economise use of fertilizer input but also enhance input-use efficiency and farm income. Furthermore, all Panchayat should have soil testing facilities or they should be able to arrange for soil testing through other government or private agencies. Private sectors, NGOs and rural youth should be encouraged to establish infrastructure for soil testing and advisory services.

iv. Adopt ecosystem-based approach to plant nutrition which places more reliance on accessing organic and mineral reservoirs leading to enhanced nutrient-use efficiency of cropping systems. This is preferable to the practice of replenishing the soil chemical fertilizers.

v. Include legumes to integral cropping system. These can contribute to N economy of the soil ecosystem in two ways-by drawing zero or minimal nitrogen for their growth; and by fixing atmospheric nitrogen into the soils. Adopt integrated nutrient management (INM) with rhizobial bio-fertilizers coupled with supplemental inputs of essential elements (P, S, B, and Mo) to help realise their growth and N-fixing potential in the agro-ecosystems.

vi. **Parampragat Krishi Vikas Yojna,** Promotion of organic farming – there are substantive cultivation tracts in India, where by default the intensity of use of agro-chemicals is low. These areas include hilly & tribal pockets, as also certain pockets of rainfed regions. With dependence on monsoons, the scope for increasing use of fertilizers is less. The yields are lower too. It is possible in such areas to realise higher than current yields by promoting comprehensive organic farming practices. Two integrated schemes, namely, PKVY and MOVCD-NE are comprehensive and appropriate. Properly implemented, organic farming will take care of soil health and sustainability particularly, in major part of the hill ecosystem. To support this, develop a common agri-value system platform to promote post-harvest/value addition facilities and to provide a platform for buyers and sellers.

vii. Follow suitable **crop-land-management practices** like conservation agriculture, cover crops, erosion reduction measures (contour cultivation on sloping land), agro-forestry, use of manure, compost, green manuring and other bio-solids including city sludge, mulch farming biochar application which have positive impact on input use efficiency, soil carbon sequestration and crop productivity. Waste dumps, sewage and sludge need greater regulation and designated safe disposal places, to reduce load of heavy metals in agricultural soils and in the food chain.

viii. The country generates large quantities of farm waste / biomass which are a good source of organic carbon. To capture organic carbon from these sources, programmes such as Swachh Bharat can be linked with Government program like National Mission of Sustainable Agriculture, National Soil Health Mission and National Project on Organic Farming; and a **carbon working group** be setup to meet the commitments in the "4 per 1000 Paris Declaration.

ix. Pulses are generally more responsive to organic production system and thus offer an alternative option in the area where chemical fertilizer application is inherently low. Encouraging greater inclusion of food legumes in cropping systems is needed as a move towards organic agriculture.

x. Adopt suitable crop rotation preferably legume-non-legume, remunerative crop diversification and inter-cropping for enhancing carbon sequestration and crop assurance in the changing climatic scenario.

xi. On a regional scale, above and below ground biomass production is probably the major determinant of the relative distribution of soil organic carbon (SOC). Vegetation type and root architecture contribute to soil C maintenance. Therefore, growing of deep rooted crops with profuse canopy, preferably legumes, to produce more biomass and better C-sequestration is recommended in the crop planning system.

xii. An ideal cropping system for increasing SOC storage should produce and retain the abundant quantity of biomass or organic C in the soil. Grow cover crops between main crop growing seasons, reduce fallow period, summer or winter fallow to improve SOC storage. Certain cropping systems can act as a sink for CO_2. In addition, increase cropping intensity to decrease the rate of decomposition of organic matter and rate of mineralization/oxidation of SOC.

xiii. Initiate school curricula for school students to understand role of soil in food security and environmental sustainability and also the importance of soil testing for nutrient status based soil health managment.

7.4. Water Related Recommendation

It is clear from the discussions in Chapter 1, that water scarcity will intensify in future, with expected increase in population and demand for food, fodder, and fuel apart from competition from non-agricultural sectors. Given the complexity of the various factors and processes affecting agriculture and water use, no single technology or methodology would be adequate for attaining this goal. A multi-dimensional approach that seeks improvements in water science and technology, policy and governance is essentially required.

i. The soil health card scheme can be extended to testing and recording water health, as a next step. This will provide a more holistic understanding of the ecological capability for productivity planning.

ii. Augment existing water supplies by development of additional water resources or/and by conservation of existing resources; in addition to efficient and economic use of water in every activity.

iii. Adopt agronomic options for more productive use of water in the agricultural fields. New irrigation technologies that improve field level water application efficiencies will be critical components of the demand side option. The use of sensors and automated irrigation systems will be a necessary option to minimise wasteful water use.

iv. Re-use and recycle waste water as much as possible on a large scale as there is considerable scope and incentive to use this alternative. 'Re-use' applies to wastewaters that are discharged from municipalities, industries and irrigation and then withdrawn by users other than the dischargers.

v. For desalination, available technologies are improving consistently, though they may currently not be viable. However, there is need to adopt technologies, like cryo-desalination and nano-technologies, which have the potential to provide relatively cost effective alternatives for desalination and water purification.

vi. The Pradan Mantra Krishi Sinchai Yojana, (PMKSY) encompasses 'Per Drop More Crop' component, which mainly focuses on enhancing water use efficiency at farm level through precision/micro irrigation (drip and sprinkler Irrigation). During last three years (2015-18) an additional 18.6 lakh ha of land has been covered under micro-irrigation, and 83,135 water harvesting structures were created with irrigation potential of 1,59,320 ha area. Astute crop planning, preferably integrating low water use crops, with judicious supply, the stored water may cover even more area than its projected potential. Proper maintenance of water structures, control over leakage and misuse of the stored water and capacity building of local people are some of the considerations for greater success of this scheme.

vii. Focus more on simultaneous precision application of water, fertilizer and other inputs to match the crop requirements on the field to increase the marginal productivities of water and inputs, through impact on the quantity and quality of produce (nutrient and water-use efficiency). Crop alignment should become an integrate component of all irrigation projects. In addition to crop alignment and micro-irrigation, IOT (Information of Things) should be encouraged.

viii. There is no single law that deals with groundwater legislation running across the country. All laws relating to groundwater are legislated in the form of state Acts. Therefore, the model bill drafted by the Central Groundwater Board should be considered and adapted by the states to ensure equitable development and sustainable use of groundwater resources. This bill proposes: compulsory registration of bore-well owners; compulsory requirement of statutory permission to sink a new bore-well; creation of a groundwater regulatory body; restriction on the depth of bore-wells; establishment of protection zones around drinking water wells; and, other measures.

7.5. Other Recommendations

Adaptation is an anticipatory and planned process, managed through policies, technologies and developmental activities. While mitigation practices are important to reduce the drivers of non-sustainable practices and events such as climate change, it is the adaptation strategies that are essential in the long run. There are several strategies and practices that fall into the broad categories of crop/cropping system-based technologies, resource conservation-based technologies and socio-economic and policy interventions. The government needs to develop and promote adaptation strategies, evolve them as new sciences and technologies that are understood and get the society to be future ready.

i. In view of climate change and other ecologically diverse changes that have occurred there is a need to re-categorise the agro-ecological regions and climatic zones of the country. This will help provide fresh direction in respect of all other sustainable strategies and practices.

ii. Shift in the cropping systems and/or production practices in accordance with the resource availability, particularly soil characterisation and water status. Diversified cropping systems including pigeon pea-wheat, maize-wheat, and inclusion of pulses in the predominating cropping systems are examples of sustainability perspective.

iii. Adopt rice cultivation as a predominant crop in acid sulphate soils of coastal areas. It will increase the pH of soil and reduce the iron and aluminium toxicity.

iv. There is available a vast tract of around 12 million ha. of post-kharif fallow land, once the standing paddy crop is harvested. The available soil moisture is also adequate, though various depending upon the rainfall of the region. These areas can be used extensively for pulse cultivation, that fix nitrogen into the soil, and also aid soil organic carbon build up.

v. Rainfed Area Development (RAD) is being implemented as a component under National Mission for Sustainable Agriculture (NMSA) from 2014-15 in the Country which focuses on Integrated Farming System (IFS) for enhancing productivity and minimizing risks associated with climatic variability. ICAR has developed many IIFS models for different locations through various institutions across the country. These models may be validated through state mechanism under NMSA for and adopted.

vi. Legumes are ideal crops components for conservation agriculture (CA) for soil cover and rotation. Water use efficiency improves with conservation agriculture as it allows for earlier planting, reduced soil evaporation, better weed management, and increased access to nutrients.

vii. Diversification of the rice-wheat system under CA in the Indo-Gangetic Plain will be the key to sustainability. It is possible to achieve the same or realise even higher yield with zero-tillage in comparison to conventional tillage.

viii. Develop a crop residue management policy in each state, clearly defining various competitive uses; adopt appropriate legislation on monitoring of on-farm crop residue handling through incentives and technology support.

ix. Retain crop residues on soil surface for success of conservation agriculture in the long-run, because zero-tillage along with residue has beneficial effects on soil moisture, temperature moderation and weed control. Grow cover crop like summer greengram, blackgram or green manure crops of sunhemp, sesbania, cowpea etc.

x. Support conservation agriculture by facilitating the farmers with access to appropriate machineries through custom hiring centres.

xi. Popularise conservation agriculture technologies at KVKs and state agricultural departments for creating greater awareness among the farmers. Conservation agriculture is a machine-herbicide & management-driven system. For its successful adoption, integrated weed management involving chemical and non-chemical methods (residue, cover crops, varieties etc.) needs to be advocated.

xii. Introduce and provide carbon-credit to the farmers practicing conservation agriculture for carbon sequestration and greenhouse gas mitigation.

xiii. Adopt new agronomic practices like adjustment of planting dates to minimize the effect of high temperature increase-induced effects. Changes in spatial distribution of rainfall and temperature patterns are getting more apparent in the recent decade on account of climate change. Hence, the need for change selling new sowing & planting dates.

xiv. Improve the water-use efficiency of crop plants, their drought and pest resistance for better adaptability for the changing scenario.

xv. Rice is consumed as staple food by more than half of the world's population. Puddling, a procedure of ploughing soil in standing water, expends a substantial amount of water. There is a danger that rice producers in India will most likely have insufficient access to irrigation water in future. Therefore, there is need to adopt alternatives of rice establishment techniques like unpuddled transplanted rice (UPTPR), zero tillage transplanted rice (ZTTPR), and zero tillage direct seeded rice (ZTDSR).

xvi. A detailed evaluation of the country's germplasm collections with respect to special traits is required. Thereafter, making available genes and gene constructs for drought tolerance, photo-insensitivity, pest and disease resistance, male sterility, mineral and vitamins to breeders is recommended. India has one of the richest diversity of germplasm.

xvii. Prioritize bio-prospecting of medicinal plant germplasm and that of indigenous livestock to take advantage of pharma industry linkages for commercialization of new bio-molecules in diagnostics and disease management.

xviii. Adopt a broader range of indicators, covering long-term ecosystem health; total resource flows; sustainable interactions between agriculture and the wider economy; the sustainability of outputs; nutrition and health outcomes; livelihood resilience; and the economic viability of farms with respect to debt, climate shocks, etc.

xix. The union and state governments must reward an array of positive outcomes in diversified agro-ecological systems. Such measures will promote implementation, such that farms diversify and transition towards agro-ecology. In particular, they must support adoption of agro-ecological farming, rather than being locked into the cycle of industrial agriculture, where use us agro-chemcials is predominant.

xx. Adopt a system approach, comprising diversification of income-generation activities at the farm level, to mitigate food loss. This helps in securing higher total output without having to produce more with avoidable stress on the production ecology. A system approach should be linked to changing market trends, utilise information technology in agricultural sectors, and enhanced agro-processing including industrial uses and food supply chains which will generate new opportunities, and make the agricultural system sustainable.

xxi. Governments should support and promote repurposing infrastructure in cities to favour farmers' markets. These can be developed in modern lines to generate direct footfall of consumers for daily fresh produce needs. More attention should also be paid to the role of informal markets and policy measures must be put in place that empowers emerging initiatives linking farmers to consumers. The provision of Model APLM Act 2017 facilitates such a requirement, and therefore need to be adopted by the state and UT.

xxii. Support farmers' groups, community-based organizations and social movements which encourage the spread of agro-ecological practices and advocate for sustainable food systems, and ensure the participation of diverse civil society groups.

xxiii. Public research agendas must be redefined around sustainable production priorities. Investments must be redirected towards equipping the farmers to ease their shift in production and cropping system.

Article 48 of the Constitution of India requires that the country endeavour to organise agriculture and animal husbandry on modern and scientific lines. Science is an evolving subject and the modern learnings as they apply to agriculture will inherently require to shift as and when scientific knowledge progresses. The current day information of a stressed agricultural eco-system, and the possibility to organising the system in line with modern scientific knowledge is not only compulsory but is indispensable for sustainable development and for the welfare of farmers.

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Annexures

Annexure-I

Indicators of key natural resources in rainfed cropping systems

SN.	Indicators	Key management aspects
1	Nutrient balance	Organic matter - rate of change Nitrogen cycling - especially when using grain legumes in rotation with cereals Monitoring status of phosphorus, sulphur and potassium Micro-nutrients
2	Erosion	Vegetation cover - includes trees as well as stubble Soil surface cover - stubble retained (30 per cent sufficient to prevent wind and water erosion) Stream bank Sheet and gully erosion
3	Productivity, yield and quality	Water use efficiency - i.e. actual versus potential (in some areas the potential is much less than the actual) (biomass/grain yield/net return), recharge (dryland salinity and nutrient leaching) Pasture composition - legume and perennial Matched animal versus pasture production - appropriate enterprise selection/capability Maintenance of genetic base/improvement
4	Soil structure	Infiltration Permeability/water storage Stability Waterlogging Compaction
5	pH	Change Toxicity - deficiency Indicator plants
6	Energy efficiency	Energy input vis-à-vis energy output of the whole agricultural system
7	Biological factors	Soil macro/micro flora and fauna Animal health Plant health (root growth and other) Pests (animals and plants)
8	Farm management skills	Understanding - a good indicator would be the understanding of the farmers of their own technical system

Annexure-II

Change in SOC storage equilibrium ($dCs/dt = aX\text{-}b\ SOC$) in relation to total input required to maintain SOC in different cropping systems

Cropping System	**Equation**	**Amount of C inputis required (kg ha^{-1} y^{-1}) to maintained SOC**	**References**
Soybean- wheat (IISS, Bhopal)	Y=0.1806X-160.34	888	Kundu et. al. (2001)
Rice-wheat-jute (Barrackpore)	Y= 0.0536x-298.08	5562	Manna et. al. (2005)
Soybean-wheat (Ranchi)	Y=0.0217X-92.637	4269	Manna et. al.(2005)
Sorghum-wheat (Akola)	Y= 0.0871X-53.4	613	Manna et. al. (2005)
Soyean –wheat system (Almora)	Y= 0.191X-61.3	321	Kunduet. al. (2007)
Groundnut based (Junagarh)*	Y=0.2635X-1854.4	7600	Ghosh et al. (2006)
Fallow based (Junagarh)	Y=0.1931X-834.8	4300	Ghosh et al. (2006)
Rice based#	Y=0.064X-3.60	2920	Mandal et al. (2007)
Rice-wheat (kalyani)	Y=0.14X-9.19	3.56	Majumdar et al. (2008)
Groundnut monocropping (Anantapur)	Y= 0.25X-5.57	1120	Srinivasarao et al. (2012)
groundnut–finger millet (Bangaluru)	Y -0.45X- 2 9.58	1620	Srinivasarao et al. (2012)
Sorghumtmonocropping (Solapur)	Y= 0.228X+47.09	1100	Srinivasarao et al. (2012)
Rice–Lentil (Varanasi)	Y= 0.099X-5.131	2470	Srinivasarao et al. (2012)

Annexure-III

Effect of different cropping system and management of C- sequestration rate in SAT benchmark soils of India

Location	**Soil type**	**Cropping system**	**Study period**	**Sampling depth (cm)**	**Initial SOC (Mg ha^{-1})**	**Final SOC (Mg ha^{-1})**	**C-seques-tration rate (kg ha^{-1}yr^{-1})**
Madhya Pradesh	Typichaplusters (Kheri)	Paddy-wheat	1982-2002	0-30	19.8	22.5	135
Maharashtra	TypicHaplusterts (Linga)	Citrus	1982-2002	0-30	22.0	36.9	745
Maharasthra	TypicHaplusterts (Asra)	Cotton/ Greengram+ Pigeonpea	1982-2002	0-30	17.3	35.0	885
Gujarat	Typichaplusterts (Semla)	Groundnut-wheat	1978-2002	0-30	27.3	31.9	209
Karnataka	TypicHaplusterts(Teligi)	Paddy-paddy	1974-2002	0-30	18.61	43.6	861
Karnataka	TypicHaplustalf (Vijapura)	Finger millet	1982-2002	0-30	19.3	21.9	130
Andhra Pradesh	TypicHalplustalf(Kaukuntala)	Castor + Pigeonpea	1978-2002	0-30	14.5	35.1	936

Source: Manna et al. 2008, Manna and Subba Rao, 2012b.

Annexure-IV

Future projection for changes in rainfall and temperarture for India due to climate chnage

Year/ Scenarios	Season	Temperature change (^{0}C)		Rainfall Change (per cent)	
		Lowest	Highest	Lowest	Highest
2020s	Annual	1.0	1.41	2.16	5.97
	Rabi	1.08	1.54	1.95	4.36
	Kharif	0.87	1.17	-1.81	5.10
2050s	Annual	2.23	2.87	5.36	9.34
	Rabi	2.54	3.18	-9.92	3.82
	Kharif	1.81	2.37	7.18	10.52
2080s	Annual	3.53	5.55	7.48	9.90
	Rabi	4.14	6.31	-24.83	-4.50
	Kharif	2.91	4.62	10.10	15.18

(Joshi and Kar, 2009)

Annexure-V

The global warming potential of six major greenhouse gases (IPCC, 2007).

Gas	**Global warming potential**	**Atmospheric life (Years)**
CO_2	1	5 to 200
CH_4	21	12
N_2O	310	114
HFC	140 to 11,700	1.4 to 260
PFC	6,500 to 9,200	10,000 to 50,000+
SF_6	23,900	3200

Annexure -VI

Agricultural practices for enhancing productivity and increasing the amount of carbon in soils.

Conventional practice	Recommended practice
Plough tilling	Conservation tilling/ zero tillage
Residue removal/burning	Residue return as mulch
Summer fallow	Growing cover crops
Low off-farm inputs	Judicious use of fertilizers and INM
Regular fertilizer use	Site-specific soil management
No water control	Water management/conservation, irrigation, water table management
Fence-to-fence utilization	Conversion of marginal lands to nature conservation
Monoculture	Improved farming systems with several crop rotations
Drainage of wetlands	Restoring wet lands

Abbreviations

A4NH	Agriculture for Nutrition and Health
AADs	Agricultural Associated Diseases
AARDO	African-Asian Rural Development Organization
AAU	Anand Agricultural University
AC&ABC	Agri-Clinic and Agri-Business Centre
ACCNet	Agricultural Credit and Cooperation Network
ADB	Asian Development Bank
AE&AS	Agricultural Extension and Advisory Services
C	Carbon
CA	Conservation Agriculture
DOC	Dissolved Organic Carbon
FYM	Farmyard manure
GHG	Greenhouse gas emissions
HYV	High-Yielding Variety (seeds)
IGP	Indo Gangetic Plains
MV	Modern Variety
SOC	Soil Organic Carbon
SOM	Soil Organic Matter
TV	Traditional Variety
ZT	Zero tillage

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