Chapter 5: Sustainable Agriculture

Short Answers

CSM 05: Agriculture

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- Management of Soil Organic Carbon
- Agro-ecological Based Agriculture
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- Agro-biodiversity for Smart Ecological Services
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1. Sustainability Approach in Agriculture

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.

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.

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.

1.1 Degradation of Natural Resources

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 overgrazing, 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.

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 redistributed. 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.

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).

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.

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.

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.

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.

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2. Management of Soil Organic Carbon

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.

2.1 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.

2.2 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 CO2. 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.

2.3 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.

I. Carbon sequestration
II. Options for sequestering carbon in soils
III. Conservation tillage and cycling
IV. Nutrient management and cropping systems
V. Cover crops and fallowing
VI. Plant roots and carbon sequestration
VII. Agro-forestry and agro-pastoral systems
VIII. Residue management and mulching
IX. Water management
X. Cropping systems and crop diversification

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3. Agro-ecological Based Agriculture

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 agroecosystems

- 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.

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.

3.1 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.

3.1.1 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.

3.1.2 Improved agro-techniques for irrigated systems

- **I.** Laser land levelling
- **II.** Conservation tillage (zero/minimal tillage)
- **III.** Bed planting (narrow/broad beds)
- **IV.** Direct-seeded rice
- **V.** Furrow irrigated raised bed system of planting

3.2 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 Constraints in Dryland farming

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.

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.

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.

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.

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.

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4. Conservation Agriculture and Residue Management

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. Derpschet 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.

4.1 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.

4.2 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.

Zerotillage 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.

4.3 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 (Lafondet al., 2009; Nathet 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.

4.4 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.

4.5 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.

4.6 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.

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5. Climate Change

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 oC (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, CO2 has the highest positive forcing leading to warming of climate. CO2 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.

5.1 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.

5.2 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 CO2 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.

5.3 Impact of Climate Change on Agriculture

Agriculture and fisheries are highly dependent on the climate. Interestingly, increases in temperature and CO2 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.

5.4 Issues around Climate Change

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.

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 33.8-42.2O 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 NH4-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.

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.

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.

5.5 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 $CH4$ and $CO2$ 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.

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6. Agro-biodiversity for Smart Ecological Services

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 agrobiodiversity 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.

6.1 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. 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 storehouse 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.

6.2 Status of Agro-biodiversity

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 micropropagation and in-vitro conservation of vegetative propagated species and also for cryopreservation 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.

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.

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).

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.

6.3 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, photoinsensitivity, 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.

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7. Watershed Management

A watershed is a defined geographic area through which water flows across the land and drains into a common body of water, whether a stream, river, lake, or ocean. The watershed boundary more or less follows the highest ridgeline around the stream channels and meets at the bottom or lowest point of the land, where water flows out of the watershed, the mouth of the waterway. Much of the water comes from rainfall and storm water runoff. The quality and quantity of storm water is affected by all the alterations to the land--mining, agriculture, roadways, urban development, and the activities of people within a watershed. Watersheds are usually separated from other watersheds by naturally elevated areas.

Importance of Watershed

Watersheds are important, because the surface water features and storm water runoff within a watershed ultimately drain to other bodies of water. It is essential to consider these downstream impacts when developing and implementing water quality protection and restoration actions. Everything upstream ends up downstream.

Declining soil productivity is a great threat to sustainability in agricultural production. It, thus, calls for optimal utilization of soil resources that can only be affected once land use is made as per capability. Incompatible land use is responsible for inducing degradation processes.

Watershed management is a major land development program in the country. It is essential to introduce Referencing System of Watershed at National level as different watershed development programs are operationalized by various departments and ministries. This system will help recognize the watershed by way of national code and avoid duplication on the part of implementing agencies.

Factors affecting Watershed Management

Vegetative cover

It is an important landscape element in any watershed. The distribution of vegetation species may be diverse and highly variable across the watershed, but vegetation communities can be described in more general terms as well. Drainage density can affect the shape of a river's hydrograph during a rain storm. Rivers that have a high drainage density will often have a more 'flashy' hydrograph with a steep falling limb. High densities can also indicate a greater flood risk.

Climatic characteristics

The greatest factor controlling stream flow, by far, is the amount of precipitation that falls in the watershed as rain or snow. However, not all precipitation that falls in a watershed flows out, and a stream will often continue to flow where there is no direct runoff from recent precipitation. The amount of rainfall affects the flow of the streams within the watershed area, and ultimately the quantity of water that is stored in the watershed.

Watershed characteristics

The shape of the watershed contributes to the speed with which the runoff reaches a river. A long and narrow catchment will take longer to drain than a circular catchment. Basin shape is not generally used directly in hydrologic design methods. Watersheds have an infinite variety of shapes, and the shape supposedly reflects the way that run-off will "bunch up" at the outlet. A circular watershed would result in run-off from various parts of the watershed reaching the outlet at the same time. An elliptical watershed having the outlet at one end of the major axis and having the same area as the circular watershed would cause the run-off to be spread out over time, thus producing a smaller flood peak than that of the circular watershed. The size helps determine the amount of water reaching the river, as larger the catchment the greater the potential for flooding. Topography determines the speed with which the run-off will reach a river. Clearly, rain that falls in steep mountainous areas will reach the primary river in the watershed faster than in case of flat or lightly sloping areas. Topographic maps show lines of equal elevation. Watershed slope affects the momentum of run-off. Both watershed and channel slope may be of interest. Watershed slope reflects the rate of change of elevation with respect to distance along the principal flow path. It is usually calculated as the elevation difference between the end-points of the main flow path divided by the length. The elevation difference may not necessarily be the maximum elevation difference within the watershed since the point.

Contributors to water pollution

Common contributors to water pollution are nutrients and sediment which typically enter the stream systems after rainfall washes them off the poorly managed agricultural fields, called surface run-off, or flushes them out of the soil through leaching. These types of pollutants are considered non-point source pollution, because the exact point where the pollutant originated cannot be identified. Such pollutants remain a major issue for water ways, because the difficulty to control their sources hinders any attempt to limit the pollution. Point source pollution originates a specific point of contamination, such as failure of a manure containment structure and its contents entering the drainage system or when a factory discharges its waste directly into a body of water using a pipe.

Management of Watershed

Crops and system management

Crop rotations are required for optimal utilization of land to feed ever increasing population and are useful in reducing pest and disease problems, reducing weed pressure, reducing soil erosion, building organic matter, and supporting a diverse soil microbial community. Rotations that include several crops of different plant families support better soil health than simpler rotations. A diverse crop rotation that includes legumes and deep rooted crops can enhance an efficient cycling and utilization of crop nutrients. On sloping land, integrating a conservation crop rotation with other practices such as strip cropping or contour buffer strips can greatly reduce soil erosion and protect soil health. This includes cover crops, green manures, catch crops in single season crop and alley cropping, inter-cropping, hedgerows, etc., for perennials

Agro-forestry

The single crop areas having saline water (ground water quality) in the block are the best sites for the adoption of the Agro-forestry (with salt tolerant spp.). The concept of Agro-forestry implies the integration of annual crops with perennial trees on the farm to the benefit of the agriculture system. This concept originated from realisation of the fact, that the trees play a vital role in safeguarding the long term interest of the agriculture, and in making farm economy viable. Trees can be incorporated within a farming system by planting them on land which is not suitable for crop production. Trees help to preserve the fertility of the soil through the return of organic matter and fixation of nitrogen. As a result, less run-off is generated and erosion is better controlled. Agro-forestry system requires careful selection of both crop and tree species if a beneficial interaction is to be obtained.

Implementing agencies

The watershed programme is being carried out in desert, drought prone and rainfed areas through DRDA/Zilla Parishad at the district level. Project implementation agency is also selected by DRDA / Zilla Parishad. However, other institutions like Integrated Tribal Development Agencies (ITDAs), agricultural universities, research institutions, government undertakings, non-governmental organisations etc. are also entrusted with some watershed projects for implementation. Not for profit organisations also take up independent work with supporting contribution from private sector.

Strategy for Soil and Water Conservation

The Division of Natural Resource Management (NRM) in DAC&FW, Government of India adopts micro-watershed as a basic unit of treatment with a view to developing the land resources under natural system in the catchments of River. The policy of the department is to treat the most vulnerable micro-watersheds on priority basis based on scientific data base, dissemination of data base to the implementing agencies and monitoring the progress of the developmental activities. The strategy adopted by the Department comprises:

- Dissemination and adoption of National Level Micro-Watersheds developed by dedicated organizations.

- Use of detailed scientific soil, land and water information generated on high spatial resolution for planning of vulnerable areas under watersheds.

- Integration of baseline survey maps for development of integrated action plan for development of each micro-watersheds.

- Awareness campaign and peoples' participation in watershed management.

- Evaluation of the impact of watershed development program.

Action Plan for Integrated Watershed Management

The Common Guidelines for Watershed Development Projects lay down a pragmatic approach to resolving issues of “institutional” versus “natural” boundaries by defining “operational watersheds” that align largely to village boundaries. This tactic - based on socially, politically, and/or administratively meaningful units—has been successfully applied. Since the watershed program is primarily a social program, and also because Village Watershed Committees (VWCs) within each Gram Panchayat are to be the ultimate implementing agency, the Guidelines offer a practical management solution.

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8. Rainfed Agriculture: challenges and strategies

Currently, the rainfed agriculture, which is totally rain dependent, accounts for 55 per cent of the net sown area of the country. Rainfed agriculture is crucial to country's economy and food security since it contributes to about 40 per cent of the total foodgrain production (85, 83, 70 and 65 per cent of nutri-cereals, pulses, oilseeds and cotton, respectively); supports two-thirds of livestock and 40 per cent of human population; further also influences livelihoods of 80 per cent of small and marginal farmers and is most vulnerable to monsoon failures. Even if full irrigation potential gets to be created, still 40 per cent of net cultivated area will remain as rainfed agriculture which would continue to be a major foodgrain production domain.

The Green Revolution in mid-sixties, though a boon to Indian agriculture at the macro level, it ushered in an era of wide disparity between productivity of irrigated and rainfed agriculture. It largely by-passed the rainfed agriculture including the eastern region of the country. Several development programmes were initiated for improving rainfed farming. The "Everything Everywhere" approach of taking up all major interventions uniformly across all regions of the country has not paid much dividend. The developmental approach in rainfed areas did not fully capture aspects like livelihood, soil resources, reliability of irrigation, socio-economic profile, infrastructure, etc. neglecting region-specific interventions befitting to the natural resource endowment, social capital, infrastructure and economic condition (NRAA, 2012). Rainfed agriculture is complex, diverse and risk prone. It is characterized by low levels of productivity and input usage coupled with vagaries of monsoon emanating from climate change, resulting in wide variation and instability in yields. In view of the growing demand for foodgrains in the country, there is a need to develop and enhance the productivity of rainfed areas. If managed properly, these areas have tremendous potential to contribute a larger share in food production and faster agricultural growth compared to irrigated areas which have reached a plateau. The state of rainfed agriculture is precarious and the problems associated with it are multifarious. To name the more striking ones: low cropping intensity, high cost of cultivation, poor adoption of modern technology, uncertainty in output, low productivity, increasing number of suicides among farmers, lack of institutional credit, inadequate public investment and high incidence of rural poverty (Singh et al., 2010).

The major challenge of rainfed agriculture in the decades to come will be sustaining the livelihoods of small and marginal farmers who will still depend on agriculture despite increased climate variability and shrinking land holdings.

Managing Risks: Key Issues

The rainfed agriculture is totally dependent on south-west monsoon and thus, is synonymous with risk due to erratic monsoon. A decrease of one standard deviation from the mean annual rainfall often leads to a complete loss of the crop. Dry spells of 2 to 4 weeks during critical crop growing stages cause partial or complete crop failure. Climate change and climate variability impacts Indian agriculture in general and more pronounced by the rainfed agriculture. The evident climate shifts in rainfed areas will have larger implications for crop planning, water resources assessment and prioritizing drought proofing programmes. Rainfed crops are likely to be worst hit by climate change because of the limited options for coping with variability of rainfall and temperature. The projected impacts are likely to further aggravate yield fluctuations of many crops with negative influence on food security and prices. Compound growth rates and instability index of major rainfed crops reveal that all the major crops registered negative growth in spite of the technologies such as new variety, fertilizers etc. The yield could not be increased significantly due to vagaries in monsoon and temperature, despite intervention through various governmental schemes.

Climatic risks like droughts and floods, and poor water and nutrient retention capacity of soil and low soil organic matter (SOM) impact negatively the rainfed agriculture. Risk is also to be addressed in terms of building resilience of crops, soils and farmers. Resilience to climate change will depend on increasing agricultural productivity with available water resources; refining technologies and timely deployment of affordable strategies to accomplish potential levels of arable land and water productivity. In this context, it seems rational for overall agricultural policy as well as the research system to prioritize issues related to resilience to climate risks, and strengthen the capacity of natural resources to overcome various forms of climate stress, as a critical requirement to achieve food security.

Environmental footprints of changing demand profile

With rising incomes, the demand for high energy food (milk, meat, eggs and oils) will increase. For instance, milk and meat demands in India by 2050 are estimated to be around 110 and 18.3 mt respectively. Such production levels could be attained by intensive animal rearing systems like semi- and stall-feeding; placing more demand for fodder, feed and water; and breed improvement. The projected domestic demand for different crop groups shows that rice and wheat may be surplus whereas other cereals will be in acute shortage (CRIDA Vision, 2015).

The deficit would be primarily for oilseeds, fruits, vegetables and pulses. Hence, the challenge would be to enhance productivity levels of these crops by promoting breeding programs and dryland horticulture. Further, as rice and wheat are going to be surplus, we need to follow a two-pronged strategy i.e. to increase their productivity by bridging the yield gaps and shifting some of the area under these crops to other cereals and vegetables through integrated farming systems approach which optimize the use of natural resources. Currently, there is an imbalance between natural resources endowment and cropping patterns in the country. It is an irony that areas with less rainfall are net exporters of agricultural produce to areas with sufficient rainfall and untapped groundwater potential (CRIDA Vision, 2015).

Strategies for Sustainable Agriculture in Rainfed Areas

- **I.** Enhancing and stabilising productivity
- **II.** Commodity crop specific strategies
- **III.** More crop and income per drop of water
- **IV.** Soil fertility management
- **V.** Quality seed production
- **VI.** Diversifying within farm
- **VII.** Dryland horticulture
- **VIII.** Alternate land use system

IX. Animal husbandry
X. Protected agriculture
XI. Fodder production
XII. Food processing & value addition
XIII. Farm mechanization

Strategies for increasing irrigated potential/area in rainfed areas are:

- Harvesting available water resources for stable irrigation.
- The groundwater potential in eastern region of the country is yet to be utilised rationally.
- Flood water management in north-eastern region
- Implementation & popularization of agro-ecology specific (soil & rainfall) in-situ moisture conservation practices.
- Mapping potential sites for rainwater harvesting in farm ponds.
- Popularization of farm pond technology package (selection of ideal site, digging, harvesting, lining, minimizing evaporation losses, lifting pump, micro-irrigation system)including efficient utilization of stored water for higher water productivity (More Crop and Income per Drop of Water).
- Desilting tanks to increase stored volume of water for irrigation of crops & groundwater stabilization.
- Adoption of water saving technologies viz., drip & sprinkler irrigation in commercial field & horticultural crops.
- Augmenting & popularization of use of treated waste-waters for irrigation.
- Popularization of recommended tank silt application in light textured soils

Government initiative

Climate change has already demonstrated its adverse impact on rainfed agriculture. The prevalence of extreme events and increased unpredictability of weather patterns can lead to reductions in production and lower incomes in these areas. Concerning the impact of climate change on rainfed agriculture, Government of India has emphasized on high priority on research and development to cope with climate change in agriculture sector.

Given the context, ICAR launched a mega project ‘National Initiative on Climate Resilient Agriculture’ (NICRA) to enhance the resilience of Indian agriculture, covering crops, livestock and fisheries to climatic variability and climate change through development and application of improved production and risk management technologies; to demonstrate the site specific technology packages on farmers’ fields for adapting to current climate risks; and to enhance the capacity of scientists and other stakeholders in climate resilient agricultural research and its application.

The thrust areas covered are, (i) identifying most vulnerable districts/regions, (ii) evolving crop varieties and management practices for adaptation and mitigation, (iii) assessing climate change impacts on livestock, fisheries and poultry and prioritising adaptation strategies.

Enhancing food security while contributing to mitigation of climate change and preserving the natural resource base and vital ecosystem services requires transition to agricultural production systems that are more productive, use inputs more efficiently, have less variability and greater stability in their outputs, and are more resilient to risks, shocks and long-term climate variability. More productive and more resilient agriculture requires a major shift in the way land, water, soil nutrients and genetic resources are managed to ensure that these resources are used more efficiently.

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9. Organic Farming

Organic agriculture is recognized as an innovative farming system, that balances multiple sustainability goals and will be of increasing importance in global food and ecosystem security (Reganold and Wachter, 2015). High demand for organic foods in Europe and North America has resulted in the import of organic foods from large farms. Organic agriculture relies on location specific varieties (resistant/tolerant to pest and diseases), crop rotation, organic composts, green manure, biological pest management and prohibits the use of synthetic fertilizers and pesticides, antibiotics, genetically modified organisms, and growth hormones. Concerns about the un-sustainability of conventional agriculture (based on synthetic inputs) have promoted interest in other farming systems, such as organic, integrated and conservation agriculture (CA).

Organic farming has the potential to produce high quality food, enhance natural resource base and environment, increase income (coming from premium price on the produce, even in the face of a slight dip in the yields) and contribute to the wellbeing of the farmers. Under extreme climatic conditions such as drought which are expected to increase with climate change, organically managed farms may produce higher yields than their conventionally managed farm due to improvement in soil properties (Das et al., 2016). Under severe drought conditions, which are expected to increase with climate change in many areas, organically managed farms have frequently been shown to produce higher yields than their conventionally managed farms due to the higher water-holding capacity of organically farmed soils (Siegrist et al., 1998). In addition, improvements in management practices and location specific crop varieties for organic systems may also narrow down this yield gap.

Organic and Towards Organic Agriculture

Organic farming is to create integrated, humane, environmentally and economically sustainable production systems, which maximize reliance on farm-derived renewable resources and the management of ecological and biological processes and interactions. The purpose is to realise acceptable levels of crop, livestock and human nutrition, protection from pests and disease, and an appropriate return to the human and other resources. Organic farming provides long-term benefits to people and the environment. There are two significant areas where organic systems have higher yields compared to conventional systems. These are:

- under conditions of climate extremes; and
- in small holder systems.

Both these situations are critical to achieving safe food security for future in India. Organic farmers grow a variety of crops and raise livestock in-order to optimize competition for nutrients. This results in less chance of low production, improved availability and positively impact local food security. Studies by national and international agencies have proved these positive aspects of organic agriculture systems.

Organic farming: concepts

The concept of organic farming is based on the following principles:

• Nature is the best role model for farming, since it does not use any input(s) nor demands unreasonable quantities of water.

• The entire system is based on intimate understanding of nature's ways. The system does not believe in mining of the soil of its nutrients and does not degrade it in any way for today's needs.

• The soil in this system is a living entity and the soil's living population of microbes and other organisms are significant contributors to its fertility on a sustained basis and must be protected and nurtured at all cost.

• The total environment of the soil, from soil structure to soil cover is more important.

Organic farming: focus

Organic agriculture is a holistic production management system which promotes and enhances health of the agro-ecosystem, including bio-diversity, biological cycles, and soil biological activity. Its emphasis is on the use of management practices in preference to the use of off-farm inputs, taking into account that regional conditions require locally adapted systems. This is accomplished by using, where possible, cultural, biological and mechanical methods, as opposed to using synthetic material, to fulfil any specific function within the system. Organic farming aims to optimize quality in all aspects of agriculture by taking into consideration the natural capacity of plants, animals and the land. It emphasizes on the health of agricultural ecosystem and prohibits the use of synthetic herbicides and pesticides, synthetic fertilizers in crop production and hormones antibiotics in livestock production, and genetically modified organisms. It respects the law of nature to increase yields and disease resistance. Organic farming requires a high level of farm management skills and demands use of wide range of resources to solve the problems. The organic farming focuses on:

• Maximization of biological activity in soils.

• Maintenance of long term soil health and minimization of soil erosion.

• Enhancing genetic and biological system and the surroundings.

• Raising of livestock with optimal living conditions for well -being and better health.

• Recycling of materials of plant and animal origins, nutrients to the soil.

• Minimization of the use of non-renewable resources.

Principles of organic farming

It aims to work as much as possible within a closed system, and draw upon local resources with a view to:

- maintain the long-term fertility of soils;
- avoid all forms of pollution that may result from agricultural techniques;
- produce foodstuffs of high nutritional quality and sufficient quantity;
- reduce the use of fossil energy in agricultural practice to a minimum;
- give livestock conditions of life that confirm to their physiological need; and
- make it possible for agricultural producers to earn a living through their work and develop their full human potential.

Various forms of Organic Agriculture

Bio-dynamic agriculture

Bio-dynamic agriculture is a method of farming that aims to treat the farm as a living system which interacts with the environment, to build healthy & living soil and to produce food that nourishes and vitalizes and helps to develop mankind. The underlying principle of biodynamics is making life-giving compost out of dead material. The methods are derived from the teachings of Rudolf Stainer and subsequent practitioners. These bio-dynamic preparations named BD-500 to BD-507 are not food for the plants, but they facilitate effective functioning of etheric forces. They are also not the usual compost starters, but can stimulate compost organisms in various ways. In short, they are biologically active dynamic preparations which help in harvesting the potential of astral and etheral powers for the benefit of the soil and various biological cycles in the soil. So far, 9 bio-dynamic preparations have been developed, named as formulations 500 to 508. Out of these, formulation-500 (cow horn compost) and formulation- 501 (horn-silica) are very popular and are being used by large number of organic farmers. Formulations-502 to 507 are compost enrichers and promoters, while formulation 508 is of prophylactic in nature and helps in control of fungal diseases.

Rishi krishi

Drawn from Vedas, the Rishi Krishi method of natural farming has been mastered by farmers of Maharashtra and Madhya Pradesh. In this method, all on-farm sources of nutrients including compost, cattle dung manure, green leaf manure and crop bio-mass for mulching are utilised to their best potential with continuous soil enrichment through the use of Rishi Krishi formulation known as "Amritpani" and virgin soil. A quantum of 15 kg of virgin rhizosperic soil collected from beneath the banyan tree (Ficus bengalensis) is spread over one acre and the soil is enriched with 200 lit Amritpani. It is prepared by mixing 250 g ghee into 10 kg of cow dung followed by 500 g honey and diluted with 200 lit of water. This formulation is utilized for seed treatment (beejsanskar), enrichment of soil (bhumisanskar) and foliar spray on plants (padapsanskar). For soil treatment it is need to be applied through irrigation water as fertigation. The system has been demonstrated on a wide range of crops i.e. fruits, vegetables, cereals, pulses, oilseeds, sugarcane and cotton.

Panchgavya krishi

Panchgavya is a special bio-enhancer prepared from five products - cow dung, urine, milk, curd and ghee. The cost of production of panchgavya is about Rs. 25-35 per lit. Panchgavya contains many useful micro-organisms such as fungi, bacteria, actinomycetes and various micronutrients. The formulation acts as a tonic enriching the soil, inducing plant vigour with quality production.

Natural farming

Natural farming that goes beyond organic farming, emphasizes on efficient use of on-farm biological resources and enrichment of soil with the use of Jivamruta (fermented microbial culture used for soil enrichment) to ensure high soil biological activity. Use of Bijamruta (fermented microbial culture used for soil enrichment) for seed/ planting material treatment and Jivamruta for soil treatment and foliar spray are important components of natural farming. Jivamruta has been found to be rich in various beneficial micro-organisms. One application in one acre requires 200 litres of jivamruta. It can be applied through irrigation water by flow, by drip or sprinkler or even by drenching of mulches spread over the field or under the tree basin.

Natu-eco farming

The Natu-eco farming system follows the principles of eco-system networking of nature. It goes beyond the broader concepts of organic or natural farming in both philosophy and practice. It offers an alternative to the commercial and agro-chemical intensive techniques of modern farming. Instead, the emphasis is on the simple harvest of sunlight through the critical application of scientific examination, experiments, and methods that are rooted in the neighbourhood resources. It depends on developing a thorough understanding of plant physiology, geometry of growth, fertility, and biochemistry. Natu-eco Farming emphasizes `Neighbourhood Resource Enrichment' by `Additive Regeneration' in preference to dependence on external commercial inputs.

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10. Integrated Farming System

Integrated farming system (IFS) is an entire complex of development, management and allocation of resources as well as decisions and activities, within an operational farm unit, or combinations of units, that result in agricultural production, processing and marketing of the products. IFS is a whole farm management approach that combines the ecological care of a diverse and healthy environment with the economic demands of agriculture to ensure a continuing supply of wholesome, and affordable food. It is a dynamic concept which must have the flexibility to be relevant on any farm, in any country, and it must always be receptive to change and technological advances. Above all, IFS is a practical way forward for agriculture that will benefit the society, not just those who practise it. IFS can be defined as a positive interaction of two or more components of different nature like crops, livestock, fishery, trees etc. within the farm to enhance productivity and profitability in a sustainable and environmentally friendly way. A judicious mix of two or more of these farm enterprises with advanced agronomic management tools may compliment the farm income together with help in recycling the farm residues. The selection of enterprises must be based on the cardinal principles of minimizing the competition and maximizing the complementarity between the enterprises. In general, farming system approach is based on the following objectives:

- Sustainable improvement of farm household systems involving rural communities
- Farm production system improvement through enhanced input efficiency
- Raising the family income
- Satisfying the basic needs of farm families
- Minimising the risk that comes from a single activity

Farming System Steps

Embedded in general principle is an essential five-step procedure for farming system research and adoption.

Classification: Classification is concerned with the geo-referenced identification of homogenous group of farmers with similar natural and socio-economic characteristics. It forms the basis for the setting of priorities and for targeting of research and extension to particular farm types.

Diagnosis: Diagnosis has to do with identifying the limiting factors, constraints and development opportunities of particular target farm types.

Experimentation and recommendation: Recommendations made from the knowledge, but in field situations which involves experimentation, either at the farm level or at the research station or at both, as a pre-requisite.

Implementation: Implementation commitment is usually found in farming systems programs directly through support to the extension agencies.

Evaluation: Evaluation is an important component and will lead to reappraisal, preferably on GPS location basis.

Farming Systems Typology

An analysis of benchmark data of 732 number of marginal households across the 30 NARP (National Agricultural Research Project) zones indicates existence of 38 types of farming systems. Of these, 47 per cent of households have adopted integration of crop + dairy, 11 per cent crop + dairy + goatery, 9 per cent crop + dairy + poultry systems and 6 per cent households have only crop component. In terms of number of components integrated by marginal households, 52 per cent households practise only two components while 7 per cent do only one component. The remaining 41 per cent households have components ranging from 3 to 5. There exists scope in the case of 59 per cent of marginal households for integration of allied enterprises for improving the per capita income. Though, the mean holding and family size of marginal households practising upto 2 or more components remains almost same (0.82 ha with 5 no's in 2 component category; and 0.84 ha with 5 no's in > 2 component category), the mean income level is much higher (Rs.1.61 lakh) in case of farms having more than 2 components (e.g., crop + dairy + goatery; crop + dairy + goatery + poultry; crop + dairy + goatery + poultry + fish etc.) in comparison to farms having 2 or less components (Rs.0.57 lakh only in crop alone, dairy alone, crop + dairy, crop + goatery etc.). Diversification of one and two component systems (crop alone, dairy alone, crop + dairy, crop + piggery, crop + poultry, crop + fisheries, crop + horticulture, crop + goatery, dairy + goatery) in the case of 59 per cent marginal household is essential to augment the per capita income.

Farm Diversification under Extreme Weather Situations

The national trends indicate that the non-vegetarian population is increasing over the years and this trend is likely to persist. Therefore, the demand for livestock and fishery products can be expected to increase in future. The traditional system of sole crop or cropping system as prevailing is not sufficient to meet the food and nutritional needs of small households. Diversification is considered to be a good alternative to improve system yield with enhanced profitability. The farming system approach takes into account the components of soil, water, crops, livestock, labour, capital, energy and other resources, with the farm family at the centre managing agricultural and related activities, and is highly location specific in nature. There are two approaches of farming systems, namely, holistic and innovative. The holistic approach deals with improving the productivity of existing components in totality, while innovative approach aims at improving the profitability of existing farming systems. However, a farm family functions within the limitations of its capacity and resources, socio-cultural setting etc. Since small farms are often vulnerable to natural vagaries like flood & drought, farming remains at risk. With increasing population and competing demand from industries and urbanisation, horizontal expansion of agricultural area is not possible. However, vertical expansion of small farms is possible by integrating appropriate farming system components and generating additional space and scope for activities, jobs and income.

Cropping System as a Tool to Enhance Farmers' income

Crops and cropping systems with differential behaviour and requirement provide newer challenge as well as opportunity for management to achieve higher productivity of input like water and nutrients.

More than 250 double cropping systems are followed throughout the country, amongst which 30 have been identified for irrigated conditions. These systems are rice-wheat, rice-rice, rice-gram, rice-mustard, rice-groundnut, rice-sorghum, pearl millet-gram, pearl millet-mustard, pearl millet-sorghum, cotton-wheat, cotton-gram, cotton-sorghum, cotton-safflower, cotton-groundnut, maize-wheat, maize-gram, sugarcane-wheat, soybeanwheat, sorghum-sorghum, groundnut-wheat, sorghum-groundnut, groundnut-rice, sorghumwheat, sorghum-gram, pigeon pea-sorghum, groundnut-groundnut, sorghum-rice, groundnutsorghum and soybean-gram. However, the systems that are considered to be the major contributors to national food basket are: rice (Oryza sativa L.)-wheat (Triticum aestivum L. emend. Fiori & Paol.) (10.5 million ha), rice-rice (5.9 million ha) and coarse grain (now renamed as nutri-cereals) based systems (10.8 million ha).

Specific Strategies for Sustainability of Integrated Farming Systems

Integrated farming systems for different zones

The concepts associated with IFS are practised by numerous farmers across the globe. A common characteristic of these systems is, that they invariably have a combination of crop and livestock enterprises and in some cases may include combinations of aquaculture and trees. Water storage structure will be central to all the farming activities. Suggested IFS for different zones in India (Jayanthi et al. 2002) are given below:

High altitude cold desert: Pastures with forestry, sheep, goats, rabbits, and yak along with limited crops like millets, wheat, barley, vegetables and fodders.

Arid and desert regions: Animal husbandry with camels, sheep and goat with moderate crop component involving pearl millet, wheat, pulses, oil seeds and fodders.

Western and Central Himalayas: Emphasis on horticultural crops with crops like maize, wheat, rice, pulses and fodders on terraces, pastures with forestry, poultry, sheep, goats, rabbits, and yak (at altitudes above 2,500 m amsl).

Eastern Himalayas: Horticultural crops with crops like maize, wheat, rice, pulses and pasture on terraces, pastures with forestry, sheep, goats, rabbits, yak and cold water fisheries at altitudes above 2000 m amsl. Maize, rice, french bean, ricebean, piggery, poultry, fishery and cole crops above 1000 m amsl. Rice, pulses, dairying, fish culture, vegetables in case of less than 1,000 m amsl.

Indo-Gangetic Plains: Intensive crop husbandry involving rice, maize, wheat, mustard and pulses and dairy.

Central and southern highlands: Crops such as millets, pulses, and cotton along with dairy cattle, sheep, goat and poultry.

Western Ghats: Plantation crops, rice and pulses as also livestock components including cattle, sheep and goats.

Delta and coastal plains: Rice and pulse crops along with fish and poultry.

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