# PRESIDENTIAL ADDRESS

## Sustaining Productivity in Rainfed Agriculture System

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Sustaining and enhancing agriculture productivity has been recognized as one of the key pathways of reducing and eliminating hunger, poverty and malnutrition. Agricultural sector is regarded as the key component of the economies of many developing nations, including India. Globally, agriculture accounts for a large share of GDP, it employs a significant proportion of the labour force, represents a major source of foreign exchange earnings, supplies bulk of basic food and provides subsistence and other income to the agriculture dependant growing population in the world. The strong linkages that agriculture has with other economic sectors representing both forward and backward linkages provide significant stimulus for growth and income generation. It is therefore obvious that significant progress in promoting economic growth, reducing poverty and enhancing food security cannot be achieved without developing a sound, effective and vibrant agriculture system that pays concurrent attention to the human potential and productive capacity of the agriculture sector. These in turn will ensure enhanced contribution of agriculture to the overall economic and social development. Therefore, a strong and effective food and agricultural system forms the primary pillar in the strategy of overall economic growth and development, and more specifically for the developing nations.

In the Indian Context, agriculture has played and will continue to play a dominant role in the growth of Indian economy. Agriculture represents the largest sector and contributes to around 20 percent of the GDP, the largest employer providing more than 60 percent of the jobs and is the prime contributor for enhancing the living standards for seventy percent of India's population particularly those living in the rural areas. The Government of India, taking into account these factors together with a strong determination and commitment to achieve self-sufficiency in food grains production, and with appropriate use of science, technology and policy option have ensured a high priority for agriculture sector in the successive development plans of the country. At the same time participation and involvement of large pool of farmers and farm workers, has enabled conversion of the research leads and trends to field level demonstration and heled achieving phenomenal productivity growth in agriculture sector. It is well established that Indian agriculture landscape is dominated by small and marginal farmers with limited land holdings. Therefore, the future of sustainable agriculture growth and food security in India will depend on the performance of small and marginal farmers, based on principles of sustainable production and evolving an effective value chain approach so as to ensure profitability at the individual farmer's level. The green revolution technologies promoted and implemented in 1970's resulted in enhanced productivity growth and this was singularly responsible for enabling the transition of the country to a food secure nation. The current cultivated land area of India is estimated to be about 184 million ha which produces 526 million mt of agricultural produce comprising food grains, pulses, oilseeds, cotton, jute, sugarcane, etc. With several innovative and participatory interventions undertaken during the last five decades, the food grain production of the country has increased by about fourfold.

However, the country is facing decline in growth in agriculture relative to other sectors. The agricultural sector grew at a rate of 2.7%, relative to about 10% growth in both the service and industry sector, in the recent times. Agricultural incomes are lower and the rate of growth is slower than incomes in other sectors. This has resulted in persistence of unacceptable levels of hunger, poverty and malnutrition among large section of India's population. Enhancing productivity of food grains during the first green revolution based on assured surface and ground water irrigation, energy inputs, deep alluvial soils, improved technologies, extension, mechanization, internalizing of social capital, rural infrastructure, marketing and credit has nearly reached its technological limits. Added to this, it is well established that small holding farmers face new challenges on integration of value chains, liberalization and globalization effects, market volatility and other risks and vulnerability, adaptation of climate change etc. (Thapa and Gaiha 2011).

**Rainfed Agriculture**

With increase completion of land available for cultivation, the need of the hour is to ensure productivity growth per unit area, given the area expansion for agriculture is hugely limited. This calls for enhancing productivity growths in large cultivated rainfed and dryland areas of the country. Rainfed agriculture (crop and animal husbandry) is now emerging as a major opportunity in raising overall agricultural growth. Globally 80 per cent of the agricultural land area is rainfed which generates 65 to 70 per cent staple foods. These areas account for 70 per cent of the population those inhabit these areas and with low and variable productivity there is inherent struggle for addressing their food security concerns.

India ranks first among the rainfed agricultural countries of the world in terms of both extent and value of produce. Even after achieving the full irrigation potential, nearly 50% of the net cultivated area still remains dependent on rainfall. Rain-fed agriculture supports nearly 40% of India's estimated population. Rainfed agriculture is practiced in two-thirds of the total cropped area and contributes to nearly 40 per cent of the national food basket. In the Indian context, rainfed agriculture productions systems accounts 55 per cent production of rice, 91 per cent coarse grains, 90 per cent pulses, 85 per cent oilseeds and 65 per cent cotton thereby demonstrating the importance of rainfed agriculture in the country. These regions also account for nearly 50 percent of the total rural workforce and 60 percent of livestock in the country. In these rainfed systems the annual rainfall varies for 400 mm to 1000 mm and given their uneven distribution and highly uncertain and erratic nature a significant fall in food production is often noticed.

Spanning several agro-ecological regions and spread across the length and breadth of the country, the rainfed areas represent areas with largest concentration of poverty and backwardness. Several efforts have been made during the past years employing science and technology as well as policy interventions with an effort to extend sustainable and appropriate technologies to these areas to enhance productivity of the rainfed farming systems. This, however, has not led significantly to achieve significant gains. At the same time resource degradation problems, such as loss in soil fertility, groundwater depletion, loss of biodiversity and increase in climate associated vulnerabilities have continued to exacerbate. Inadequate support for rainfed agriculture in terms of support price, availability of appropriate inputs, credit, market access and agricultural research and extension has compounded to the problems and has caused widespread desperation among farmers.

In addition to the crop based farming systems, livestock, fisheries and agroforestry systems plays a key role in maximizing the returns from the rainfed agriculture systems and provides significant opportunity for enhanced livelihoods to the rural communities. Livestock production forms a key component of rural livelihoods in rainfed regions. The rainfed areas account for almost 80 percent of all small ruminants in the country. It is estimated that 70% of agricultural GDP in arid areas and 40% in semi-arid areas come from rearing of livestock - accounting for around 55% of the total livestock population (450 million in 2009). Resilience in agriculture production systems is closely linked to livestock, which again is not recognised or given sufficient importance. Right from producing food to manure and draught power, livestock is truly a low-carbon system which is overlooked time and again. Over decades, this critical link has been broken due to the lack of understanding of the role of livestock in dryland farming systems through various policy approaches in the name of better economic development, which has resulted in serious unintended consequences. Livestock development is one of the important risk mitigation strategies and therefore there is a strong need to be support integrated livestock development through appropriate investments in water harvesting, soil conservation, regeneration of grasslands, assured access to common lands and availability of local germplasm as well as nurturing of local breeds coupled with policy support regimes.

The magnitude of the problems facing rainfed agriculture systems requires concerted efforts to ensure productivity gains through appropriate management and interventions. Rainfed agriculture will continue to play a central role in achieving food security and sustaining livelihoods of the resource poor marginal agricultural families. The challenge before us, therefore, is to continue developing management practices with the goal of increasing resilience of the rainfed farming systems.

**Impact of Climate Change**

Climate change is recognized as a major factor and important driver of ecological changes in the world's drylands. More frequent and intense extreme weather events in many dryland regions are projected to be a major consequence of global climate change. This will result in a significant increase in the extent of dryland and these are also likely to be affected by more intense and longer drought periods (IPCC 2007). Several projections in climate change trends for drylands indicate a upward trend in temperature leading to higher levels of evaporation from soils, crops, and water bodies, adding stresses to human and animal health. Several studies also indicate that there will be significant regional differences in the outcome of climate change. However, in general, it is projected that climate change will lead to a decrease in availability and quality of water (10% - 30% in the next 40 years), while extreme weather events such as droughts and floods will increase in number and/or intensity (Davies et al. 2012). IPCC projections also show that while majority of rainfed areas are likely to receive less rain, and result in extremely dry seasons in the coming years, countries in East Africa and Southern Asia are expected to receive higher levels of rain and a greater number of seasons and years that would be considered extremely wet (IPCC 2007; Trenberth and Jones 2007; Venkateswarlu et al. 2009).

Increasing temperatures are expected to add to water management problems by increasing water stress through additional loss of moisture from the soil. It is reported that by 2020 between 75 and 250 million people are likely to be exposed to increased water stress. The rain-fed agricultural yields could result in a reduction by up to 50% if production practices remain unchanged (IPCC 2007). Less frequent and more intense rainfall will impact the livelihood of communities by limiting their ability to properly plan for crop production, as well as by causing damage to crops and homes through flooding. Climate change will therefore result in reduced agricultural productivity in the drylands and this will have severe impacts on food security (Davies et al. 2012).These changes will place an additional pressure on an already fragile water situation, and further undermine the livelihoods of pastoralists and agro-pastoralists. The projected higher frequency of dry spells might encourage dryland farmers to increase water withdrawals for irrigation. It is also likely to drive changes in the water provision service through reduction of water quality and due to increased solubility of minerals with the temperature increase. Reduced river flows and increased water temperatures will lead to higher concentration of pollution and the growth of algal blooms, thereby adversely affecting the quality of water.

Climate change will also have adverse impacts on natural resources, food and nutrition security, human health, environment, economic activity and physical infrastructures (IISD 2007). UNDP report of 2007, points out that if global temperature increase of 3-4°C, changed run-off patterns and glacial melt could force an additional 1.8 billion people to live in a water-scarce environment by 2080 (UNDP 2007). Raworth (2008) observes that climate change is likely to worsen existing inequalities between women and men.

Based on several analysis and documentations, it is increasingly evident that climate factors are among the main determinants of agricultural production and there is significant concern about the impact of climate change and its variability on crop yields and production (Dinar et al. 1998; Cline 2007). Widely accepted predictions show that the on-going pattern of climate change will not only result in increased temperature regimes, but will also intensify the water cycle, reinforcing existing patterns of water scarcity and abundance thereby increasing the risk of droughts and floods. In addition, as the world warms, the risk of abrupt and large-scale changes in the climate system will rise – also the frequency and intensity of extreme events are likely to increase (Stern 2007).

Climate change projections for India indicate an overall increase in temperature by 2-4C by 2100 with no substantial change in precipitation quantity (Kavikumar 2011). Many studies have also shown that India is likely to witness one of the highest agricultural productivity losses in the world with the observed and projected climate change patterns. Most of the studies projected that the decreased yield in rainfed and dry land wheat and rice and loss in farm net revenue between 9 to 25 per cent for a temperature increase of 2 to 3.5c. Sinha and Swaminathan (1991) projected that an increase of 2 degree Celsius in temperature could decrease rice yield by about 0.75 tons/ha; and a 0.5 degree Celsius increase in winter temperature would reduce wheat yield by 0.45 ton/ha. Saseendran et al. (2000) showed that for every one degree rise in temperature the decline in rice yield would be about 6 percent. The impacts of climate change in drylands are likely to lead to still more people and larger areas of land being affected by water scarcity and the risk of declining crop yields – with the peoples of drylands in developing countries least able to adapt due to poverty.

Adoption of any strategy to increase agricultural production in drylands should include ways and means by which smallholders and other land users in drylands can adapt to cope with changing climate, including improved *in situ* water conservation, water harvesting and reduction in evaporation. Improved management of soil organic matter and conservation agriculture will not only help small holders and pastoralists adapt to climate change, but also involve changing traditional agricultural practices to increase storage of C in soils and on the soil surface, contributing to mitigating emissions of GHGs. Shifting agricultural zones, planting of drought resistant/fast maturing strains of crops and protection of local agro-biodiversity offer other ways by which smallholders and pastoralists can cope with the rapid rate of human-induced climate change.

Thomas et al. (2007) through a comprehensive analysis has summarized the following key impacts of climate change and climate variability on dryland agro-ecosystems. They include:

- Reductions in crop yields and agricultural productivity with subsequent threats to the food security of dryland countries.
- More erratic rainfall patterns and difficulties in determining timings of sowing and harvesting, and the selection of suitable crops with varying durations.
- Reduced availability of water in already water scarce regions coupled with extreme rainfall events with increased loss of water via run off, etc.
- Complete loss of crops resulting from extreme events such as prolonged droughts and torrential rains.
- Slow pervasive loss of soil fertility through loss of soil carbon from erosion and higher decomposition of soil organic matter as a result of higher temperatures, reduced soil moisture and moisture storage capacity.
- Lower livestock productivity from heat dissipation and reduced availability of feed and fodder.
- Alterations in pest and disease risks for both crops and animals (and humans) as temperatures increase.
- Changes in agro-ecologies and the threats from new invasive plant and animal species.
- Reduction of biodiversity of key crop species through habitat change and loss.
- Increased vulnerability of pastoralists because of erratic rangeland production, through shifts in rainfall patterns and loss of vegetative land cover.

These impacts will further constrain the livelihoods of rural communities in dry areas resulting in greater poverty, reduced livelihood opportunities and increased rates of migration. It is clear from the above that there is an urgent need to improve the management of natural resources (land, water and biodiversity) and the ability of populations to prepare for, and respond to, future climate conditions.

**Conservation Agriculture**

It has been widely recognized that currently practiced agricultural cultivation systems in dryland regions are severely affected by many emerging challenges and has been one of the main reasons for the poverty and food insecurity faced by smallholders in most parts of the rural regions in developing countries. Unsustainable agricultural practices has led to exhaustion and degradation of forest and soil resources which in turn has resulted in reduced land productivity, land degradation, and reduction in biodiversity. In order to address such problems facing dryland agriculture systems, Conservation agriculture has been evolved as a concept for addressing specific problems faced by smallholder farming systems in the tropics (Hobbs 2007; Hobbs et al. 2008) This concept is gaining popularity in the tropics and is being promoted by many national and international organizations. Initially introduced by the FAO (2008), CA is a concept for resource-efficient agricultural crop production based on an integrated management of soil, water and biological resources combined with external inputs. It is based on three principles that enhance biological processes above and below the ground (1) minimum or no mechanical soil disturbance; (2) permanent organic soil cover (consisting of a growing crop or a dead mulch of crop residues); and (3) diversified crop rotations. It is now widely recognized as a viable concept for sustainable agriculture due to its comprehensive benefits in economic, environmental and social terms. Its ability to increase grain yields to provide better economic performance and reduce production risks and to improve energy use efficiency has been well-documented.

Conservation agriculture is practiced on over 96 m ha area worldwide, most of it is in USA, Brazil, Argentina, Canada and Australia. CA became an acceptable practice for the farmers in these countries due to decades of research and extension and concerns of the farmers, scientists and the public on soil erosion. Due to the efforts of the Rice-Wheat Consortium and several institutions of the national agricultural research system, zero till technology has been introduced into India and neighboring countries and it is currently adopted by farmers in over 2 million ha largely in the Indo-Gangetic plains. World-wide, CA or no-till farming has spread mostly in the rainfed agriculture. However, in India its success is more in irrigated belt of the Indo-Gangetic plains. Considering the severe problems of land degradation due to runoff induced soil erosion, rainfed areas particularly in arid and semi-arid regions require the practice of CA more than the irrigated areas in order to ensure a sustainable production.

The production systems in rainfed arid and semi-arid areas are quite heterogeneous and diverse with respect to the management of land, water and cropping systems. The rainfed cropping systems are mostly single-cropped in the red soil areas, whereas in the black soil regions a second crop is taken on the residual moisture. Conservation tillage is a more appropriate strategy for rainfed production systems to promote CA. Conservation tillage is a generic term encompassing many different soil management practices. It is generally defined as ‘any tillage system that reduces loss of soil or water relative to conventional tillage; mostly a form of non-inversion tillage” and allows protective amount of residue mulch on the surface. Conservation tillage i) allows crop residues as surface mulch, ii) is effective in conserving soil and water, iii) maintains good soil structure and organic matter contents, iv) maintains desirably high and economic level of productivity, v) cut short the need for chemical amendments and pesticides, vi) preserves ecological stability and vii) minimizes the pollution of natural waters and environments (Lal 1989). In other words, the basic principles of conservation tillage and dryland agriculture are essentially same.

The success of conservation agriculture in rainfed areas depends on two critical elements, viz., residue retention on surface and weed control. Since residues are generally used as fodder in drylands, there is a need to determine the minimum residue that can be retained without affecting the crop-livestock system. Initially, emphasis may be given for crops whose residues are not used as fodder. More research are required on weed management under minimum tillage in a cropping system perspective. Identification of alternative sources of fodder for livestock is crucial to spare crop residue for conservation farming. Identification of critical thresholds of tillage for various rainfall, soil and cropping systems is essential so that the main objectives of rainwater conservation are not compromised. This will balance the need for conserving soil and capture rainwater in the profile. Farm implements are needed for seed and fertilizer placement simultaneously for ensuring optimum plant stand, early seedling vigour in rainfed crops under minimum tillage.

Experience from several experiments in the country showed that minimum or reduced tillage does not offer any advantage over conventional tillage in terms of grain yield without incorporation of surface residue. Leaving surface residue is the key to control runoff, soil erosion and hard setting in rainfed areas which are the key problems. In view of the shortage of residues in rainfed areas in arid and semi-arid regions, several alternative strategies have emerged for generation of residues either through in situ cultivation and incorporation as a cover crop or harvesting from perennial plants grown on bunds and adding the green leaves as manure cum mulching. Agroforestry and integrated cropping systems are other options where biomass generation can be integrated along with crop production. This indicates that the concept of CA has to be understood in a broader perspective in arid and semi-arid areas which includes an array of practices like reduced tillage, land treatments for water conservation, on-farm and off-farm biomass generation and agroforestry

Conservation agriculture in arid and semi-arid regions has to be understood in a broader perspective. It should involve both soil and water conservation methods mutually reinforcing each other. Conservation tillage appears more appropriate under rainfed agriculture than zero tillage. Tillage alone without residue retention may not be of much utility. Therefore, the real challenge lies in ways and means of sparing the crop residue for conservation farming and find out alternative strategies of meeting fodder requirements of livestock. CA practice has to be adopted holistically so that it minimizes soil loss, conserves water and controls weeds which are essential for success of crop production under rainfed conditions.

**Managing water resources**

Dryland ecosystems are characterised by frequent droughts, inherent low levels of biological productivity and low soil fertility. Drylands are among the world's most variable and unpredictable environments where rainfall is low and erratic. Combined with social, economic and political factors these environmental challenges make development of dryland regions complex and have led to political and economic marginalization of the communities dependent on rainfed agriculture. Effective and efficient use of water resources is essential to overcome the climate extremes that are central to unlocking the development potential of dryland areas (Nkonya et al. 2011).

Rain-fed agriculture will continue to play an important role in achieving for food security and sustainable agricultural development. Over the years, many approaches have been followed for water resources management and development in dryland areas those include development of groundwater resources for domestic and productive uses, capturing more surface water in the soil, soil and water conservation, and water harvesting. In the rainfed areas, rainwater is the main source of agriculture sector. Groundwater is an important source for irrigated agriculture as it generally furnishes reliable and flexible inputs of water. However, it has been established that the current use efficiency in crop production is low (30-45%). This establishes that groundwater is instrumental in managing risk and optimizing food production in the rainfed areas.

Depleting groundwater is a serious problem throughout Asia and more so in India as more than 22 million wells are operational in India supporting the economy. Many research institutions, government agencies and non-governmental organsiations have been promoting integrated watershed development as an effective strategy in the country for sustainable development of dry land areas. These programmes have shown that integrated watershed can become the growth engine for sustainable development of dry land areas by improving the performance of 2/3$^{rd}$ watersheds in the country (Wani et al. 2009). In most of the developed watersheds with concerted efforts to manage rainwater, the groundwater availability is improved not only in the watershed, but the downstream areas also benefited with increased groundwater recharge (Pathak et al. 2007). These interventions, while increased surface and groundwater availability with concomitant private and public investments, substantially contributed to increased incomes as well as improved livelihoods (Pathak et al. 2007). Increased water availability also had a positive impact in improving on productivity per unit of land and water as well as on welfare for the women, reduced drudgery, and protecting the environment. However in many of the cases where watershed approaches were practiced, no noticeable increased in productivity per unit of land and water were observed. This calls for a need to adopt more water use efficiency measures along with integrated management of water resources in watersheds for sustaining the development measures.

Effective management and utilization of groundwater are essential not only as a source of water for agriculture and other consumptive purposes, but also as a supplementary source of surface water flows, wetlands and wildlife habitats. This requires increased attention to monitoring, managing and addressing issues of both quality and quantity of water. Therefore, the focus on the development activities must be balanced by management mechanisms, enabling policy and institutional mechanisms to achieve a sustainable utilization of groundwater resources. The groundwater management rather than development is the major challenge facing the organizations/institutions dealing with water resources.

The vast potential of rain-fed areas remains untapped as the current farmers' crop yields are lower by two to five folds than the achievable yields with large yield gaps in the semi-arid and sub humid tropical regions (Falkanmark 2000; Rockstrom et al. 2007; Wani et al. 2008; Singh et al. 2009). It is vital to get people involved in water management for agriculture at local level by real participation and transparent decision making. Water use and management should become everyone's business. Its goal should be to maximize the production of food and the creation of jobs per unit of water. Enabling individuals and communities to understand their options for change, to choose from these options, to assume the responsibilities that these choices imply, and then to realize their choices could radically alter the way the world uses its limited water resources. The ultimate aim of water management is to optimize water use in such a way that all users have access to the water they need.

A successful initiative undertaken by M. S. Swaminathan Research Foundation (MSSRF) enunciated the concept of a Bio-industrial watershed, which is a new paradigm of prosperity where issues of ecology, economics, employment and equity are dealt in a holistic manner. The approach builds on the conventional system of watershed management through value addition and new markets with appropriate socio-economic and institutional support systems, owned and managed by the community. This programme have enabled for organically evolved grass-root institutions to help overcome constraints faced by small and marginal farmers and integrating them in value chains and in non-market interventions. The Watershed Communities have demonstrated that through the adoption of scientific methods of climate smart agricultural practices, water harvesting and sharing both employment and income security can be enhanced (MSSRF 2013).

The common approach in an integrated rainwater management in general address the links between investments and risk reduction, between rainwater management and multiple livelihood strategies, and between land, water, and crops. Many on field demonstrations and pilot scale initiatives have developed strategies for upgrading, including technologies and management in watershed areas and watershed development plans. However, the missing links for scaling-up and scaling-out are social and economic processes and institutions that can link to suitable policies as well as sustainability of the institutions (Wani et al. 2008). India has experienced important success from integrated watershed management, with local ownership combined with tangible economic benefits among rural households. However, several initiatives undertaken in the country do point out to the limitation of a compartmental approach. In many instances, the benefits of increased productivity were not realized to the desired extent, equity issues were not addressed, and community participation was not achieved, resulting in neglect of the various water-harvesting structures in the watersheds.

Therefore, an integrated on farm approach to land, water, and crop management is required. At the same time watershed development strategies are essential to increase yields in rainfed agriculture. Investments in upgrading rainfed agriculture need to consider the wide range of benefits that contribute to the overall resilience of rural communities

**Genetic Resources and adoption of Climate resilient crops**

The choice and selection of crops and varieties those could be use for dryland farming systems are essentially based on the land use capability, water availability, need for crop substitution, quantity and distribution of rainfall, soil depth and overall performance of selected crop varieties. In general depending on the agro climatic zones and the duration of growing period different cropping systems are generally practiced and adopted. Soil depth and available moisture enable farmers in determining the type of crops to be cultivated in a given region. In many instances, rainfed farmers adopts intercropping and mixed cropping as a possible option for crop diversification in regions having limited rain fall and effective growing season. Early planting and harvesting at physiological maturity of crops, less number of tillage operations, deep placement of fertilizers are among few crucial practiced that has been followed by farming communities in the dryland areas.

An important approach in selecting appropriate cropping practices is to ensure efficiency of water use following sound water-management practices and selecting cultivar those could perform well in the given scenario. This allows a considerable increase in productivity. Seasonal shifting, i.e. the development of crop varieties that can be grown in lower evaporative demand represents an additional challenge for breeders. In addition, productivity enhancement coupled with disease and pest resistance traits are taken into consideration choosing specific varities for cultivation in rainfed areas. Early and complete canopy establishment to shade the soil and reduce evaporative loss from the soil surface are among the practices that are being followed to enhance the water productivity of rainfed crops.

Farmers living in rain fed, semi-arid and dry areas are most vulnerable to vagaries of monsoon and climate. Scientists' predictions indicate that drought and low soil moisture conditions are likely to increase in the future and affect crop production. An alternative approach, particularly appropriate for subsistence smallholders in drylands is to resume growing the wider range of more traditional grain crops and legumes, which are better adapted to dry land conditions, not restricting themselves to the small range of varieties of crops which have become ubiquitous in the late twentieth century (wheat, barley, sorghum, maize) and legumes (chickpea and clovers).

Global food security has been increasingly narrowing down to a handful of crops. Over 50% of the global requirement for proteins and calories are met by just three grains, maize, wheat and rice. The narrowing base of global food security is limiting livelihood options for the rural poor, particularly in marginal and climate challenged areas. Specifically in the rainfed and dryland areas, there is a strong need to broaden the research and development focus to include in the cropping system a much wider range of crop species. This will allow selection and cultivation of crops those are suitable to the climatic conditions in the region as well as bring about productivity increases of the cropping systems. Many of these species, cultivated historically in the regions, occupy important niches as they are adapted to the high risk and fragile conditions where significant sections of the rural communities practice marginal farming. These crops have a comparative advantage in marginal lands where they have been selected to withstand stress conditions and contribute to sustainable production with low inputs at low cost of production. They also contribute to the diversity-richness as well as to the stability of agro-ecosystems.

One such group of crop which can be suitably utilized in dryland farming systems is the millets or nutri-cereals. Millet farming is a climate resilient framing system consisting of hardy crops suited to low and erratic rainfall and soil nutrient conditions. For example, since Early 1990s M.S. Swaminathan Research Foundation (MSSRF 2013) partnering with marginal farm families has been working for revitalization of millet cultivation to prevent erosion of millet crop diversity. Through participatory research and development programmes, Foundation has nurtured family farmers and formed them as groups and confederated them with the objective of conserving and enhancing values of Millets. Scouting of local growers, assessment of traditional knowledge, collection, characterization and evaluation of landraces, multiplication of high quality seeds, revitalization of seed storage and exchange systems through community seed banks, dissemination of best cultivation practices (including intercropping), provision of low cost processing machines accessible to communities, enhance capacities of communities in value addition, develop new products and brands owned by communities, strengthen community-based institutions and effectively link local production to peri-urban and local markets are among the concerted efforts being promoted by the Foundation. These initiatives have shown that local farmers in dryland and rainfed farming conditions can attain greater productivity and through appropriate market linkages can contribute to enhanced livelihoods for the poor and marginal tribal communities. Through policy advocacy it has also been possible to include such nutri-cereals in the public distribution system and its inclusion in the National Food Security Act of the Government of India.

Agricultural biodiversity and crop germplasm exploration for desirable traits that are of relevance to the dryland and water stressed environments requires priority attention in the coming days. Seeds, plants and plant parts exhibiting tolerance to enhanced temperature, reduced precipitation and other atmospheric stresses caused by climate change needs to collected and conserved to aid crop breeding research. Evaluation of crop germplasm including wild relatives, land races, extant varieties, and modern varieties and breeding stocks could help in unraveling traits than could prove more useful. Vast genetic resources, including natural variability and those conserved and evolved through continued efforts of the farming communities over the years could well prove to be the most important cost effective basic of identifying and selecting cultivars which will allow agriculture to adapt to various dimensions of climate change (Dawson et al. 2011). A large body of research during last two decades has shown that considerable progress has been made in the genetic dissection of flowering time, inflorescence architecture, temperature, and drought tolerance in model plant systems and by comparative genomics in crop plants (Jung and Müller 2009) and these research leads will provide significant impetus to the identification and development of location specific varieties and cultivars those could profitably be used in farming systems in the dryland areas.

**Integrated Farming Systems**

Declining trend in size of land holding in Indian context poses a serious challenge to the stability, sustainability, productivity and profitability of farming systems. In view of the decline in per capita availability of land from 0.5 ha in 1950-51 to 0.15 ha in 2000-01 and a projected further decline to less than 0.1 ha by 2020, it is essential to develop strategies and agricultural technologies that enable adequate employment and income generation, specifically for the small and marginal farmers who constitute more than 80% of the farming community, in the country. It is absolutely essential that we make shift from crop and cropping system based research to a farming systems based research those are carried out in a holistic manner for the sound management of available resources by small farmers. Under the gradual shrinking of land holding, it is necessary to integrate land based enterprises like fishery, poultry, duckery, apiary, field and horticultural crops, etc. within the bio-physical and socio-economic environment of the farmers to make farming more profitable and dependable. No single farm enterprise is likely to be able to sustain the small and marginal farmers without resorting to integrated farming systems (IFS) for the generation of adequate income and gainful employment year round. Farming systems approach, therefore, is a valuable approach to addressing the problems of sustainable economic growth for farming communities in India.

The farming system mode involving (i) in situ recycling of organic residues including farm wastes generated at the farm to reduce the dependency on external inputs (ii) decrease in cost of cultivation through enhance input use efficiency as well as engagement of family workforce, (iii) effective forward and backward linkages within the farm components (iv) upgrading of soil and water quality and increased diversity in the fields, (v) effective water management and productivity, (vi) nutritional security through soil-plant–animal- human chain, offers unique opportunities for improving productivity of the system (Parida 2012). Farming system provides a vast canvass of livelihood gathering, a better risk coping strategy, continuous flow of income and employment throughout the year for small landholders. Therefore, farming system represents an appropriate combination of farm enterprises, viz., cropping systems, horticulture, livestock, fishery, forestry, poultry and the means available to the farmer to raise them for profitability. It interacts adequately with environment without disclosing the ecological and socio-economic balance on one hand and attempts to meet to national goal on others.

Integration of various agricultural enterprises viz., cropping, animal husbandry, fishery, forestry etc. in the farming system has great potentialities in agricultural economy. These enterprises not only supplement the income of the farmers but also help in increasing the family labor employment throughout the year (Jayanthi et al. 2002; Singh et al. 1993 and Singh et al. 1997).
Channabasavanna et al (2009) reported that IFS consumed 36% higher water than the conventional system of rice-rice but the water use efficiency was 71% higher in IFS than conventional system. Jayanthi et al. (2000) indicated that integrated farming requires less water per unit of production than mono-cropping systems. Channabasavanna et al. (2009) also reported that integrated farming system requires only 1247 mm of water and on the other hand conventional farming system requires 2370 mm of water.

Based on the principle of enhancing natural biological processes above and below the ground, the integrated system that reduces erosion, increases crop yields, soil biological activity and nutrient recycling, intensifies land use, improving profits can therefore help reduce poverty and malnutrition and strengthen environmental sustainability. Therefore, a well designed integrated intensive farming system based on the traditional agriculture practices that are specific to a particular agro-ecosystem need to be developed based on marketing opportunities for the products of small farms. This system also provides an opportunity for the involvement and engagement of family labour and home consumption of diversified agricultural baskets.

**Breeding for Abiotic Stress**

One of the major bottlenecks in enhancing productivity of dryland farming system is identification and use of crop varieties with tolerance/ resistance to abiotic stresses. Breeding for traits such as temperature and drought tolerance and high yield in various important crops are needed to be undertaken on a priority basis so that the desired varieties are available when climate change effects are experienced. The genetic resources, especially land races and wild relatives of specific crops need to be explored, identified and characterised from areas where past climates mimicked the projected future climates and these potentially could serve as the starting genotypes for identification of novel genetic combinations for breeding crops for tolerance, maturity and yield attributes. Abiotic stresses have been recognized as the major causes that limit productivity of crop plants worldwide and specifically for the drylands. Plants have evolved and developed adaptation strategies both at physiological and molecular levels to respond to these adverse environmental conditions.

Recent development in the field of molecular biology and biotechnology offers uncommon opportunities to aid and improve classical plant breeding programs. Using modern approaches, it is now possible to analyse both the phenotype and the genotype of new/ existing varieties and predict the performance of specific new traits. The Marker Assisted Breeding approach enables successful transfer of several genes of interest, as well as Quantitative Trait Loci involved in polygenic traits, in many crop plants. The availability of molecular data, linked to pedigrees and phenotypic evaluation, now makes breeding analysis much easier. Development of genomics and associated DNA technologies is hugely increasing molecular understanding of important plant breeding traits. Advanced marker technologies, such as Single Nucleotide Polymorphisms or second-generation massive parallel DNA sequencing technologies offer new ways to improve efficiency and effectiveness of many breeding programmes.

A combination of conventional, molecular marker assisted, mutational and transgenic-breeding approaches will be required to develop crop cultivars which could provide better resistance to abiotic stress factors and provide opportunity for enhanced yield and income for the farming communities in the dryland regions. This would require research initiatives to understand the plant traits that are linked to adaptation.

Integration of various omics approaches for abiotic stress tolerance is being considered as a viable approach for developing breeding material for abiotic stress tolerance. It is well established that significant genomic advances have been made for abiotic stress tolerance in many crop species in terms of availability of molecular markers, QTL mapping, genome-wide association studies (GWAS), genomic selection (GS) strategies, and transcriptome profiling. Combining QTL mapping based on GWAS along with transcriptome profiling can provide a valuable approach to identify candidate genes involved in desired trait(s). It is being considered that detailed analysis of proteomics, metabolomics and ionomics and their integration with genomics approach will provide significant stimulus to future research focus to understand abiotic stress responses.

The primary considerations for developing traits to improve crop varieties for dryland environments must be correlated with yield characters in the target environment and should have greater heritability (Messina et al. 2011). The traits must show wide variability within the species and should have the ability to control yield over a time scale influencing either water use, water use efficiency and partitioning of biomass to grain (Venkateswarlu and Shankar 2007). Past and current researches in this area have focused on traits such as better root system with high biomass production. Abscisic acid (ABA) that plays a role in root-to-shoot and cellular signaling in drought stress and in regulation of growth and stomatal conductance, Osmotic adjustment (OA) that facilitates plants under drought to continue water absorption and maintenance of tissue turgor and contribute to higher photosynthetic rate and expansion growth are among the well studied areas for developing crops for drought tolerance. A number of studies focusing on identification of genes for accumulation of compatible solutes under drought stress have also been attempted. Researchers have also attempted to focus on genes those could contribute to stay green trait in several crops such as maize, rice and sorghum. Significant progress has also been made in using the variability in water use efficiency for breeding for drought tolerance (Tuberosa et al. 2007). Development of transgenics with an enhanced drought tolerance is another significant achievement and most of these genetically engineered plants are under advanced stages of testing in several crops. Several genes have been identified those express in response to drought stress, which include mainly (i) those, which encode products that directly protect cellular metabolism under water deficit and (ii) those regulating gene expression and signal transduction (Maheswari et al. 2010). Stress inducible genes identified so far include functional genes with protective roles in osmoprotection, Reactive Oxygen Scavenging, Ion transport, LEA and HSP. Regulatory genes imparting stress tolerance are those encoding signaling molecules such as phospolipid metabolism and various kinases (MAP, CDPKs, histidine kinases etc.) and several transcription factors such as DREB, ABRE etc (Ray et al. 2011; Prashath et al. 2007; Jitesh et al. 2006; Ganesan et al. 2012; Kumaresan et al. 2011; Mehta et al. 2005; George et al. 2006; Sairam and Tyagi 2004). Macromolecules, such as Heat Sock Proteins (HSPs) form the integral part of tolerance to high temperature in crops. HSPs are believed to be important for the protection of cells against heat injury both in basal thermo-tolerance as well as in acquired thermo tolerance responses. Many drought-adaptive traits may be useful under heat stress as well. Examples would include leaf glaucousness, awn photosynthesis and early maturity (Balkan and Genctan 2009; Salekdeh et al. 2009).

Application of molecular plant breeding is now focusing to discover new genes and their functions opening new avenues for basic plant biology research. For example, the work of M. S. Swaminathan Research Foundation (Prashant et al. 2007; Parida 2012) has demonstrated that genetic characters from across the sexual barriers can be mobilized to generate transgenic materials free from IPR. The work on identifying and isolating the genes from mangrove species and other naturally tolerant species such as *Prosopis juliflora* and transferring them into locally cultivated rice varieties have been successful in developing rice cultivars with tolerance to salinity, drought and quality enhancement.

Abiotic stresses such as drought, salinity and mineral toxicity negatively impact growth, development, and yield and seed quality of plants. Large losses of grain yields in plants occur as a result of pathogen attack, in particular during vulnerable stages of grain development and germination. Stress perception and plant response occurs *via* signal transduction pathways that regulate expression of several classes of stress responsive genes. Once the stress response pathways are defined efforts could be made for enhanced gene functions through reverse genetics approaches employing genetic engineering methods or novel alleles can be sought through germplasm screening or mutagenesis.

These offer alternatives to traditional breeding. The new knowledge acquired through research of abiotic and biotic stress tolerance mechanisms in plants will help in the application of stress responsive determinants and in engineering plants with enhanced tolerance to stress. Research efforts in breeding for abiotic stresses involving genomics and breeding approaches have been quite comprehensive and have contributed to enhanced knowledge base on these complex traits. Despite a wealth of information available, a large number of issues still remain to be understood in a broader perspective. A combination of approaches are therefore essential to understand the molecular basis of abiotic stress response and this will enable appropriate strategies for the development of stress-tolerant crop varieties suitable for dryland agriculture system.

**Conclusion**

In developing countries and countries dominated with small and marginal framers rainfed agriculture will continue to play crucial role in sustainable food security and enhanced livelihoods. The resilience in the face of adverse effects of climate change on small holder agriculture need to be developed that could bring in sustainability of farming systems. The challenge before us, therefore, is to continue to develop management practices that increase climate adaptability to varying climate scenario and built resilience of the farming communities and farming systems. Resilience to predicted 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. A holistic approach is needed to dryland farming wherein soil and water conservation practices are combined with integrated site specific nutrient management at the watershed level that can potentially increase sustainability and agricultural productivity. Reducing water loss is the main strategy in rainfed agriculture, and in this context, an integrated approach is essential. Continued research on abiotic stresses is of paramount importance that would enhance our understanding of plant responses to different stresses both at cellular and molecular levels. This in turn will enable identification of genetic factors multiple stress tolerance, identification of metabolic alterations and stress signaling pathways, metabolites and other genes controlling tolerance responses to multiple stresses. These research leads could then be used for breeding for more efficient and better adapted new crop cultivars for dry areas. Large scale screening and identification of genotypes of crop species and their wild relatives, based on farmers perception and knowledge systems with climate resilience will provide breeders genetic material those could be effectively used in developing suitable crop genotypes for cultivation in drylands. These initiatives along with desired policy level changes are essential to develop sound strategies for adaption to and mitigating the effect of the emerging climate change scenarios and can bring in productivity gains in the dryland framing systems in the country and enhance the food and nutrition security of the marginal and resource poor farm families inhabiting these challenging regions of the country and other parts of the world.

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