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Resilient rainfed technologies for drought mitigation and sustainable food security

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सार – यद्यपि सूखा बहुत से सामान्य लक्षणों में से एक है, जो वर्षा पर निर्भर कृषि को प्रभावित करता है, इसे जलवायविक चरम घटना मानने की जरूरत है जिससे निपटने के लिए विभिन्न प्रकार की उपशमन नीतियों की आवश्यकता है। फसलों की खेती बाड़ी सफलतापूर्वक करने में शामिल जाखिम सूखा (तीव्र एवं आकस्मिक) की प्रकृति, इसकी संभावित अवधि एवं मौसम के अंतर्गत इस घटनाकी बारंबारता पर निर्भर करती है। भविष्य में इस प्रकार की असाधारण परिस्थितियों में अधिक वृद्धि होने की संभावना है। सूखे के प्रसरण के दौरान तीव्रता या विस्तारण में वृद्धि से अक्सर खादयान उत्पादन में उल्लेखनीय रूप से गिरावट देखी गई है। सूखा न केवल फार्म स्तर पर खादयान उत्पादन को बल्कि राष्ट्रीय अर्थव्यवस्था एवं समग्र खादयान्न सुरक्षा को भी प्रभावित करता है। विभिन्न सूखे की स्थितियों से जूझने के लिए स्थान विशेष की वर्षा आधारित प्रौद्योगिकियॉ उपलब्ध हैं। भारत में वर्षा आधारित कृषि से संबंधित मृदा एवं वर्षा जल संरक्षण एवं सूखा परीक्षण पर काफी अनुसंधान कार्य किए गए हैं। सूखा प्रशमन के लिए प्रमुख प्रौद्योगिकियॉ हैं:- आकस्मिक फसल योजनाएँ, पूर्ण छिड़काव तथा समाकलित कृषि प्रणालियों सहित उस स्थान की नमी संरक्षण, वर्षा जल की सिंचाई एवं पुन:चक्रण लोचदार फसल एवं फसल प्रणालियॉ। जबकि क्षेत्रीय स्तर पर सूखे से निपटने की तैयारी एवं आकस्मिक उपायों का वास्तविक समय पर कार्यान्वयन करने के लिए मजबूत सरकारी नीति एंव विभिन्न संस्थानों के बीच अभिसरण सहित सुघटित संस्थागत सहयोग की आवश्यकता है। कृषि मंत्रालय भारत सरकार द्वारा सूखे से निपटने की तैयारी के लिए चलाई जा रही विभिन्न सरकारी योजनाओं जैसे कि MGNREGA, RKVY, मेगा स्पीड प्रोजेक्ट, NFSM, NHM, IWMP मृदा स्वास्थ्य योजनाएं आदि के अभिसरण की प्रक्रिया को सरल बनाने की आवश्यकता है। प्रधानमंत्री राष्ट्रीय जलवायु परिवर्तन कार्य योजना (NAPCC) के अंतर्गत चलाए जा रहे मिशनों में से एक मिशन राष्ट्रीय सतत कृषि मिशन (NMSA) है जिसमें समर्पित नोडल अधिकारियों एवं बजट के प्रावधान सहित राज्य कार्य योजनाओं (SAP) में इस मिशन की सक्रियता के समावेशन से यह आकस्मिकता के कार्यान्वयन में प्रमुख भूमिका निभा सकता हैं।

ABSTRACT. Even though drought is one of the most common features affecting rainfed agriculture, it is necessary to consider it as an extreme climatological event that requires different types of alleviating strategies for overcoming it. The risk involved in successful cultivation of crops depends on the nature of drought (chronic and contingent), its probable duration, and frequency of occurrence within the season. These aberrations are expected to further increase in future. A significant fall in food production is often noticed with increase in intensity or extension in duration of drought prevalence. Drought affects not only the food production at farm level but also the national economy and overall food security. Location-specific rainfed technologies are available to cope with different drought situations. Much of the research done in rainfed agriculture in India relates to conservation of soil & rainwater and to drought proofing. The key technologies for drought mitigation are *in situ* moisture conservation, rainwater harvesting and recycling, resilient crops and cropping systems including contingency crop plans, foliar sprays, and integrated farming systems. However, drought preparedness and real time implementation of contingency measures at field level needs well structured institutional support for farmers with strong government policy and convergence among various institutions. Ministry of Agriculture, Government of India, needs to facilitate the convergence process of various government schemes such as MGNREGA, RKVY, Mega Seed Project, NFSM, NHM, IWMP, Soil health schemes etc. for drought preparedness. National Mission for Sustainable Agriculture (NMSA), one among the missions under the Prime Minister National Action Plan for Climate Change (NAPCC) may take a lead role in implementation of contingency, by inclusion of this activity in State Action Plans (SAP) with a dedicated Nodal Institution /officers and budget provision.

Key words – Contingency plans, Drought, Insurance, Rainwater harvesting, Resilient crops, Soil organic matter.

1. Introduction

Drought has been a recurring feature of agriculture in India. In the past, India experienced twenty four large scale droughts in 1891, 1896, 1899, 1905, 1911, 1915, 1918, 1920, 1941, 1951, 1965, 1966, 1972, 1974, 1979, 1982, 1986, 1987, 1988, 1999, 2000, 2002, 2009 and 2012 with increasing frequencies during the periods 1891-1920,

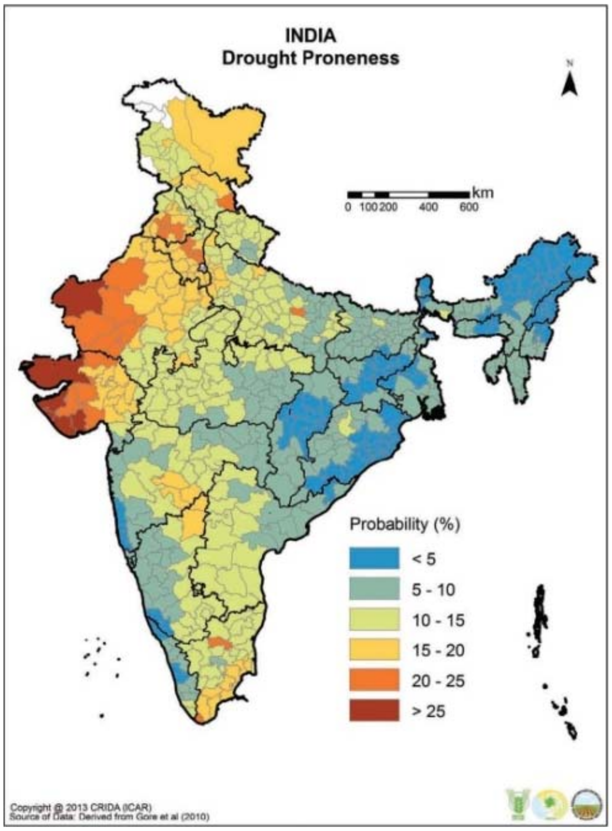

Fig. 1. Probability of drought occurrence in different parts of India (*Source* : Rama Rao *et al*., 2013)

1965-1990 and 1999-2012 (NRAA, 2013). 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 may be of severe intensity (Srinivasarao *et al*., 2013b). Occurrence of the drought is very frequent in the meteorological sub-divisions like West Rajasthan, Tamil Nadu, Jammu & Kashmir and Telangana (NRAA, 2013). The risk involved in successful cultivation of crops depends on the nature of drought (chronic and contingent), its duration, and frequency of occurrence within the season. In the arid region where the mean annual rainfall is less than 500 mm, drought is almost an inevitable phenomenon in most of the years (Ramakrishna, 1997). In semi-arid regions (mean annual rainfall 500-750 mm), droughts occur in 40 to 60% of the years due to deficit seasonal rainfall or inadequate soil moisture availability between two successive rainfall events. Even in dry sub-humid regions (annual rainfall 750-1200 mm), contingent drought situations occur due to breaks in monsoon (Rao *et al*., 1999). Another study (Rama Rao *et al*., 2013) showed, on a probability scale of 0-25, that a very high incidence of drought (>25%) is observed in a few districts in Rajasthan and Gujarat while the incidence is relatively low (5-10%) in the Western Ghats, eastern India and northeastern India (Fig. 1).

1.1. *Impact of drought*

The severity of the drought depends on its duration, degree of water/moisture deficiency, and the size of the affected area. Droughts in India, have periodically led to famines, including the Bengal famine of 1770, in which, up to one third of the population in affected areas died; the 1876-1877 and 1899 famines in which over 5 million and more than 4.5 million people died, respectively. Loss of assets in the form of crop, livestock (mortality, loss in productivity, health and loss in fertility); and 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 some of the major causalities due to drought. The effect of droughts for the last 30 years reflected more in *kharif* season rice production, scarcity of green/quality fodder affecting animal health, animal draft power, milk production, and further there would be more causalities of animals, particularly small ruminant as the already overgrazed grasslands might have low quality/quantity of forage with limited water-points in these grazing areas (Chary *et al.*, 2013). Analysis of top six severest droughts during 1877 to 2005 in India indicated that the rainfall deficit varied from -19 to -29.1%, whereas the geographical area affected ranged from 49 to 63% with an average of 64%. Deficiency in the month of July (crop sowing period) was agronomically more critical for agricultural production and the deficit was highest during the drought of 2002 with severest 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 million ha area was not sown and 47 million ha of the sown area was subsequently damaged and food grain production reduced by 29 million tons, agricultural GDP was reduced by 3.1% with Rs. 390 billion loss of agricultural income, loss of 1250 million person-days employment, and every day about 1.5 billion liters of drinking water was transported by tankers, railways and other means (DAC, 2004). In 2009, the whole country (about 352 districts were declared drought hit) suffered from the effects of a severe drought which lead to immense agricultural loss and affected the life and living of about 400 million people. The seasonal mean (June to September) rainfall recorded a deficit of 22% of its long-term mean. The food grain loss was about 15 million tonnes. The contingent plan was to initially go for late sowing crops, then late sowing short-duration crops, and then for some fodder crops and short-term pulses. The strategies further changed in mid-term, and towards

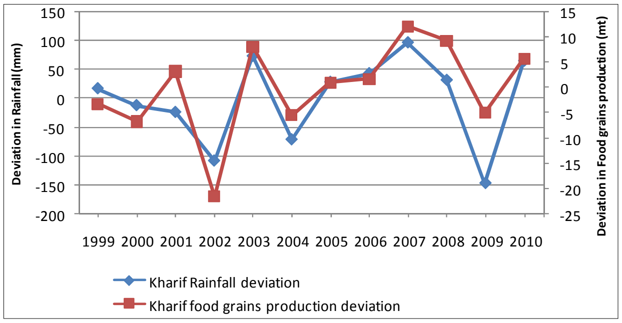

Fig. 2. Rainfall *vs* food production in *kharif* season (Source: enkateswarlu *et al*., 2011)

terminal part of monsoon. Due to these adjustments, the loss in production of food grains was minimized.

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. Monthly rainfall over the country as a whole was 72% of LPA (long period average) in June, 87% of LPA in July, 101% of LPA in August and 111% of LPA in September. As a result of drought, 5.68 million hectare of area was not sown during *kharif* with a loss of about 12.76 million tonnes of *kharif* food grain production. Distress sale of animals were reported especially from Karnataka. In 2014, during the first half of the season (1 June to 31 July) country received 78% of its Long Period Average (LPA) value, (June deficiency alone was 42%), while during second half of season (1 August to 30 September) it received 97% of its LPA value. The rainfall for the season was below normal over northwest India (78.6% of LPA) and East & Northeast India (88.2% of LPA), while it was normal over Central India (90.4% of LPA) and south peninsula (93% of LPA). The country's foodgrain production is estimated to have declined by 4.66% to 252.68 million tonnes (MT) in 2014-15 due to poor monsoon (12% deficit rains) and unseasonal rains in February-March. Total foodgrain production in the country is estimated at 252.68 MT, which is lower by 12.36 MT than the last year's record foodgrain production of 265.04 MT.

The growth of crops and the food production of the country are strongly influenced by the total rainfall as evident from the positive and significant correlation coefficient of +0.78** (1999-2010). During 2002, the deviation in the amount of rainfall received and the deviation in the food production were -100 mm and -20 million tons, respectively, whereas, the corresponding values during 2009 were -150 mm and -5 million tons, respectively (Fig. 2) indicating that drought proofing of Indian agriculture has been achieved to some extent due to improved practices, better logistics and timely interventions from Central and State Governments during drought years. However, rainfall aberrations including drought during south-west monsoon continue to be major factors contributing to instability in crops production in rainfed areas. Hence, there is a need to make rainfed areas more resilient through adoption of drought proofing technologies.

2. Resilient rainfed technologies

Major deficiencies or anomalies in the amount of rainfall as well as variation in time and space require proper management. In most of the drought situations, normal cropping systems and cultivation practices are not possible especially under rainfed conditions. The All India Coordinated Research Project for Dryland Agriculture (AICRPDA) in association with State Agricultural Universities, Technical Universities and Research Institutes of Indian Council of Agricultural Research have developed location-specific rainfed technologies to cope with different drought situations. The key technologies for drought mitigation are *in situ* moisture conservation, rainwater harvesting and recycling, resilient crops and cropping systems including contingency crop plans, integrated farming systems, etc. (Srinivasarao *et al*., 2014a).

2.1. *Rainwater management*

Effective rainwater management is critical for drought mitigation and successful rainfed agriculture. The strategy of rainwater management in arid and semi-arid regions consists of selection of short duration and low water requiring crops and conserving as much rainwater as possible so that crops can escape moisture stress during the growing period. In addition to *in-situ* conservation, efforts need to be made to divert the surplus water into torage structures which can be used either as standalone resource or in conjunction with groundwater for meeting the critical irrigation requirements.

2.1.1. *In-situ moisture conservation*

In-situ soil and water conservation (SWC) practices improve soil structure and soil porosity, increase infiltration and hydraulic conductivity, and consequently increase soil water storage that helps crops to withstand moisture stress. These measures are more feasible and practical proposition under most situations and can be adopted by individual farmers with less draft and amenable even for a small holder. The suitability of a practice depends on the topography of the field, temporal and spatial distribution of rainfall, type of soil, crop, etc. Based on extensive research conducted at various

TABLE 1

Location specific *in-situ* moisture conservations practices

Practice	Crops/cropping system	Remarks
Compartmental bunding	*Rabi* sorghum sunflower, safflower, chickpea, maize, pearl millet, cotton	The impact of the practice is more during sub-optimal rainfall years. It also significantly controls runoff. This practice is adopted on 800 ha in Bijapur, Bagalkot and Raichur districts of Northern Kamataka
Conservation furrow	Fingermillet + pigeonpea (8:2), Groundnut + pigeonpea (8:2), soybean + pigeonpea (4:2), cotton + soybean (1:1)	Opening of conservation furrow enhances *in-situ* moisture conservation, thus the crops can overcome the effect of dry spells during vegetative and or reproductive stages of crops resulting in increased rainwater use efficiency, better performance of crops and additional net returns.
Broad bed & furrow (BBF)	Soybean, groundnut	BBF system helps draining out of excess water from the black soils. Further, the rainwater conserved in the furrows helps in better performance of crop during long dry spells.
Ridges and furrows	*Rabi* sorghum, pigeonpea + rice	The practice conserves 30-45% more moisture than farmers' practice, retains it for longer period (up to 60 days) and increases crop yield. This practice is widely adopted in 60% of *rabi* sorghum area in Solapur district.
Ridge planting	Pearlmillet	Ridge planting provides enough aeration and porosity to soil for enhanced root growth, safe disposal of excess rainwater and reduction in soil loss apart from moisture conservation during low rainfall period.
Set furrow	Pearlmillet-sunflower cropping, pigeonpea + groundnut (2:4)	Conserves more moisture and make it available for longer time to the crops. This helps to overcome the effect of drought.
Inter-plot rainwater harvesting	Sunflower, sorghum, chickpea	This practice makes possible to take up two crops even in drought years mainly by allowing rainfall infiltration into the soil profile. Further, during low rainfall years also, 10-15, 20-25 and 10-12 q/ha of sunflower, sorghum and chickpea yields can be harvested with this technology.

Source : Compiled by authors from Annual Reports of AICRPDA

locations in the country, several *in-situ* moisture conservations practices have been recommended (Table 1) and some of these practices are being adopted in significant areas in the country.

2.1.2. *Mulching*

Mulching or mulch-cum-manuring has many advantages. It reduces soil water evaporation, protects the soil as well as changes the micro-climate by reducing soil temperature, thereby reduces unnecessary water loss and therefore effective in managing mid-season drought, which is a common feature in rainfed farming. The effect of mulches on crop productivity and profitability in different locations are given in Table 2. Similarly, frequent cultivation between the crop rows to create dust mulch is a useful operation that helps in breaking the soil crust especially in red soils. It augments infiltration and breaks the capillary movement of water to top layers and minimizes the evaporation losses.

2.1.3. *Rainwater harvesting and recycling*

Rainwater harvesting is an age-old technique and the evidence for rainwater harvesting practice can be seen from the existence of tanks and farm ponds in many villages particularly in the peninsular India. The importance of rainwater harvesting has increased in recent years due to the increased rainfall variability, depletion of groundwater levels and raising temperatures. It has been estimated that, 27.5 M ha of rainfed area of the country, excluding the very arid and wet areas, can contribute an amount of 114 billion m^3 of water for water harvesting which is adequate to provide one supplementary irrigation of 100 mm depth to 20 M ha during drought years and 25 M ha during normal years (Sharma *et al*., 2010). Harvesting the runoff water and storing it in farm ponds is a possibility in rainfed regions and the size of the pond depends on the rainfall, topography, and soils of the region. The so harvested water during the *kharif* season can be used either for supplemental irrigation during dry

TABLE 2

Effect of various mulch materials on crop productivity and profitability at different locations in India

Location	Crop	Type of mulch	Yield increase over without mulch (%)	Net return (Rs/ha)	
				With mulch	Without mulch
Ballowal Saunkri (Jammu & Kashmir)	Sarson	Paddy straw	41.9	9820	4453
	Lentil	Subabul	35.2	9042	4462
	Maize	Sugarcane trash	56.8	8359	6600
	Wheat	Paddy straw	59.7	15067	12358
SK Nagar (Gujarat)	Castor	Crop residue mulch	28.5	16594	12595
Indore (Madhya Pradesh)	Pigeonpea	Crop residue mulch	8.7	23812	21766
	Soybean	Polythene mulch	42.7	34839	23666
Varanasi (Uttar Pradesh)	Upland rice	Straw mulch	19.4	3799	1802

Source : Compiled by authors from Annual Reports of AICRPDA

spells coinciding with critical crop stages in *kharif* or for establishment of *rabi* crops. The advantages of supplemental irrigation are significant and considerable improvement in crop yields has been noticed at locations of various AICRPDA centers as given in Table 3.

2.1.4. *Watershed approach for drought mitigation*

Watershed management is a holistic approach towards optimizing the use of land, water and vegetation to alleviate drought, reduce floods, prevent soil erosion, and improve water availability and increase fuel, fodder, fiber and agricultural production on a sustained basis. Watershed development programs are silently revolutionalizing the rainfed areas and can become growth engine for inclusive and sustainable development in vast rainfed tracts in India. Meta analysis of 311 watershed case studies from different agro-eco regions in India revealed that watershed programs benefitted farmers through enhanced irrigation areas by 33.5%, increase in cropping intensity by 63%, reduction in soil loss by 0.8 t/ha and runoff by 13% and improvement in groundwater availability. Economic assessment showed that the watershed programs were beneficial and viable with a benefit-cost ratio of 1:2.14 and an internal rate of return of 22% (Joshi *et al*., 2005).

2.2. *Soil management*

Soils hold the key to productivity and resilience to climate vagaries including drought in rainfed agriculture. Yet, loss of fertile soil as erosion, depletion of soil organic matter, emerging secondary and micronutrient deficiencies, soil compaction, surface crusting, loss of soil biodiversity have become potential limiting factors for productivity enhancement in these regions (Srinivasarao *et al*., 2012; Srinivasarao *et al*., 2014c). Hence, these factors need improvement in facing the climate adversities.

TABLE 3

Effect of one supplemental irrigation (5 cm) from harvested rainwater in farm ponds on yield of rainfed crops

Crop	Yield (kg/ha)	Yield increase due to irrigation (%)	Location
Sorghum	1270	19	Anantapur
Sorghum	1350	32	Bijapur
Maize	4333	71	Arjia
Cotton	1730	14	Kovilpatti
Soybean	2050	14	Indore
Castor	1320	31	Hyderabad
Wheat	2143	25	Ballowal Saunkhri
Pea	2207	44	Varanasi
Barley	3001	32	Agra
Safflower	1014	48	Parbhani

Source : Compiled by authors from Annual Reports of AICRPDA

2.2.1. *Improving water retention through enhanced soil organic matter*

Increased organic matter in soil, improves soil aggregation which in turn improves soil aeration, soil water storage, reduces soil erosion, improves infiltration, and generally improves surface and groundwater quality. However, the soil organic carbon which is the seat of

TABLE 4

Effect of foliar nutrition in different field crops

Crop	Foliar spray	Performance
Maize	VAM-C 50% SL @ 3.75 1/ha, potassium solution @2% and thiourea @250 g/ha	Gave higher yield up to 16, 24, 33 and 15% in blackgram, maize, soybean and horsegram, respectively compared to no foliar spray
Cotton	Two foliar sprays of $MgSO_4$ and $ZnSO_4$	Gave an additional seed cotton yield of 300 kg/ha over farmers' practice and additional net returns of Rs.15000/ha
Chickpea	Combined application of urea, KCl, kaolin and selenite	Gave higher seed yield (1215 kg/ha) with net return of Rs.33845/ha compared to no foliar spray
Toria	KNO_3 spray @ 2% before flowering	Gave higher seed yield (738 kg/ha) with net return of Rs.10171/ha
Wheat	Seed soaking with thiourea (1000 ppm) + foliar spray at maximum tillering and booting stage with thiourea (1000 ppm)	Gave higher grain yield (2716 kg/ha) during with net return of Rs.31566/ha
Maize	$ZnSO_4$ spray @ 0.5% + $FeSO_4$ spray @ 0.5%	Gave higher seed yield (1137 kg/ha) with net return of Rs.13833/ha
Maize	Thiourea @ 500 ppm at pre-flowering and 50% silking stage and brassinosteroid @ 400 ppm at knee height stage	Foliar spray of thiourea @ 500 ppm at pre-flowering and 50% silking stage was found superior compared to brassinosteroid @ 400 ppm at knee height stage

Source : Compiled by authors from Annual Reports of AICRPDA

major soil processes and functions, is only <5 g/kg in rainfed soils, while the desired level is 11 g/kg. Maintaining or improving soil organic matter is a prerequisite to ensuring soil quality, productivity and sustainability. Some recommended practices for improving infiltration and water retention in soils include diverse crop rotations with legumes and addition of farmyard manure (FYM), use of groundnut shells and other crop residues, green leaf manuring, etc. From several long-term manurial experiments conducted under rainfed conditions, it was observed that the highest soil organic carbon (SOC) stock (t/ha) was measured in 50% RDF + 4 t/ha groundnut shells (47.2) followed by that in 100% RDF (36.2) and the lowest in the control (32.2) in groundnut based system. In case of finger millet monocropping, the profile SOC stock (t/ha) was the highest in the FYM 10 t/ha + 100% NPK (85.7) followed by100% NPK and control (63.5) treatments. In case of groundnut-finger millet rotation, the SOC stock (t/ha) was the highest in the FYM + 100% NPK (73.0) and lowest in control (51.7) treatments. In case of sorghum, the highest SOC stock (t/ha) of 68.5 was observed in the 25 kg N (crop residue) + 25 kg N (Leucaena) followed by that of 65.8 in the 25 kg N (crop residue) + 25 kg N (urea) N, and lowest (49.0) in the control. In case of pearl millet based system, the profile SOC stock (t/ha) was the highest in 50% recommended dose of nitrogen (RDN) (fertilizer) + 50% RDN (FYM) (25.5) followed by that in the 50% RDN (FYM) (23.4), and the lowest in the control (17.9). On-farm generation of organic matter with appropriate policy support needs to be promoted to maintaining soil health and crop productivity (Srinivasarao *et al*., 2014b).

2.2.2. *Balanced nutrition*

Soils in most parts of India not only show deficiency of NPK but also of secondary nutrients (S, Ca and Mg) and micro nutrients (B, Zn, Cu, Fe, Mn etc.). Balanced nutrient application to crops based on the nutrient requirement to produce a unit quantity of yield, the native nutrient supplying capacity of soil and specific targeted yield improves crop yields while minimizing nutrient losses and cost of cultivation. In Andhra Pradesh and Telangana, balanced nutrition was demonstrated in eight districts to address nutrient deficiencies which exist within farmers' fields, with promising results. For example, in Warangal, balanced nutrition improved cotton yields significantly in many farmers' fields. In some fields, cotton yields reached 1.6 t/ha with balanced nutrition registering an increase in yield by 10 to 25% over farmers' practice. Further, farmers in this district achieved 30 to 40% yield improvements in most of the crops due to balanced nutrition (Srinivasarao *et al*., 2010a).

2.2.3. *Foliar sprays for drought mitigation*

Nutrients not only facilitate better plant growth and development, but also help to alleviate different kinds of abiotic stresses like drought. Leaf feeding is the use of foliar fertilizers to enhance the overall nutrient level in the plant and increase sugar production during times of stress. This form of foliar nutrition does not address any specific nutrient deficiency but supplies a small amount of all nutrients to keep leaf growth lush. Several studies

TABLE 5

Efficient intercropping systems to cope with rainfall variability in different rainfed areas

Soil zone and region	Intercropping system	Optimum row ratio
	Vertisols and related soil zone	
Malwa plateau (Madhya Pradesh)	Soybean + pigeon pea	4:2
	Sorghum + pigeon pea	2:2
Vidharbha (Maharashtra)	Cotton + sorghum + pigeon pea + sorghum	6:1:2:1
	Cotton + greengram	1:1
Southern Rajasthan	Maize + blackgram	2:2
	Groundnut + sesame	6:2
Northern Karnataka	Pearl millet + castor bean	3:1
	Pearl millet + pigeon pea	4:2
Saurashtra (Gujarat)	Groundnut + castor bean	3:1
	Groundnut + pigeon pea	3:1
Southern Tamil Nadu	Cotton + blackgram/ greengram	2:1
	Inceptisols and related soil zone	
Western plateau (Jharkhand)	Pigeonpea + rice	2:3
Bastar plateau (Chattisgarh)	Maize + cowpea	2:2
	Oxisols zone	
Eastern Ghat zone (Odisha)	Maize + pigeon pea	2:2
	Finger millet + pigeon pea	4:2
	Alfisols and related soil zone	
Southern Karnataka	Groundnut + pigeon pea	8:2
	Finger millet + pigeon pea	10:2
Telangana	Sorghum + pigeon pea	2:1
Rayalaseema (Andhra Pradesh)	Groundnut + pigeon pea	7:1
	Arid soil zone	
North-western Gujarat	Castor bean + cowpea	1:2
	Pearl millet + cluster bean	2:1

Source : Compiled by authors from Annual Reports of AICRPDA

have indicated the beneficial effect of foliar sprays in different field crops (Table 4).

2.3. *Resilient crops and cropping systems*

Crop based approaches for drought mitigation include growing crops and varieties that fit into changed rainfall and seasons. In addition, adoption of intercropping systems, crop diversification, improved agronomic practices and agro-forestry systems helps to cope with any adverse event, and in particular rainfall variability and drought.

2.3.1. *Efficient crops and varieties*

Since rainfed agriculture is risky due to weather aberrations, selection of proper crops based on the bio-physical and climatic factors of a given area is an essential pre-requisite for enhancing crop productivity and profitability. Generally, the crop should be of short duration, drought tolerant and high yielding. Based on the analysis of long-term climatic data in terms of probability of the onset of monsoon, withdrawal of monsoon, and occurrence of dry spells, effective cropping seasons have been worked out for different regions of the country.

These serve as a good guide in selection of efficient crops and their sowing time. For example, in arid regions of the country where rainfall is above 300 mm and the length of humid period is about 1-4 weeks, short duration drought tolerant pulses such as mungbean, mothbean, cowpea, and cereals of 10-12 weeks duration such as pearl millet and minor millets are suitable. Similarly, short-duration varieties/hybrids with higher harvest indexes that have potential to mitigate the effects of drought periods (often occurring at the beginning and the end of the growing season) have been evolved for different agro-climatic conditions (Srinivasarao *et al*., 2014a). Such cultivars are considered as a key component of drought management strategies.

2.3.2. *Intercropping*

Intercropping involving growing more than one crop of different durations alongside each other on the same field helps to distribute the risk due to adverse climate. Studies on intercropping over the years and across locations of AICRPDA in India have resulted in identification of very useful and productive crop combinations (Table 5) with matching production technologies. Amongst the several combinations tested, pearl millet and pigeon pea proved to be the best combination across several regions. The combination has done exceedingly well in regions where late rains are likely to occur in September/October (Bijapur and Solapur) or where deep and moisture retentive soils exist (Akola) benefitting long duration pigeonpea crop. Cotton and mungbean/black gram/soybean is yet another combination which has demonstrated the advantage of intercropping. Groundnut + pigeonpea intercropping system in 7:1 proportion is one of the most successful one adopted by farmers in scarce rainfall zone of Andhra Pradesh. About 70% of the total groundnut area of 0.85 million ha in this zone is under groundnut + pigeon pea intercropping system. The system is also adopted on a large scale by farmers in southern Karnataka. Similarly, sunflower + pigeon pea system is practiced in more than 6000 ha covering 30% of cropped area during rainy season in Solapur district and pearl millet + pigeon pea is practiced in 80000 ha covering 35% of cropped area during post-rainy season in Ahmednagar, Pune and Dhule districts of Maharashtra (Venkateswarlu *et al*., 2009).

2.3.3. *Crop diversification*

With the available dryland technologies like rainwater management, choice of crops, short duration varieties, and other agronomic practices, a greater portion of rainfed areas can be put under intensive cropping systems including relay cropping and double cropping. In areas having sufficient rainfall (usually more than 750 mm) with a soil storage capacity of more than 150 mm of available soil moisture, double cropping is possible. Double cropping is also possible with rainwater harvested in farm ponds which is used for establishing winter crop. Out of the two crops, the first crop is a short duration legume of 60-70 days and the succeeding crop a long duration cereal of 110-120 days. Similarly relay cropping is another well known strategy to combat dry spells of different intensities in drought prone regions. In this practice, second crop is sown either by dibbling manually or by using seed drill in between two rows of first crop during reproductive/maturity stage of the crop. For example, in North Gujarat, relay cropping of castor bean in green gram is practiced on about 35000 ha.

2.3.4. *Contingency crop planning*

Contingency crop planning is essentially aimed at stabilization of crop output in the situation of late onset of monsoon, mid season and terminal droughts. Contingency planning covers different drought situations, *i.e*., late onset of monsoon (delay by 2 weeks, delay by 4 weeks, delay by 6 weeks and delay by 8 weeks); mid season drought (at vegetative stage, at flowering/fruiting stage); terminal drought (early withdrawal of monsoon). ICAR-CRIDA has developed district level agricultural contingency plans for 580 districts so far in collaboration with respective SAUs, AICRPDA and AICRPAM. These plans are intended to benefit district authorities including line departments to overcome the adverse effect of weather aberrations. The suggested drought contingency measures include change in crop/cropping system, crop management, soil nutrient and moisture conservation measures.

Any contingency measure, either technology related (land, soil, water, crop) or institutional and policy based, which is implemented based on real time weather pattern (including extreme events) in any crop growing season is considered as Real Time Contingency Planning (RTCP). If done timely and effectively, RTCP contributes to household and village food and fodder security (Srinivasarao *et al*., 2010b). For example, during *kharif* season 2013, ridge/furrow or broad bed and furrow method implemented fields maintained almost normal soybean yields, while under farmers' practice (flat bed sowing) crop damage was almost 80 to 90% due to excessive rains which lead to water stagnation and poor drainage in deep black soil regions of Malwa, Madhya Pradesh. In Southern Karnataka, delay in onset of monsoon, was managed with cultivation of medium duration finger millet variety (GPU 28) with intercropping of pigeonpea and soil moisture conservation practice of conservation furrow. Mid-season droughts have been managed with foliar sprays, reduction in plant population

TABLE 6

Impact of real time contingency implementation on additional income in different crops/regions under weather aberrations (late onset and mid-season droughts)

State	District	Crop / System	Contingency-situation dealt	Intervention	Additional income in crores Rs/ one lakh ha
Karnataka	Bangalore Rural	Finger millet	Late onset of monsoon	Transplanted finger millet	48.74
Karnataka	Bangalore Rural	Finger millet-pigeonpea	Mid-season drought	Intercrop with conservation furrow	195.45
Gujarat	Jamnagar	Cotton	Mid-season drought	Castor relay cropping with cotton	161.88
MP	Indore	Soybean	Mid-season drought	Foliar spray	73-153
AP	Kurnool	Groundnut	Mid-season drought	Critical irrigation with pond water	138.11
TN	Thoothukkudi	Cotton	Mid-season drought	Critical irrigation with harvested water	89.75

Source : Srinivasarao *et al.* (2015)

TABLE 7

Influence of *aonla* based agri-horti systems on yield and monetary returns at Bangalore

Agri-horti system	Fruit yield (kg/ha)	Intercrop yield (kg/ha)	Aonla eq. yield (kg/ha)	Cost of cultivation (Rs/ha)	Net income (Rs/ha)	BC ratio
Aonla + finger millet	392	2187	1849	25649	29831	2.16
Aonla + cowpea	420	890	1903	27533	29548	2.07
Aonla + horsegram	432	831	1264	25916	11994	1.46
Aonla + field bean	460	953	1255	28433	9210	1.32
Aonla (sole)	493	-	493	8260	6537	1.79

Source : AICRPDA Annual Reports

and critical irrigation with harvested water (Srinivasarao *et al*., 2013a). Overall, the aberrations or extreme events can be managed with components of preparedness and real time implementation of agriculture contingencies as observed in pilot models in about 34 villages across the country (Srinivasarao *et al*., 2015). If the same contingency is implemented in larger areas in the same agro-ecosystem, the crop losses can be reduced and additional income is possible considerably from the same land resources (Table 6).

2.3.5. *Agro-forestry systems*

In India, the practice of growing trees and crops together has been prevalent for centuries. Large number of tree based systems were developed based on rigorous experimentation after the initiation of systematic research at National Research Center for Agroforestry, Jhansi and at All India Coordinated Research Project on Dryland Agriculture (AICRPDA), Hyderabad. The experimental results were also field tested and the proven systems are being scaled up through developmental programmes such as Integrated Watershed Development Programme, Mahatma Gandhi National Rural Employment Generation Programme, National Horticulture Mission, etc. Due to the multifarious advantages associated with the tree systems, the acceptance of these systems is observed to be gradually expanding. The total area under agro-forestry in India is reported to be about 25.32 m ha out of which 7 M ha is in irrigated regions and 13 M ha is in rainfed regions (Dhyani *et al*., 2013). Among different *aonla* based agri-horti systems tested under semi-arid Alfisols at AICRPDA centre Bangalore, *aonla* + finger millet and *aonla* + cowpea systems recorded similar but significantly higher *aonla* equivalent yields (1849-1903 kg/ha) compared to other systems, with net income of Rs.29548-29831/ha (Table 7).

2.4. *Integrated farming systems*

One of the major approaches for drought mitigation and building farm resilience is through spreading risks and creating buffers, *i.e*., not putting 'all fruits in one basket'. This can be achieved through integrated farming system approach, which is considered as important and relevant especially for the small and marginal farmers. Location-specific IFS will be more resilient and adaptive to climate variability. For example, in an on-farm trial involving different small and marginal farmers in Anantapur district of Andhra Pradesh, it was found that farmers having crop production alone incurred losses due to complete failure of crops (groundnut and pigeonpea) as a result of drought/prolonged dry spells in both 2010 and 2011. However, integration of livestock rearing with crop production improved the economic returns of both marginal and small farmers (Gopinath *et al*., 2012).

On-station and on-farm research in different regions of the country has resulted in identification of a number of sustainable and profitable IFS models for rainfed areas. In general, in regions with rainfall of 500 to 700 mm, farming systems should be based on livestock with promotion of low water requiring grasses, trees and bushes to meet fodder, fuel and timber requirements of the farmers. In 700 to 1100 mm rainfall regions, crop, horticulture and livestock based farming systems can be adopted depending on the soil type and the marketability factors. Runoff-harvesting is a major component in this region in the watershed based farming system. In areas where the rainfall is more than 1100 mm, IFS module integrating paddy with fisheries is identified as ideal.

2.5. *Fodder systems*

In general, livestock farmers do not make special efforts for forage and pasture management during drought years. This leads to severe fodder crisis, which ultimately forces distress sale of valuable animals. Early season drought reduces the area under fodder crops, whereas mid-season drought results in less fodder yields and impacts fodder availability especially during lean period. Terminal drought has much less effect on fodder production but it affects the availability of seed material for the succeeding year. It is essential to give high priority for ensuring availability of enough fodder and forage on a continuous basis, especially during drought years. One of the viable strategies for achieving this is to establish "Fodder Bank" at strategic locations in drought-prone regions and utilize the stored material for supply to places of deficit. Similarly, more emphasis should be given for fodder production in community lands during drought/flood, improved fodder/feed storage methods, availability of the fodder within purchase limit of poor farmers, and efficient feed management for livestock during aberrant weather situations. For example, various innovations were implemented during 2007-2012 to increase feed and fodder base in selected village clusters in eight backward districts of Andhra Pradesh (Dixit *et al*., 2012). The farmers were encouraged to cultivate annual fodder crops like maize, lucerne, cowpea, horsegram, sunhemp etc., on tank bed areas at the end of winter season and perennial fodders like CO-2, CO-3, APBN-1 etc. in cultivated lands with available limited water. *Stylosantus hamata* was sown on the available bunds in the villages for strengthening of bunds and also as leguminous fodder source for livestock. In Jaffergudem cluster of Warangal district, majority of rice fields were kept fallow because of deficit rainfall during *kharif* 2009. Farmers were anticipating severe fodder shortage. Hence, fodder sorghum cultivation was encouraged in the villages. The intervention became popular with farmers having milch animals.

Similarly, *Azolla*, a blue green algae which is having more than 25% crude protein and can be doubled in quantity within 5-7 days was encouraged to establish in pits at backyard depending on the number of milch animals of the farmer. *Azolla* yield is much more than the perennial fodder varieties like APBN-1 or CO-3 etc and is around 1000 MT per hectare at the rate of 300 g/m^2/day even after taking into account wastage space between two *Azolla* beds. It is more nutritious than the leguminous fodder crops like lucerne, cowpea, berseem etc and can be fed to cattle, buffalo, sheep, goat and also poultry after mixing with concentrate mixture at the ratio of 1:1. Efficient utilization of available feed resources was strengthened through supply of chop-cutters to the custom hiring centers in the villages. Farmers hire the implement by paying user charges. For instance, chopping of sorghum stover, which is available in large quantity in Adilabad district, was promoted to reduce wastage (by at least 50%) and improve its digestibility.

3. A success story on "Drought mitigation and prosperity through adoption of resilient rainfed technologies"

Water is a critical and limiting factor in semiarid southern Rajasthan where rainfed agriculture is predominant. The rainfall variability and early or mid season droughts during crop season cause either poor performance or even failure of *kharif* crops. Smt. Kesar Devi, of Kochariya village (Bhilwara district) used to take up only mixed cropping of maize and blackgram during *kharif* and leaving the field fallow during *rabi* season. She was not having any irrigation facilities either to protect the *kharif* crops from dry spells or to take a second crop during *rabi* season. The AICRPDA Centre, Arjia adopted Kochariya village in 2011 to improve the agricultural productivity in the village through demonstration of climate resilient technologies including *in-situ* moisture conservation, rainwater harvesting in farm ponds and efficient use, and intercropping systems. Smt. Kesar Devi volunteered to adopt the farm pond technology and constructed a farm pond with lining (*kachcha*) having capacity of 1242 m^3 (size: of 18 × 30 m top; 12 × 24 m bottom; 3 m depth with 1:1 side slope). Due to availability of water in the farm pond, she diversified the cropping pattern from maize and blackgram mixed cropping to improved intercropping systems of maize and black gram (2:2) as well as groundnut and sesame (6:2) during *kharif* as suggested by the AICRPDA Centre. She also raised mustard and chickpea during the ra*bi* season. Efficient use of farm pond water through micro-irrigation method (sprinkler) for *kharif* crops during dry spells, and pre-sowing irrigation to mustard made agriculture a profitable venture for her. The cropping intensity increased from 100% to 212%, and the net returns increased up to Rs.35,090/ha from Rs.15,090/ ha. After recognizing the achievement of Smt. Kesar Devi in Kochariya village, the Government of Rajasthan came forward to help other women farmers in the village for construction of form ponds.

4. Government policy and support

Appropriate investments and policy reforms will be required to enhance the contribution of rainfed agriculture, particularly water storage and its efficient use at farm, watershed, village and larger command level. Further, soil and crop management through effective interventions at state and village level should receive attention. Water harvesting either individually or collectively should be made mandatory. At village panchayat level, community water harvesting ponds should be encouraged. Policy interventions and concerted efforts are needed for sensitizing, skill development and need based capacity building of the stakeholders about the constraints and potentials of particular land and their optimum use for enhancing the productivity and income in rainfed areas. All India Coordinated Research Project for Dryland Agriculture (AICRPDA) with its 25 centers in different agro-ecological regions covering diverse rainfed production systems has developed several location-specific technologies during past 40 years for different drought situations. Promotion of these technologies with KVKs, ATMA and several national programmes of Government of India is utmost important. To take forward the technologies, proper convergence requirements among various stakeholders have to be met. State rainfed agriculture missions set up in Karnataka and Maharashtra are important institutions which have to be effectively managed with good technical support and proper convergence. Many other Indian states are in process of establishing state rainfed commissions to address rainfed farming predominant in these states. Farm pond technology and watershed programmes in recently NRAA prioritized districts needs capital supports. Large scope exists to strengthen these programmes under MoRD, Government of India. Similarly, farm mechanization needs strengthening for successful implementation of various land treatments. Government of Maharashtra has purchased about 15000 BBF makers to bring wider adoptability of BBF technology in the state. Lifting devices and solar systems needs to be promoted for efficient recycling of harvested water. Many of the resilient dryland technologies can be up scaled with MGNREGA where drought proofing is an important component of Schedule I interventions.

5. Agriculture insurance

The increasing frequency and severity of droughts, storms and other extreme weather events associated with climate change reduces livelihood options for millions of small-scale farmers in low-income countries like India. Weather index-based insurance is an attractive approach to managing weather and climate risk because it uses a weather index, such as rainfall, to determine payouts and these can be made more quickly and with less argument than is typical for conventional crop insurance. The underlying premise of weather insurance is that weather parameters can be reliable proxy indicators for the actual losses incurred by farmers (Singh, 2013). Weather index-based insurance was formally introduced to Indian farmers in 2003 through a programme initially supported by the World Bank. The first weather index insurance in India was a rainfall insurance contract underwritten in 2003 by ICICI-Lombard General Insurance Company for groundnut and castor farmers of BASIX's water user associations in Mahabubnagar district of Andhra Pradesh. By 2007, the national government had adopted it as an alternative to the existing crop-yield-index insurance. And by 2012, up to 12 million farmers growing 40 different crops over 15 million hectares were insured against weather-related losses (CCAFS, 2013). There are still lacuna in these pay out structures and need to be refined by the insurance companies in consultation with Agrometeorologists and other SAU scientists of the concerned state.

6. Conclusions

To make rainfed farming more economical and sustainable under increasing frequency of droughts, decrease in number of rainy days, and extreme & untimely rainfall, efficient use of water, soil and farm management practices in an integrated approach is both essential and a prerequisite. All India Coordinated Research Project for Dryland Agriculture (AICRPDA) with its 25 centers in different agro-ecological regions covering diverse rainfed production systems has developed several location-specific technologies to cope with different situations including delayed onset of monsoon, mid-season drought and terminal drought. Some of these technologies are *in-situ* moisture conservation, rainwater harvesting in farm ponds and efficient utilization, integrated nutrient management modules, foliar sprays for drought mitigation, resilient crops & cropping systems, and contingency crop plans. Rainwater harvesting not only reduces runoff and soil loss but also facilitates groundwater recharge. It enables the farmers to provide supplementary irrigation to crops grown during monsoon season and also to go for the second crop during winter season, as brought out by the success story in Rajasthan. There is a need to upscale these technologies through KVKs, ATMA and several national/state programmes of the Governments for realizing the productivity enhancements and large scale impacts.

7. Way forward

(*i*) Water is a critical natural resource and managing rainwater *in-situ* or harvesting runoff water and its recycling is key to mitigate drought. Location-specific needs of soil & water conservation measures *vis-a-vis* changing rainfall scenario will address water issues much better.

(*ii*) Well conceived watershed programmes impacted positively and these positive attributes of successful watershed programs need to be strengthened. Public-Private-Partnerships (PPP) that create market links have proved their productivity in several watersheds sites and created win-win situations for all stakeholders involved. Therefore, it is necessary for formulation of a coherent set of guidelines to enable governmental actors and consortium partners to efficiently approach the private sector and begin fruitful collaborations in PPPs. These partnerships need to strengthen market linkages and value chains and increase investments by the private sector in watershed development. The District Collector should function as the central agent who connects the different actors, aligns and harmonizes the cooperation of all departments involved.

(*iii*) The main emphasis in rainfed farming systems is to build the soil organic matter (SOM) for soil health restoration. Field burning of crop residues must be stopped and constant efforts are needed to move these surplus residues into soil system either as manure or surface cover. Techniques of residue management must be taught at all levels, including extension workers and land managers. Apart from these, a region-specific, need based crop residue management plan should be developed. The opportunity to promote adoption of various location specific integrated nutrient management (INM) practices in rainfed systems need to be pursued to a greater extent with convergence of various government programmes being implemented.

(*iv*) Community level seed banks with buffer stocks of seed material of diverse crops appropriate for the village/area need to be maintained. Seed banks should be controlled and maintained by organized farmer groups.

(*v*) A specific and viable system has to be put in place for developing feed and fodder banks at strategic places in the rainfed areas. Biomass intensification specially targeting the small ruminants should receive the highest priority; much of the shrub/tree-biomass for goats and sheep can be enhanced easily with little effort/resources. Small fodder banks could be established with the surplus fodder collected at monthly intervals from the common lands during rainy season.

(*vi*) There is an increased need for weather based agro-advisory services (AAS) in farming activities for access to real time weather information, timely agricultural operations, improved crop yields, reduced cost of cultivation, need based changes in cropping patterns and finally improved livelihoods. The district level weather forecast could be used along with current crop and weather condition for preparation of block level advisories by respective KVKs. A pilot methodology for preparing and issuing agromet advisories at block level has been tested at KVK, Belgaum. The main innovation in this project is to set up an architecture involving KVKs, state line departments and field information facilitation for collection of real time crop data, formulation of an appropriate advisory and its dissemination. Field Information Facilitators (FIF) have been appointed in 10 Talukas of the district to collect information on weather, crops, disease and pest incidence. They supply information by phone or by e-mail to contact staff at KVK who in turn develop a qualitative Agromet Advisory specific to the village/farmers, in consultation with Agrometeorologist of SAU and Scientists of KVK. This helps in further value addition in terms of management options.

(*vii*) Drought preparedness and real time implementation of contingency measures at field level needs well structured institutional support with strong government policy and convergence among various institutions. Rainwater management interventions like water harvesting and storage structures are capital and labour intensive thus, can be converged with RKVY, MGNREGA, NHM and IWMP programmes. Further *in-situ* moisture conservation interventions which are land based activities can be converged with MGNREGA and DRDA (District Rural Development Agency) programmes in a district. Efficient utilization of stored rainwater in farm ponds with micro-irrigation systems like drip, sprinkler etc could be converged with government schemes like Micro-irrigation Project in Andhra Pradesh, NHM and SHM (State Horticulture Mission). Mega Seed Project and National Seeds Project of GoI, Seed multiplication programmes in State Agricultural Universities and Stae governments and District authorities have greater role to provide suitable drought tolerant and short duration seed material to cope with delayed onset of monsoon.

(*viii*) Greater emphasis has to be laid down by the extension department for increasing exposure visits, trainings and demonstration of location-specific farming system models, for creating greater awareness and capacity building of the farming community towards upscaling relevant climate resilient technologies.

(*ix*) There is an urgent need to revamp the weather/crop based insurance programs. The risk in weather insurance is not only inherent in the location of reference weather station but it is also a function of the design of the Weather Based Crop Insurance Scheme (WBCIS) product. The specialized nature of product development, the esoteric terminology used in a term sheet, and the concoction of agro-meteorology, statistics and economics within the underlying parameters have the undesirable effect of turning weather insurance into an incomprehensible device. Further, one of the common criticisms of weather insurance has been its limitation of insignificantly compensating the insured farmers for even the worst of crop seasons. The insurance programs should be aimed to facilitate both repay of crop loans and investments for crop cultivation. Part premium payment could be met out of watershed based programmes or a special fund could be created.

(*x*) Considerable efforts are needed at all levels to sustain the momentum.

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