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Abiotic Stress Management with Focus on Drought, Food and Hailstorm

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Preface

Agriculture in India frequently impacted by abiotic constraints to some degree, are either natural or anthopogenic in nature. The complexity underlying management of these stresses involves single strategy approach or combination of strategies. Depending upon the level of severity for example water stress (salinity and aridity) and heat stress (drought and heat) either singly or in combination control the degree of adverse impacts in terms of decline in ability of soil to support the crop. Thus it is a formidable task to sustain food security challenged by constraints of declining soil quality, reduction in per person land area, water scarcities and extreme weather events. Therefore, it becomes imperative to develop appropriate coping strategies to protect our agriculture economy directly linked with livelihood security of our people.

Realizing the importance of this issue, the National Academy of Agricultural Sciences (NAAS) organized a Brainstorming Session (BSS) on “Abiotic Stress Management with Focus on Drought, Flood and Hailstorm” with Dr P.S. Minhas, as the Convener on May 23, 2016. The BSS was attended by eminent experts and deliberations were enriched by their presence.

The policy paper is an output of above deliberation, and I gratefully acknowledge the contribution of the convener, co-conveners, the participants, and reviewers. The editorial support extended by Dr K.K. Vass and Dr V.K. Bhatia is duly acknowledged. I am sure that this policy paper will be useful to Fellowship and other stakeholders.

(Panjab Singh)
President

Abiotic Stress Management with Focus on Drought, Flood and Hailstorm

1.0 PREAMBLE

Ensuring the food and nutritional security for about 1.6 billion of Indians by 2050 is a formidable task challenged by constraints such as deterioration of soil quality, drastic reduction in agricultural land per person, forecasted water scarcities in addition to predicted adverse and amplifying effects of climate change. The dimension of challenge further expands with a common expectation that food security must be achieved through sustainable approaches to enhance productivity of land and water resources. This concern emerges from ever increasing pressures for land from urban agglomerations that will not allow expansion of cultivable area beyond 141 million hectares (Mha) while much of it has environmental foot prints of technologies adopted to boost the crop production till recent past. The green revolution witnessed fertiliser-and-irrigation responsive high yielding varieties (HYV's) during the late sixties, but the greater share of future food production has to come from abiotic stressed areas prone to droughts, floods, hailstorms, which are common features in many parts of the country. These natural disasters cause widespread land degradation apart from heavy monetary losses and a serious setback to economic development of the country.

The agriculture in the country continues to be the most vulnerable to the vagaries of the "Extreme Weather Events". The growing incidence and severity of droughts, heavy rains, floods, hailstorms, heat waves and other extreme events in the recent decade have raised serious concerns about food security and livelihood options for the farming community. The year 2015 has emerged among the worst years in India, characterized by large number of westernly disturbance in the beginning, leading to the large scale devastation by hailstorms in northern, central and western parts. This has been followed by low summer rainfall and thereafter leading to severe drought in almost 350 districts of the country. Since the extreme events are increasing, there is dire need for actions towards a better understanding and characterizing the related issues.

In view of above consideration, a Brainstorming Session was organized by NAAS on May 23, 2016 at NASC, New Delhi under the convenership of Dr P.S. Minhas, Fellow and Former Director, ICAR-National Institute of Abiotic Stress Management, Baramati, Maharashtra.

2.0 PERDITION AND PROBLEM

Virtually all global agriculture is afflicted with abiotic constraints to some degree which are either natural or anthropogenic in origin. Complexity underlying management of these stresses, is that rather than singly, they commonly exist in combinations. Typical examples are that of salinity and aridity and also drought and heat stress that are known to occur together. Often depending upon the level of severity, these control the degree of adverse impacts in terms of decline in ability of the soils to support plants and animals. This obviously occurs due to reduction in the capacity to retain and supply adequate moisture and nutrients required for optimal growth of crops.

2.1 Edaphic Stresses

The major edaphic stresses include: chemical (nutrient deficiencies, excess of soluble salts, salinity, alkalinity, low pH/ acid sulphate conditions, high P and anion retention; calcareous or gypseous conditions, low redox, chemical contaminants-geogenic and xenobiotic), physical (high susceptibility to erosion; steep slopes; shallow soils; surface crusting and sealing; low water-holding capacity; impeded drainage; low structural stability; root restricting layer; high swell/ shrink potential) and biological (low or high organic contents). So far the concepts of edaphic stresses have been generally applied and the knowledge on their assessment and management is limited and diverse. Still there are many perceptions on how these vary over time and space. But the edaphic stresses often lead to situation where cost-effective production is not feasible under given set of site conditions and cultivation practices. Therefore, based upon the soil's edaphic limitations which lead to the agricultural production marginality, the soils are often classified as degraded, marginal, under-utilized lands, unproductive, wastelands etc. Usually the edaphic constraints are used as synonymous to these terms and antonymous to the soil quality. Though authenticity and accuracy of various estimates is questionable but these bring out that about 2 billion ha (23% of the world's usable land) is affected by degradation resulting in edaphic stresses to a degree sufficient enough to reduce their productivity (Friedrich et al., 2008).

Similarly the overall land degradation figures furnished by various agencies have also been at variance in India, which is ascribed to differences in approaches, methodologies and criteria for assessment. The datasets on land degradation/ wasteland available with different agencies were harmonized on GIS environment for the whole country in 2009 (ICAR & NAAS, 2010). As per these estimates, 120.72 Mha constituting 36.5 per cent of total geographical area are degraded due to soil erosion, salinity/alkalinity/acidity, water logging, and some other complex problems. The soil erosion due to water and wind is the major cause of soil degradation (94.97 Mha) followed by chemical degradation (24.68 Mha). In the context of chemical soil degradation, the loss of soil fertility is usually taken to mean nutrient deficiencies and loss of organic matter, though deterioration due to acidity; salinity/ alkalinity, pollutants etc. are also involved. Nutrient mining has increased with intensive cultivation during post Green Revolution period and situation has been compounded with low inherent fertility of most of Indian soils. Moreover, the soil organic carbon (SOC) that governs soil productivity is already inherently low in Indian soils and same is being further negatively impacted with nutrient mining, imbalanced use of fertilizers, removal and burning of crop residues, reduced use of FYM and other organics etc. Further, the soils are getting polluted in some areas with toxic elements from geo-genic sources or from sewage water, industrial effluents, urban solid wastes and fertilizers etc. About 6.73 Mha land area is afflicted by the salinity/alkalinity while about 17.93 Mha of acidic soils (pH < 5.5) suffer from deficiencies as well as toxicities of certain nutrients and have very low productivity. The productivity of 18.3 Mha basaltic terrains in peninsular India is limited by shallowness of soils (Painuli et al., 2002). About 12 Mha land area is waterlogged and floods prone, where productivity of arable crops gets severely affected. Similarly the physical degradations processes like crust formation and soil hardening, structural decline and sub-surface compaction together affect 31.8 Mha and have negative impacts on crop yields. Thus, low organic carbon and thereby nutrient deficiencies are the most limiting factors towards crop productivity followed by shallowness of soils.

By using the 25 stresses as the key factors, nine "Inherent Land Quality Classes", that imply land quality prior to human interference, were established (Friedrich et al., 2008), with Class I having the most, and Class IX the least favorable attributes. A similar attempt was made by (Minhas and Obi-Reddy, 2017) to equate and estimate areas under different stress classes in India. Though the estimates need to be harmonized with respect to overlaps e.g. the most of the sandy terrains and dunes of north-west parts fall under aridic zone with continuous moisture stress, low water and nutrient holding etc. Moreover the salinity and aridity go together. Anyhow half the soils fall under serious limitations (i.e., areas grouped in Classes V and VI (40-60% risk) and the rest is equally distributed under severe (> 60%) and moderate (<40%) limitations. Low organic carbon and thereby nutrient deficiencies are the most limiting factors followed by shallowness of soils in peninsular India. Among the processes of degradation, water erosivity is afflicting the most land area (about 25% of the geographic area) followed by aridity (13%). Even the conservative estimates are, that the edaphic stresses cause about two-third loss of agricultural production and are threatening the sustainability of food and nutritional security of the country. Except few, the processes leading to these constraints are generally insidious and show up only gradually as the problem becomes more severe to cause yield declines. Farmers may ultimately be forced to either shift to less remunerative crops or in extreme cases soils can turn unfit for agriculture. The situation is further going to worsen with global warming when edaphic stressors are expected to show greater impacts. Thus development and promoting strategies to minimize the edaphic constraints and improving the quality and health of soils are fundamental to sustained agriculture and food security of the country. Such measures to alleviate even about half the edaphic stresses can raise the food production level to about two-fold.

2.2 Climate Variability Impacts

There is increasing evidence that climate-change related elements are contributing to accelerated resource degradation and the resultant abiotic stresses. The average increase in temperature in India during 1901 and 2005 has been 0.51 ^{0}C compared to 0.74^{0}C at global level (Chaturvedi et al., 2012). The resultant heat stress would have serious impact on agriculture, water resources, forests, fisheries, environment and energy sectors. In a simulation study on the impact of high temperature on irrigated wheat in north India indicated that grain yield can decrease by 17% if the temperature increased by 2^{0}C (Aggarwal, 2008).

Monthly rainfall data for all the 36 sub-divisions of the country indicate that it is exhibiting an increasing trend in June and August while the July rainfall showed a decreasing trend (Rama Rao et al., 2013). Analysis of long-term rainfall data for over 1100 stations across India show pockets of deficit rainfall over eastern Madhya Pradesh, Chhatisgarh and North-east region in Central and Eastern India, especially around Jharkhand and Chhatisgarh. In contrast, trends indicate increase in rainfall (10-12%) along the west coast, northern Andhra Pradesh and parts of NW India. In the Southern Peninsular region, a shift in peak monthly rainfall by 20-25 days from September to October is recorded. Further, the intensification of hydrological cycle due to global warming may result in more intense rains, frequent floods and droughts, shifting of rainy season towards winter and significant reduction in mass of glaciers causing more flow in the initial few decades but substantially reduced flow thereafter. Analysis of rainfall data with intensities of 10, 100 and >100 mm revealed that in the recent period, the frequency of rain events of more than 100 mm intensity have increased while the frequency of moderate events over central India has significantly decreased during 1951-2000 (Krishna Kumar et al., 2011). Thus high intensity storms would cause high erosion losses leading to severe land degradation problems.

2.3 Extreme Weather Events

Occurrence of floods, droughts, hailstorms and other climatological extremes is a common feature in many parts of the country. However, their incidence has witnessed an upward trend in the recent decade. These are briefed below:

2.3.1 Droughts

Drought has been a recurring feature of agriculture in India (Srinvasarao et al., 2015). Drought occurs over an extended period of time and space, making it unpredictable and the losses are not quantifiable easily. But the impact of drought on the techno-economic and socio-economic aspects of agricultural development and growth of the nation is severe and results in huge production and monetary losses. During the period 1900–2014, the number of occasions on which large Indian population got affected from drought was more than any other natural disaster. In the past, India experienced 24 large-scale droughts with increasing frequencies during the periods 1891–1920, 1965–90 and 1999–2012. Long-term rainfall data for India indicate that rainfed areas experience 3–4 drought years in every 10-year period. Of these, two to three are in moderate and one or two are of severe intensity. Occurrence of drought is very frequent in the meteorological subdivisions like West Rajasthan, Tamil Nadu, Jammu and Kashmir, and Telangana. The risk involved in successful cultivation of crops depends on the nature of drought (chronic and contingent), its duration, frequency and timing of occurrence within the season and the soil type.

Loss of assets in the form of crop and livestock (mortality, loss in productivity, health, and fertility) is a common feature following severe drought. In addition, productive capital damage as a direct consequence of water shortage or related power cuts; agro-based industries, domestic water availability, health, household activities, etc. are also severely affected. Analysis of six most severe droughts during 1877–2005 in India indicated that the rainfall deficit varied from –19% to –29.1%, whereas the geographical area affected ranged from 49% to 63%. Rainfall deficiency in the month of July (crop sowing period) was more critical for agricultural production and the deficit was highest during the drought of 2002 with the most severe economic losses (Samra, 2006). For example, the impact of 2002 drought was such that the water storage in 70 major reservoirs was 33% less than the average of previous 10 years, 22 Mha area was not sown and 47 Mha of the sown area was subsequently damaged and food grain production was reduced by 29 million tons (mt), and agricultural GDP was reduced by 3.1% (DAC, 2004). In 2009, the whole country (about 352 districts were declared drought hit) suffered from the effects of a severe drought which led to immense agricultural loss and affected the life and living of about 400 million people. The seasonal (June–September) mean rainfall recorded a deficit of 22% of its long-term mean. The food grain loss was about 15 mt. Similarly, the year 2012 was unique in experiencing a delayed onset and deficient monsoon in the initial phase, followed by heavy rainfall, cloud burst, extended withdrawal, and floods in various parts of India. About 5.68 Mha of area was not sown during *kharif* (June–September) with a loss of about 12.76 mt of *kharif* food grain production. Distress sale of animals were reported especially from Karnataka. In 2014–15, the country's food grain production is estimated to have declined by 4.66% to 252.68 mt due to poor monsoon (12% deficit rainfall) and unseasonal rains in February–March (Birthal et al., 2014).

Very high incidence of drought (>20%) is frequently observed in a few districts in Rajasthan and Gujarat. The incidence is relatively low in the Western Ghats and eastern and north-eastern India. The incidence of drought, measured in terms of occurrence of number of severe droughts per 100 years, is likely to increase in a few districts in Rajasthan, Madhya Pradesh, Chhattisgarh, Maharashtra, Bihar, eastern Uttar Pradesh, north eastern states, Karnataka, Tamil Nadu, Jammu and Kashmir, and in a majority of districts in Kerala. Some districts in eastern Rajasthan, Punjab, Uttar Pradesh, Andhra Pradesh, and Karnataka are projected to experience drought, less frequently (Rama Rao et al., 2013).

Drought prone areas are more vulnerable to land degradation. In a good or normal rainfall year, they substantially contribute to agriculture production particularly for groundnut, millets and sorghum where they account for one-third to one-fourth of the total national production. Similarly, one-sixth to one-tenth of other important crops like ragi, maize and cotton and 12% of rice production is realized from these areas besides sizeable contribution to the production of pulses and oilseeds (Srinivasarao and Gopinath, 2016).

2.3.2 Floods

India's vulnerability to floods can be visualized from the flood damages at current prices during 1953–2010 of Rs. 8.12 trillion. Floods occur in almost all river basins in India. The main causes of floods are heavy rainfall, inadequate capacity of rivers to carry the high flood discharge, and inadequate drainage to carry away the rainwater quickly to streams/ rivers. Ice jams or landslides blocking streams, and cyclones also cause floods. Flash floods occur due to high rate of water flow as also due to poor permeability of the soil. Most of the floods occur during the monsoon period and are usually associated with tropical storms or depressions and active monsoon conditions (Sikka et al., 2016).

About 60% of total flood prone area in the country lies in Indo-Gangetic basin, which supports 40% of India's population with 60 Mha of cultivable land. The incidence of floods is not restricted to humid and sub-humid regions but have also caused extensive damage in the desert districts of Rajasthan and Gujarat in the recent years. Average flood damage to houses, crops and public utilities during 1953-02 has been estimated at Rs. 13.76 billion affecting an area of 7.38 Mha and a population of 32.97 million. Human and cattle loss has been put at 1560 and 91,555 numbers respectively, affecting 3.48 Mha of cropped area in the country. The maximum damage to area, human and livestock population, crops and public utilities occurred during the years 1977, 1978, 1979, 1988 and 1998. Twenty-three of the 36 states and union territories in the country are subject to floods. About 49.8 Mha land (15.2% of geographical area) is flood prone and about 10–12 Mha is actually flooded each year.

In the period between October 2013 and October 2014, floods in three states—Odisha, Assam, and Jammu and Kashmir—have affected more than 19.3 million people. Over 62,000 people have been affected by floods in Gujarat and Bihar in the same period. Paddy crop on 31,000 ha and other crops on 7,000 ha were damaged in 509 villages of Odisha. The floods in Kashmir, its worst ever in four decades, affected about 5 million people and caused an estimated loss of Rs. 54–57 billion to the state's economy. More than 20% of geographical area is prone to incidence of floods in a majority of districts in Punjab, Haryana, Uttar Pradesh, Bihar, West Bengal and in a few districts in north eastern states, Gujarat, Andhra Pradesh, Kerala, and Odisha. In coastal area the issue of flood has additional dimension due to intrusion by sea water.

2.3.3 Hailstorms

The increased incidences of hailstorms are causing widespread damage and loss to agricultural sector in sub-tropical parts of India. The damage is determined by the size ranges and the number of hailstorms that fall per unit area during a hail fall, wind force during the event and the property of the target (Bal et al., 2014). The extent of crop-hail damages also varies depending on the time of occurrence of hail during the growing season of a given crop. Fruit crops in upper Himalayas and rabi crops in north and central India are especially vulnerable as peak hailstorm activity often coincides with the advanced stages of crop growth. Hail formation requires atmosphere with strong upward motion of air and/or lowered heights of freezing level. In the middle latitudes, hailstorms are formed near the interior of continents while in tropics, they tend to be confined to higher levels of freezing (Rao et al., 2014). Out of 597 hailstorms in India, 153 yielded hails of 3 cm or greater in size. These events killed 250 persons and caused extensive damage to winter wheat crops. A cropped area of 0.46 Mha in 1994–95, 0.74 Mha in 1995–96, 1.2 Mha in 1997–98, and 2.9 Mha in 1998–99 in the states of Haryana, Punjab, Himachal Pradesh, Rajasthan, Uttar Pradesh, Maharashtra, and Andhra Pradesh was badly hit by hailstorms. In January 2002, many parts of Karnataka state were lashed by hailstorm and the estimated loss suffered by the farming community was around Rs. 275 million. In the state of Odisha, about 375 villages were affected due to hailstorms and whirlwinds in 2005. In Andhra Pradesh, hailstorm caused a huge damage to 77,000 ha of agricultural fields in 2005–06. The state of Madhya Pradesh was badly hit during March 2006 by heavy hailstorm causing widespread damage to standing winter crops. In March 2007, heavy rains accompanied by hailstorm damaged wheat, sugarcane, and oilseed crops in thousands of hectares in Punjab and Haryana. The estimated loss ran into billions of rupees and crops were severely damaged over 50,000 ha of land (Bhardwaj et al., 2007). In 2014, a series of hailstorms struck Central India during February 26th to March 15th. The loss due to the hailstorms is estimated between Rs. 100 and 150 billion, with all fields and orchard crops put together. Apart from crop damage, loss to livestock and infrastructure was also substantial (Rao et al., 2014). The authors used hailstorm data of 38 years for the period 1972–2011 (excluding 1977 and 1984, for which data are not available) for mapping areas prone to frequent hailstorms. More than 61% of the districts experienced at least one hail event in a 38-year period. Highest frequency is noticed over districts in the northern parts of Vidharbha region of Maharashtra that are adjoining the state of Madhya Pradesh. Frequent occurrences of such events in recent times due to climate change; have necessitated the need for strong institutional arrangements to combat such losses.

3.0 COPING STRATEGIES

The strategies those help to minimize the impacts include mitigation and adaptation through novel technologies in crop production and management under these events, sound governmental policy and political will for post-disaster recovery and reconstruction for improving adaptive capacity (NRAA, 2013). Thus development and promoting strategies to minimize the impacts of abiotic constraints and improving the quality and health of soils are fundamental to sustained agriculture and food security of the country. There are essentially three coping strategies for farmland compromised by abiotic stresses i.e. mitigation of constraints by means of improved methods of soil and land management, adaptation by growing crops that are tolerant to the constraints or genetically improve tolerance through conventional and modern molecular tools and find market driven alternative uses for the land.

In fact the options to be adopted are defined by the typical edaphic factors and available opportunities (NIASM, 2015). Changes in crop land use, crop diversification and measures to improve soil quality such as soil fertility management, conservation agriculture and efficient water management through modern irrigation and drainage methods are needed. Approaches like agro-forestry and integrated crop-livestock systems can further positively influence biodiversity, soil health and ecosystem services. Stacking of functional genes by genetic engineering can increase the abiotic stress tolerance in plants. However, these approaches have not been entirely successful as far as consistency, reliability and visible effects at field levels are concerned, because of multigenic and complex nature of abiotic stress tolerance. However, increasing knowledge of resistance mechanisms and the genes governing these mechanisms has potential to enhance the progress in development of stress tolerant crops. Development of stress tolerant transgenics needs much more understanding of plant stress-tolerance and gene-regulatory network systems. The available tools, technologies and approaches need to be integrated and augmented to develop the appropriate varieties / germplasm that can withstand such stresses.

4.0 POLICY OPTIONS

In order to alleviate the effects of multiple stressors, a holistic multidisciplinary approach to build up systems perspectives is need of the hour to get best combination of technologies for a particular agro-ecosystem that are often featured by multiple stressors and that needs to be defined with greater precision. Therefore, it is of national importance not only to initiate high quality research programs, which are of global standards in this important area, but also to make efforts to capture, synthesize, adopt, and apply the technological advances taking place within and outside the country. Some of the emerging policy recommendations include:

4.1 For Planners and Line Departments

The extreme events prone areas to be identified and decentralised and anticipatory measures or strategies be prepared for insulating the farmers from such location specific events. Preparedness and recovery plans should form a part of strategy to overcome the impact of financial and asset losses. These are elaborated as under :

- Drought impact assessment and early warning are some of the yet to be operationalized issues to take drought monitoring endeavor to next level and to achieve climate resilient rainfed agriculture. The active involvement of remote sensing tools, drought experts and farming communities is highly essential for enhanced outreach and effective utilization of drought information. Digital technologies should add new dimension in implementing these approaches.
- Since labour shortage occur concurrently to extreme weather events, establishment of large number of custom hiring centres can provide access to the farm machinery and implement several resilient technologies.
- Capacity building of the sectoral departments like agriculture, animal husbandry, rural development and disaster management board/department, for community based comprehensive actions.
- Establishing weather risk, management and mitigation centres for good Weather code, Drought code, Flood code etc. for anticipatory measures and adaptation at pachayat/ village level e.g. implementation of contingency plans, providing seeds of alternate crops etc.
- Implementation of 'Weather Index Based Insurance Schemes' and associating these to credit linked insurance. Various levels and types of policies are to be made available at affordable premium rates.

4.2 For Farmers

These include the adoption of crop and resource based approaches and also to follow the 'Early Warning Systems' as short terms measures (contingency crop plans, etc.), medium term (planning natural resources) and long term (mostly socio-economic) measures.

- Shift to conservation agriculture, farm-level rainwater harvesting structures, integrated nutrient management modules, resilient crops (suitable varieties/ planting time e.g. drought tolerant/ short duration etc.).
- Since livestock contributes a major chunk in farm income, meeting their fodder requirement during extreme weather events is a tough task, alternate cropping strategies and establishment of fodder banks should be promoted.

- Large scale adoption of the new intercropping and novel farming system combinations including livestock and fisheries, which can withstand extreme weather events, can be economically viable.
- Adoption of real time contingency plans that have been successfully demonstrated.
- Maintenance of community level seed banks with buffer stocks of seed materials of diverse crops and their control by organised farmer's groups.

4.3 For Researchers

- Prioritise the focus for research on management of drought, flood and hailstorm and distribution of responsibilities related to research activities that are overlapping.
- Enhance investment on research addressing the issue related to management of abiotic stresses.
- Develop mechanisms to enhance synergies among the institutes focusing on abiotic stresses.
- Mitigation and adaptation options for abiotic stresses specifically in degraded lands brought into cultivation, to be explored and documented for immediate use by farmers.
- Augmentation of academic activities to impart training/guidelines for successful agricultural entrepreneurship in abiotic stressed environment.
- Promoting Public-Private Partnerships (PPP) to accelerate the research and academic activities for abiotic stress management.
- Developing clear guidelines for risk and crisis management related to extreme weather events especially hailstorm is one of the major issue for policy makers; the data collection for these events needs to be optimized for strengthening predictions of occurrence as well as for post-hailstorm management of crops.

5.0 ACTION POINTS FOR IMPLEMENTING

- The present abiotic stress/disaster management policies are skewed toward crisis management with possible solution in relief measures, employment opportunities etc. till the next crisis event. The policies should promote location specific measures to prevent the permanent damage to agro-ecosystem.
- It is necessary to have a real as well as virtual web based platform for interface among agricultural officers, policy makers, farmers and scientists to build a larger database and to derive appropriate decision for development and implementation of technologies for abiotic stresses.

- Establishing “Risk Management and Mitigation Centre” at the block level which should work in close coordination with line departments.
- Despite substantial progress in development of new cultivars for favourable areas, crop improvement approaches have not made as much impact in drought/flood prone areas as those in favourable environments. This is largely due to lesser investments both in infrastructure and human resources for developing dual-purpose crops and cultivars for stress-prone regions.
- Priority diversification of farming enterprise through Integrated Farming Systems to provide for life saving returns and quick recovery in case of extreme weather events.
- There should be provisions to promote exchange of germplasm and promising technologies in pipeline for management of abiotic stresses mentioned above through research collaboration with transparency in utility of material and benefits for the country.
- Priorities given to resilience to climate change at national level has now provided significant support for identification of traits and genes relevant to stress tolerance in the events of drought, flood, salinity and nutrient stress. State-of-the art facilities for applying genomics approach have been created but are not sufficiently complemented by providing adequate capacity building. Thereby capacity building is the need of the hour for the effective utilisation of these facilities.
- Molecular marker approaches have been found to be promising for drought and submergence tolerance, however, advantage of transgenic approaches and several technologies that have been patented so far are yet to be realized for improving food and fodder crops. There should be Freedom To Operate (FTO) confined field trials that can facilitate validation of these technologies at the earliest.
- Innovative technologies for mitigating the abiotic stressors are rarely adopted despite clear demonstration of benefit e.g. for dryland systems. However, some of the technologies have been successfully demonstrated as real time contingencies. Adoption of such technologies needs policy support.
- Policy initiatives in relation to access to banking, micro-credit/insurance services before, during and after a disaster event, access to communication and information services is imperative for managing post-event scenarios of extreme weather.
- Enhanced optimism among farmers is critical to promote technologies for stress prone areas- this can come from streamlining and strengthening the channels of technology transfers and supports to reinforce the demonstrated technology.
- The common lands including forest land can be utilized for demonstrating the technologies like fodder production taking into consideration probabilities of rainfall deficit. They can serve as *in situ* fodder banks particularly in drought prone areas.

- The efforts must be boosted in developing drought resistant seeds and cost-effective dry-land farming techniques. In addition, rain water harvesting techniques, moisture conservation and inter-cropping are imperative to stabilize and improve the production in the dry-land areas.
- Appropriate pricing of water, electricity and fertilizer and rationalization of minimum support prices would augment resources available for investment in irrigation, rural infrastructure and prevention of soil degradation.
- Funding policies should promote collective efforts by research institutes for addressing different components of abiotic stress management taking into consideration magnitude of the task and complexities underlying the occurrence, nature and management of these stresses.
- The choice between "risk aversion" and "loss aversion" is critical for farmer who prefers high yielding local genotypes over drought tolerant one to avoid loss aversion. Policies to support risks should be appropriately combined with technologies.
- While drought proofing tools are evolved and being propagated after persistent efforts, farmers are not appropriately covered for risks due to highly unpredictable events like hailstorm. High value agricultural enterprises like export oriented fruit orchard to be supported for adopting protective structures that cost high at initial stage which small farmers cannot afford. In addition, post harvest technology promotions should consider alternative use of damaged produce at the harvest.

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