3 Agriculture Drought Management Options: Scope and Opportunities

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Abstract

Drought is one of the recurring features of Indian agriculture especially in the rainfed areas. Severity of its impacts depends upon its nature (chronic and contingent), its duration and frequency, and the extent of area afflicted. Drought not only impacts production at farm level vis-à-vis national food security but also causes miseries to human life and livestock. The present drought management strategies, however, are skewed toward crisis management rather than risk management. The latter needs enhanced insight into even the minute features of the agroecologies for viable solutions to mitigate drought stress. These solutions are determined by capacity to reduce soil moisture deficit, minimizing the impact of drought and accelerating the recovery. However, the key technologies for drought proofing are watershed management, *in situ* water conservation, and integrated farming systems that include resilient crops, contingent crop plans, etc. Drought stress management further needs shaping through modern tools for characterization of agroecosystem, stress mitigation options, and genetic modification of crops for drought tolerance. In this context, the present review attempts to look at various options being offered by advances in drought management.

3.1 Introduction

Drought is an integral part of farmers' life in 68% of cultivated area in India that is vulnerable to water deficits resulting from failure of rains and lack of access to stored water in natural or artificial reservoirs above or below the ground. Definitions and different perspectives of this natural disasters have been elaborated in different

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reviews and reports (Kramer 1983; Wilhite and Glantz 1985; NAAS 2011). While some of these definitions are conceptual others are operational or disciplinary (Table 3.1). The management of drought has now become an essential feature of national disaster management system that has evolved as an integrated institutional mechanisms for holistic, proactive, multi-disaster-oriented and technology-driven strategy through various approaches for prevention, mitigation, preparedness, and response (GoI 2009; Rathore et al. 2014). Till recently, the focus of drought management strategy was primarily on crisis management during the drought, and there is now an increasing awareness on management of risks of drought for the human and livestock population as well as agricultural crops. Though the reasons can be traced ultimately to atmospheric and hydrological droughts, the agricultural drought is unique in the sense that it impacts the society through its adverse effect mainly on crop plants including forages, which then affect livestock. By definition, agricultural drought is the situation when crop plants face deficit of soil moisture for their growth and development which consequently lead to losses in productivity. Here drought stress refers to inadequate water availability in quantity and distribution during the life cycle of the crop, which is the most important production risk for many crops worldwide (Beebe et al. 2013). In this context, the intervention of modern science for management of agricultural drought assumes immense significance.

Countries like India with major agroecologies being rainfed have been witnessing frequent drought episodes, but their frequency has increased in the recent past. Though this cannot be exclusively attributed to climate change, the predictions are now warranting enhanced efforts to explore drought adaptation and mitigation options to ensure food demand of about 1.6 billion population expected by 2050. Even in the absence of climate change, diminishing water supplies, urbanization, shifting diets, and the additional demand on cereals like maize for fodder and fuel pose challenges for agricultural sector (Hubert et al. 2010). In countries like India where the two-fifth of irrigated agriculture contributes about half the production and the rest, which is prone to drought, contributes three-fifth of the production, the rest three-fifth comprising of rainfed ecosystems contribute only about two-fifth of production.

Despite reduced contribution of agriculture to national GDP since independence, about half the population depends on agriculture, and about half of that are vulnerable to impacts of drought. Drought-prone agricultural lands cannot be neglected as the food production needs to be doubled by 2050 particularly when climate change events are likely to amplify adverse effects of natural disasters. Lessons learnt in the past have helped evolving institutional mechanisms for reducing the impact of drought though holistic solution are yet to be evolved for this recurring problem. In addition to the focus on staple food crops, increased understanding of response of horticultural crops and livestock production system to drought is essential.

Table 3.1 Concepts and definitions of drought

Type	Description
Conceptual	A long period with no rain, especially during a planting season (American Heritage Dictionary 1976)
	An extended period of dry weather, especially one injurious to crops (Random House Dictionary 1969)
Operational	An operational definition, for example, would be one that compares daily precipitation values to evapotranspiration (ET) rates to determine the rate of soil moisture depletion and expresses these relationships in terms of drought effects on plant behavior at various stages of crop development (Wilhite and Glantz 1985)
Disciplinary	Defined according to disciplinary perspectives (Subrahmanyam 1967) 1. Meteorological/atmospheric drought
	Meteorological drought is classified based on rainfall deficiency w.r.t. long-term average – 25% or less is normal, 26–50% is moderate, and more than 50% is severe
	In India meteorological drought is classified based on rainfall deficiency w.r.t. long-term average – 25% or less is normal, 26–50% is moderate, and more than 50% is severe
	Palmer drought severity index (PDSI)-based definition: The palmer drought severity index (PDSI), developed in 1965 by W. C. Palmer, is the widely referred meteorologic drought definition in the United States and is well known internationally
	The PDSI relates drought severity to the accumulated weighted differences between actual precipitation and the precipitation requirement of evapotranspiration (ET). Although commonly referred to as a drought index, the PDSI is actually used to evaluate prolonged periods of abnormally wet or abnormally dry weather
	2. Hydrological drought
	Hydrological drought is best defined as deficiencies in surface and subsurface water supplies leading to a lack of water for normal and specific needs. Such conditions arise even in times of average (or above average) precipitation when increased usage of water diminishes the reserves
	Definitions of hydrologic drought are concerned with the effects of dry spells on surface or subsurface hydrology, rather than with the meteorological explanation of the event. For example, Linsley et al. (1975) considered hydrologic drought a “period during which stream flows are inadequate to supply established uses under a given water management system”
	3. Agricultural drought
	Agricultural drought definitions link various characteristics of meteorological drought to agricultural impacts, focusing, for example, on precipitation shortages, departures from normal or numerous factors such as evapotranspiration
	A plant’s demand for water is dependent on prevailing meteorological conditions, biological characteristics of the specific plant, its stage of growth, and the physical and biological properties of the soil. An operational definition of agricultural drought should account for variable susceptibility of crops at different stages of crop development. For example, deficient subsoil moisture in an early growth stage will have little impact on final crop yield if topsoil moisture is sufficient to meet early growth requirements. However, if the deficiency of subsoil moisture continues, a substantial yield loss would result

(continued)

Table 3.1 (continued)

Type	Description
	4. Socioeconomic drought
	Definitions which express features of the socioeconomic effects of drought in addition to features of meteorological, agricultural, and hydrological drought. For example, socioeconomic drought is said to be occurring when the supply of particular commodity drastically falls short of demand due to less precipitation and harms the progress of society for that particular year or season

3.2 Intensity of Drought and Losses

On an average, severe drought occurs once in 5 years in most of the tropical countries, though often these may occur during successive years causing huge losses to agriculture and misery to human life and livestock. Almost every year, varying intensities of drought affect one or the other region of the country. Almost two-thirds of the geographic area of India receive low rainfall (<1000 mm), which is also characterized by erratic and uneven distribution. Technical Committee on Drought Prone Area Programme and Desert Development Programme identified about 120 million hectares of the country's area, covering 185 districts (1173 development blocks) in 13 states as drought prone. Based on the historical records, about 130 droughts/famines have been reported in one or other part of the country between 1291 and 2009. During the twentieth century alone, droughts of varied intensities occurred during 28 years in India (NAAS 2011). The loss in production of food grains due to drought averaged over in 1970–1996 has been estimated to be 1.8 billion year^{-1}, which was equivalent to 8% of the value of food grain production in the region. This needs to be revisited taking into consideration the worst droughts that occurred till recently. In 1972 and 2009 the nationwide rainfall deficits were 24% and 23%, respectively. Rainfall was 19% below normal during the droughts of 1979, 1987, and 2002. Food production was declined by an average of 10% year-on-year in a drought year. In 1987, the delayed onset of the monsoon in certain parts and the prolonged dry spells in most parts of the country severely affected agricultural operations in 58.6 M ha of cropped area in 263 districts in 15 states and 6 Union territories. About half of the area was not sown at all. In Gujarat and Rajasthan the drought was third to fourth in succession and even Punjab and Haryana received less than 50% of normal rainfall. In addition to acute water shortage for 54,000 villages of Rajasthan, there was severe deficit of fodder for livestock. Drought in 1987 affected about 16.8 million cattle across the country (Anonymous 1991).

In terms of magnitude, the drought of the year 2002 ranked fifth among the severest droughts India faced since 1875. The intensity of aridness in July at 51% rainfall deficiency surpassed all previous droughts. The impact of drought spreads over 56% of the landmass threatening livelihood of about 300 million people in 18

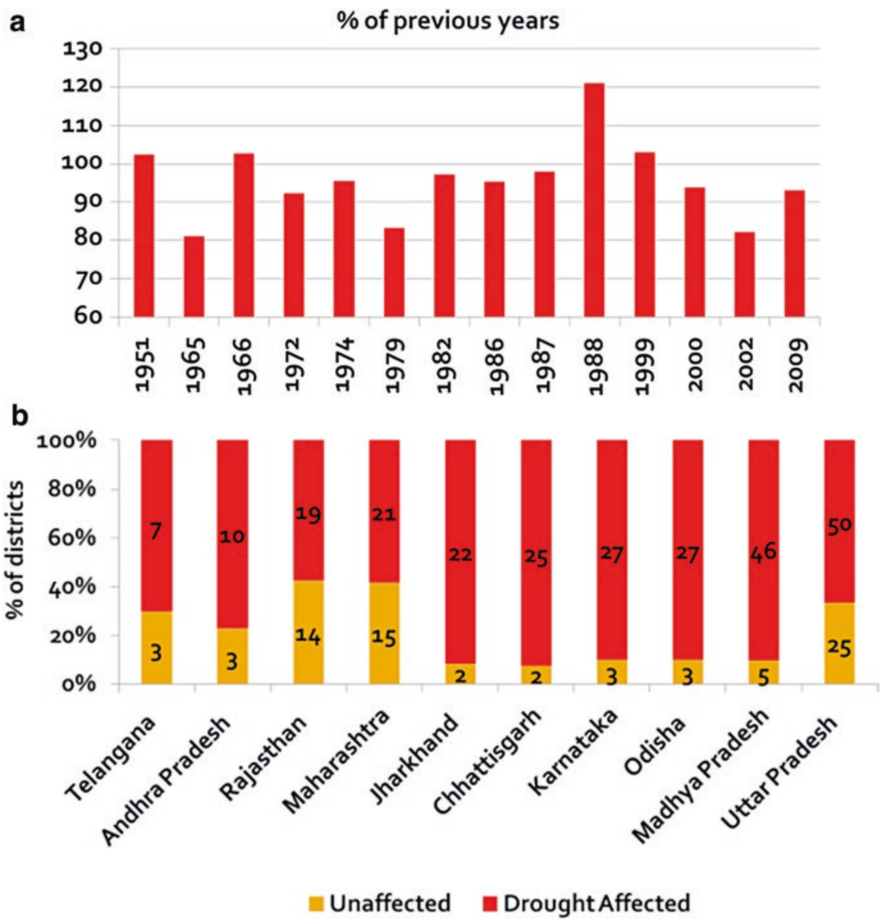

Fig. 3.1 Losses in food production during drought years (**a**) and drought-affected districts in different states of India during 2015–2016 (**b**) (Based on DOAC (2016), Gov India data)

states (NAAS 2011). This drought reduced the sown area to 112 million hectares from 124 million hectares and the food grain production to 174 million tons from 212 million tons, thus leading to a 3.2% decline in agricultural GDP (Murthy et al. 2010). Most of the drought-prone areas lie in the arid (19.6%), semiarid (37%), and subhumid (21%) areas of the country that occupy 77.6% of its total land area of 329 million hectares (Anonymous 2012). In 2015–2016, more than 40% of the area of 10 states was severely affected by drought (Fig. 3.1) indicating that drought will continue to be the major constraint in ensuring the food security that encompasses availability, access, utilization, and stability of a healthy food supply (FAO 1996). This necessitates an overview of progress made so far and scope ahead for further gains from scientific advances.

3.3 Achievements and Challenges

The growth of crops and the food production in the country are strongly influenced by total rainfall during *Kharif* season (Venkateswarlu et al. 2012). Though not completely solved by persistent efforts during the last six decades for developing improved practices, better logistics, and timely interventions, there is evidence to support the view that such drought-proofing measures have lowered the impact of droughts of the recent years (Fig. 3.2). These impacts have emerged from technologies focused for prevention, mitigation, and risk management. Providing access to water was the main goal of integrated watershed management and other in situ water conservation measures, which were successful in many places but yet to cover hitherto unattended regions. The success of these interventions was more conspicuous in regions that receive erratic or optimum rains. However, the rainfall abrasions during southwest monsoons continue to be major factors contributing toward instability of food production especially in rainfed areas.

Crop improvement options were explored extensively for almost all the crops including rainfed rice that is known to have high water requirement. Several

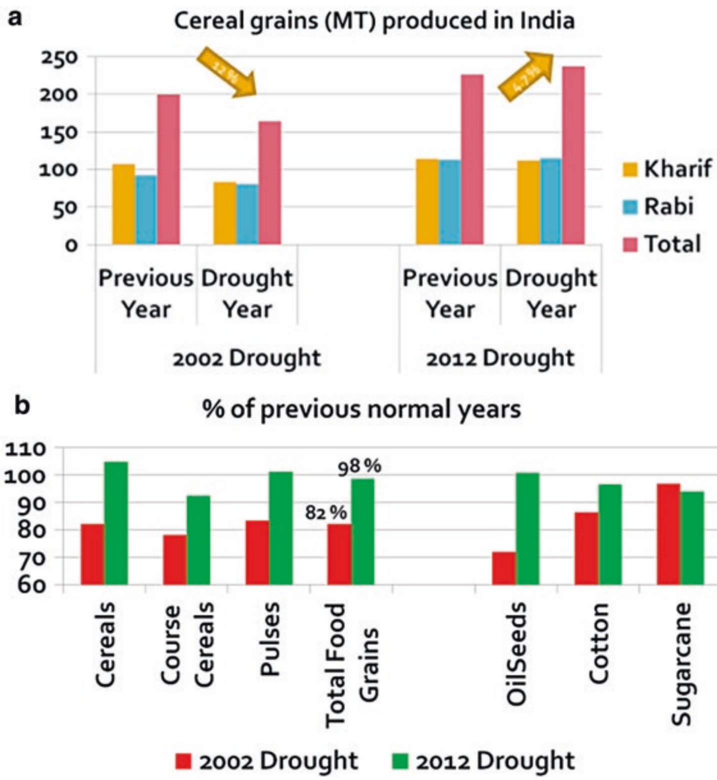

Fig. 3.2 Comparison between 2002 and 2012 drought years with respect to cereal production (**a**) and percent reduction in different food crops (**b**) (Based on DOAC (2016))

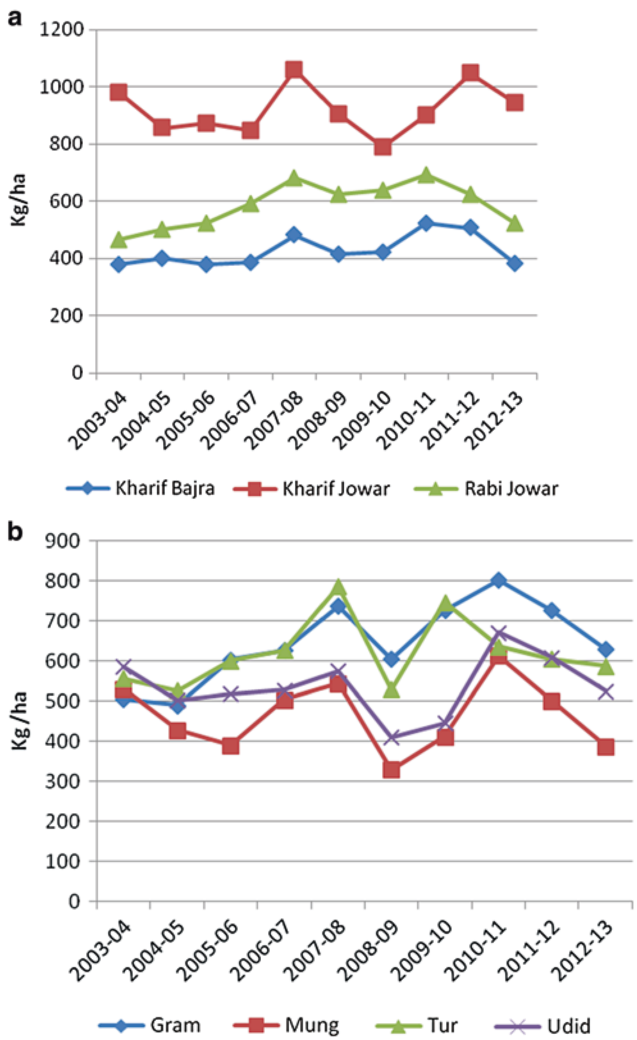

Fig. 3.3 Trend in productivity of cereal (**a**) pulse (**b**) crops in Maharashtra (Based Maharashtra Agriculture Statistics)

high-yielding varieties have been released for cultivation in rainfed and drought-prone areas by national (AICRPs for different crops) and international institutes. In addition, improved production practices have been developed to get maximum yield from these varieties. However, these technologies remain ineffective when the drought is featured by extreme delay and total failure of rains (Fig. 3.3).

Integrated farming system featured by small ruminants in livestock was perceived as viable solution for assured income under drought situation; however, the fodder crisis during drought usually limits the potential of such ventures in large scale. Unlike vast well-managed grasslands in the developed and scarcely populated rural landscapes of the west, Indian livestock production continues to depend on village common lands and largely on crop residues. Dryland fruit crops though do not require large quantities of water; the acute shortage during the dry spell can devastate their orchards as has been observed during the recent droughts in Vidarbha and Marathwada regions of Maharashtra.

Soil and water conservation measures in drought-prone areas are also given due attention as the absence of rains and consequent lack of crop cover lead to substantial soil loss contributing to land degradation. However, the distressed farmers pay little attention to this fact unless provided with support from concerned public and private agencies. Dire necessity for contingency plans to tackle the drought was emphasized in various forums, and as a consequence the contingency plans have been prepared for 614 districts. Persistent efforts are being made to scale up the best practices for rainwater and soil management through linking on-station and on-farm research (Venkateswarlu et al. 2008; Rao et al. 2014). Focus is also on alternate and diversified land use systems that can contribute to agricultural drought management. Remote sensing has emerged as robust tools for assessment, monitoring, and forewarning the drought episodes, and thereby efforts are on strengthening the forecasts for early warning, vulnerability, and assessment of drought.

3.4 Scope for Technological Interventions

Unlike other natural disaster, the occurrence and impact of drought is gradual and hence allows sufficient scope for managing it through technological interventions. Agriculture persists in drought-prone areas because the drought years are followed by normal years. For example, deviations from normal rainfall from 1998 to 2015 in Solapur District of Maharashtra (Fig. 3.4) reveal cyclic nature of drought with phase of normal years of 3 to 4 years followed by drought years of almost similar duration. While beginning of the cycle the district received 70% higher than the normal, the end of the cycle witnessed 40–60% less rains. There were intermediate years when the rain deficits were not severe. Such trends are very common particularly in rainfed areas. In this context, drought cycle management is crucial for enhancing the benefit for farmers with approaches that encompasses prevention of losses, mitigation, and risk management (Table 3.2). Such approaches should consider the short- and long-term profit without technological footprint on the environment. This should be based on weather predictions and land use plans suited to soil type and other features of agroecologies.

Through the drought cycle management, farmers can get higher productivity from improved crops and resilient livestock, production technologies, and protection technologies particularly during favorable years, while risk cover can take care of him during harsh years. At the same time during normal as well as severe drought periods, attention is needed for protecting and developing the agroecosystems through appropriate land degradation prevention efforts.

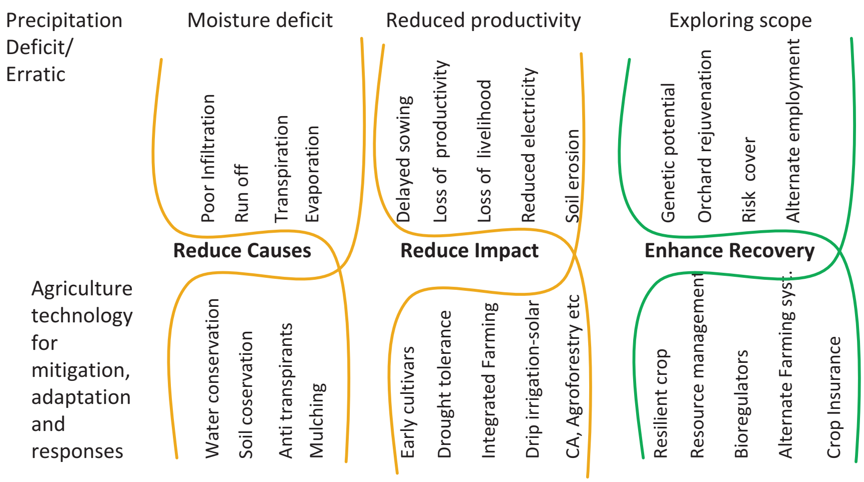

Fig. 3.4 Conceptual framework for managing drought stress through agricultural technology interventions

Table 3.2 Technology intervention for drought cycle management

Beneficiary	Source	Technologies and tools	Drought cycle
Farmer	More productivity	Improved crops and resilient livestock	Favorable years
		Improved production technologies	
		Improved protection technologies	
	Less reduction in losses	Robust weather predictions	Unfavorable years
		Resource management	
		Resilient crop with environmental plasticity	
	Continued income	Risk cover	Transition period
		Protection of biennial and perennial crops to ensure recovery	
		Sustainable farming systems	
Natural ecosystem	Prevention of land degradation	Soil conservation technologies	Unfavorable years
	Enrichment of natural reservoirs	Watershed technology	Favorable years
		Ground water recharge	

While drought management in broad sense including even nonagricultural sector has been given due emphasis for crisis management, it is suggested that the three key components (Fig. 3.5) should be integrated in conceptual framework for agricultural drought management. The conceptual framework considers precipitation deficit and erratic rainfall with long spells of dry weather as primary cause of soil

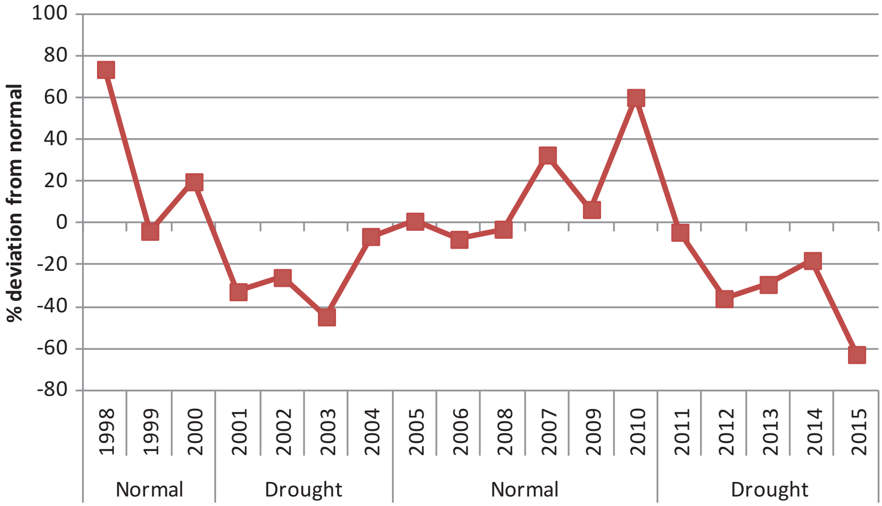

Fig. 3.5 Drought cycle at Solapur District of Maharashtra depicting deviation from normal rainfall (Based on Maharashtra Agricultural Statistics)

moisture deficit. However, it also recognizes features of soil as factor that allows determination of options for reducing the causes of soil moisture deficit. While reduced agricultural productivity is the immediate impact, it hopes on technologies to reduce these impacts with resilient commodities or stress-mitigating natural management options. Further, the framework considers recovery from stress as one of the major component for management of drought particularly with respect to perennial horticultural crops, livestock, and also farmer. There are several proposals, policies, and institutional mechanisms which cover prevention, mitigation, stress relief, and recovery in broader perspectives including socioeconomic aspects. However, the present review focuses largely on scope and options offered by science for reducing drought risks for agriculture.

3.4.1 Reducing the Causes of Soil Moisture Deficit

There are four major factors that lead to soil moisture deficit, viz., loss due to poor infiltration of water, run-off, high evaporation, and transpiration. These are largely determined by climate, soil properties and topography of land, and laws of water dynamics (Unger et al. 2010; Kirkham 2011). These causal factors also determine the type, intensity, and duration of agricultural drought and can be successfully addressed through modern approaches for integrated watershed management (Molden 2007; Joshi et al. 2008; Bhan 2013; Nagaraja and Ekambaram 2015) and conservation agriculture (Hudson 1987) involving mulching (Shekour et al. 1987; Choudhary 2016) and intercultural practices. Antitranspirants have been demonstrated to improve crop yield in sorghum (Fuehring 1975), maize (Fuehring and Finkner 1983), and potato (Pavlista 1995) but are cost prohibitive.

3.4.2 Minimizing the Impact of Drought

Major impact of drought on agriculture is manifested mainly through damage to crops and gradually the livestock dependent on fodder production and water. The prolonged drought and incessant rains can cause heavy losses by degradation of land. The agriculture once crippled by drought can affect livelihood and hence income of rural mass which consequently face severe economic constraints for farmers who often depend on loans. The nature of damage to crops depends on drought intensity, which is determined by its timing, duration, crop growth stages, and also the soil type and landscape at a particular location. Technological interventions to minimize the losses can emerge from natural resource management with focus on conservation and input use efficiency, genetic improvement with focus on tolerance to stress, and policy support research with focus on adaptation of technology and market strategies for enhancing profit for farmers. When farmers get engrossed with immediate relief from the drought, the damage to land due to soil degradation is often neglected. The community efforts supported by government and voluntary agencies can help prevent this by employing appropriate strategies involving integrated watershed concepts. Already released varieties of crops for drought-prone areas if matched with resources and agroecosystem features can minimize the losses due to drought. Contingency plans have been developed for minimizing the losses but needs to be extended to drought-prone regions. In addition to resource management technologies, improvement in resilience to soil moisture stress can be achieved by adopting drought-tolerant crops. This needs genetic improvement efforts. New omic technologies, specifically genomics and phenomics, have opened new avenues to support conventional breeding approaches for developing crop varieties tolerant to soil moisture deficit at different locations. The yield component-based selection procedure is gradually leaning toward trait-based approaches for imparting drought tolerance in crops.

3.4.3 Enhancing the Recovery from Drought

The recovery from agricultural drought should be attended by taking into consideration the necessity to recover the annual crops from mid- and early season drought, perennial horticultural plant after long dry spell, recovery of livestock, and recovery of farmers. This can be accomplished by technological interventions such as application of bio-regulators, real-time contingency plan for midseason drought, fodder banks, and risk cover through crop insurance. The foremost factor that enables recovery from drought is resumption of precipitation while technologies can enhance the recovery of crops damaged by deficit soil moisture. Technologies can benefit the crops if drought occurs at mid-, early, or late season if not throughout the crop growth stage particularly in case of annual staple food crops. The role of bioregulators have been demonstrated to alleviate the abiotic stresses including soil moisture stress in some of the crops as illustrated in other chapters. This option has to be explored for all the drought tolerant cultivars and different drought situations.

Resource management technologies for real-time contingency have been successfully demonstrated but needs to be scaled up to suit location-specific requirements. Crop improvement technologies have resulted in crop cultivars specific to rainfed, arid, and semiarid regions which experience drought; however, they need to be tailored for updated agronomic practices and nature of drought that varies widely across the location. There is a scope for development of technologies to address delayed onset to maximum of three weeks from normal date for the given region, early onset and sudden breaks, early withdrawal of monsoon, and delayed withdrawal or extended monsoon which all contribute to drought faced by the crops. There is a scope to test these technologies in real-time situation.

3.5 Reorientation of Approaches

Some of the evolved technologies are not being adopted due to constraints at the field level. These gaps can be bridged through a deep insight into the nature of drought in location-specific context, mechanisms, and traits that enable crop plants to survive and perform in soil moisture-deficit environment. Varieties of crops with high and stable yield, production technologies that can reduce gap between potential and realizable yield, and protection technology that employ bio-regulators can become integral components of drought management plans. The technologies that were evolved during the past decades may not provide much dividend as any improvement in production and productivity should not have environmental footprints.

3.5.1 Insight into Agroecosystems Facing Drought

Variability in drought ecologies exists across the country, and strategies to manage these cannot be the same though adequate access to water is ultimate solution for development. However, it is possible to outline common options as well as specific options for mitigation and adoption by soil type and the climate-dependent choice of agriculture enterprises. For example, in Maharashtra, where about 80% of cropped area is rainfed, the intensity of drought and its impact vary widely on deep/medium/shallow black soils due to deficient rains at early stages, midseason, or/and at terminal stages of crops (Fig. 3.6). So the management options should match the location-specific requirement for improvement in agricultural productivity. This also demands close link between departments of agriculture, agriculture extension agencies, research institutes, and academic institutes.

3.5.2 Effective Contingency Plans

Contingency planning is a management process that analyzes specific potential events or emerging situations that might threaten society or the environment and establishes arrangements in advance to enable timely, effective, and appropriate

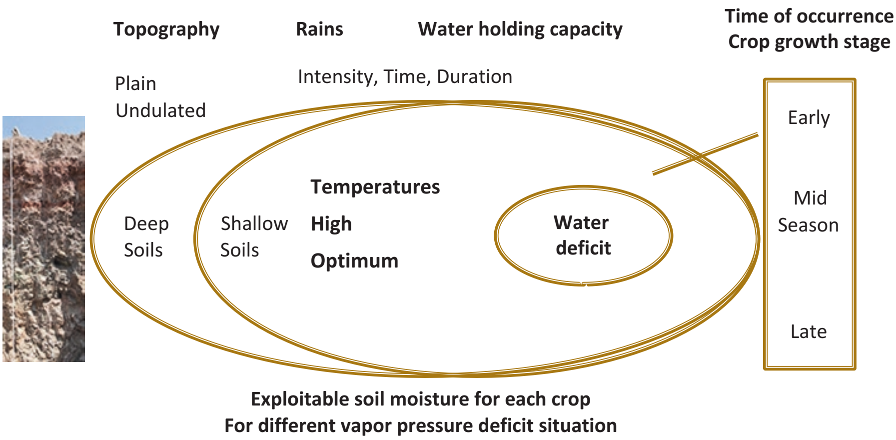

Fig. 3.6 Factors contributing variability and nature of drought

responses to such events and situations. It refers to a feasible strategy for implementation to mitigate the losses due to stress when problem occurs. The fundamental issue of prediction of drought in advance is addressed by meteorological divisions while the task of minimizing the losses to agriculture in general and crops in specific from the next drought depends on existing technologies. Hence, the contingency plan necessarily encompasses technological interventions to minimize the loss. The effectiveness of the contingency plan is determined by the scale at which it is implemented and the emphasis on the diversity in nature of drought to fit the best available technology. Crop contingency plans have been prepared for 614 districts that have now become the integral part of drought management action plan for the nation. In addition, some real-time contingency plans in the event of failed or deficient rains have been successfully demonstrated (Srinivasarao et al. 2013).

3.5.3 Drought Cycle Management

Drought is a cyclic process and therefore actions to be taken have to be phase dependent (Pantuliano and Wekesa 2008; Lesukat 2012). When drought is inevitable, seeding or planting can be avoided instead of losing crop. Vast areas remain uncultivated and become vulnerable to wind and excess rains responsible for soil erosion. However, the limited rains can sustain some cover crop that may be useful in fixing nitrogen and enriching soil with organic matter during the dry spell. This can help in improving the productivity of subsequent crops as benefit of cover crops are increasingly evident (Mahama et al. 2016). Farming system approach with new technological options for crop and livestock suited to specific agroecologies can minimize the losses due to drought. Emphasis on livestock during the predicted drought years and crop production during the favorable years needs to be optimized at each smallest unit of agriculture sector.

Farmers have learnt about the nature of drought by experiencing it and are usually hesitant to adopt costly technologies unless convinced about the benefits of emerging ventures. The technologies which are optimized for small and marginal holdings will have more acceptances. For enhancing the acceptance of these technologies, it is necessary to combine them with weather-based risk cover through crop insurance in the event of drought. Availability of quality seeds of crops and other essential inputs become major constraints for re-sowing if early secession of monsoon spoils the crop. Similarly, failure of crop during the drought year places substantial pressure on seed supply chain for the subsequent year. Hence, drought cycle management approach should include production and supply of seeds and other inputs like seed treatment formulation/microbial cultures for ensuring benefits from favorable season in drought-prone area. Further, activities essential for prevention of degradation of land and water resources can be beyond the capacity of farmers when crop cultivation is totally hampered by drought. Many of the soil health improvement approaches can be carried out during the drought periods for the benefit of crops during ensuing season with the support of disaster management agencies.

3.5.4 Integrated Models for Soil–Crop–Atmosphere Interaction

For drought cycle management, diversity-based contingency plan can be effectively implemented with an improved insight into the soil–crop–atmosphere continuum. Performance of crops under a given environment is influenced by several production factors which are embedded in soil and atmosphere, and these factors contribute to the complexity in the assessment of stress-prone areas. Crop modeling and simulation facilitate the decomposition of complex nonlinear interactions among production factors. When combined with biology, environment, and policy sciences, it strengthens agriculture decision-making (Adlul et al. 2014). Several models are being used to predict climate change, impact under different scenarios, and the crop performance. International Agricultural Model Intercomparison and Improvement Project (AgMIP) is looking forward to filling the gaps in current generation of simulation models that are inadequately account for soil–crop–atmosphere interaction responses to the wide variability of temperature and precipitation (Hatfield et al. 2011). Hence, it seeks to replace them with the most advanced and robust crop simulation models to project future crop production and to enhance development of adaptation strategies to cope with climate change (Rosenzweig et al. 2013). Further, crop modeling-based management of limited water sources (Islam et al. 2014) may be immensely useful for drought-prone regions. This is highly crucial as India is facing water scarcity as evident from per capita availability of water declining sharply from 5177 m^3 in 1951 to 1544 m^3 in 2011 (CWC 2013). It is projected to reduce further to 1465 and 1235 m^3 by the year 2025 and 2050, respectively, under high population growth scenarios (Kumar et al. 2005).

3.5.5 Emphasis on Genetics × Environment × Management Interaction

Only the genotype and environment interaction used to be the focal point for genetic improvement technologies till recently with the assumption that yield potential improvement can take care of the rest of aspects. At present there is drastic change in the way crops are raised. Conventional agronomic practices are now making ways for conservation and precision agriculture. Since our ability to expand the available land resources are not a viable option, actual yield increases and overall productivity should come from resource management for increasing land productivity. In this context, development of methods of screening genotypes for a variety of responses to combinations of environmental and management scenarios is highly essential. This needs transdisciplinary teams to represent each component of the G × E × M interaction (Hatfield and Walthall 2015). Closing the yield gap, defined as the difference between the farmer's yield and potential yield of a crop variety, is one of the best options as the gap can be as high as 50% under rainfed conditions (Lobell et al. 2009; Hatfield and Walthall 2015). Further, linking water use efficiency (WUE) with radiation use efficiency (RUE) will provide an opportunity for improvement in adaptation to drought environment (Hatfield and Walthall 2015). The proposals to consider concept of effective use of water rather than WUE may also change the way we select the crop for drought stress environments (Blum 2005).

Choice of a crop for a particular soil moisture stress environment is not necessarily governed by yield potential of a variety. For example, Lok 1 a wheat variety released 29 years ago is widely grown in central and peninsular India despite new cultivars released in the recent years. Traditional crop varieties outperform new drought-resistant varieties because of differing soil management practices (Hatfield and Walthall 2015). Recent analysis of field-level data revealed that the sensitivity of maize yields to drought stress associated with high vapor pressure deficits has increased from 1995 to 2006 though yields have increased in absolute value under all levels of stress for both soybean and maize. The agronomic changes tend to translate improved drought tolerance of plants to higher average yields but not to decreasing drought sensitivity of yields at the field scale (Lobell et al. 2014). Further, new options such as plastic mulch on ridge and bare furrows have advantage only in sandy soils and not in heavy soils (Xianju et al. 2014). Hence, it is essential to explore G × E × M approaches for further improvement in productivity of crops. Use of microbial consortium or microbial product in agriculture (Asghar et al. 2015: Xiao-Min and Huiming 2015) can add new dimension to G × E × M approach.

3.5.6 Mining Genetic Resources

There is an ample opportunity to search for stress-tolerant genes in wide range of cultivated and wild species of plants in genebanks. About 1750 plant genebanks have been established worldwide, with 7.4 million accessions maintained as ex situ collections in either seed banks, field collections, and in vitro and cryopreservation conditions (FAO 2010). Countries like India have as many as 346,000 germplasm of various crops, and these germplasm can be treasure of desirable traits for drought tolerance. In addition there are sets of mutant lines with induced genetic variation which exist for different crop species, and new techniques are emerged to create new genetic variants for gene function studies by employing molecular tools. A Robust CRISPR/Cas9 System for convenient, high-efficiency multiplex genome editing in plants is emerging and can be helpful in studying the genes associated with stress tolerance (Ma et al. 2016). Such high-end genomics and marker-aided selection can get support of emerging phenomics techniques (Furbank and Tester 2011; Yang et al. 2013; Klukas et al. 2014; Rahaman et al., 2015) to screen these large set of genotypes with great precision to discover traits and genes relevant to drought tolerance.

While the tremendous progress during the green revolution has been attributed to germplasm exchanged for crop improvement, recent trade-related issues and biodiversity ownerships have largely restricted the free flow of germplasm, which has become the cause of concerns (Aseffa and Welch 2015). At the same time, new inventions have made a way for several patents that have delayed the translation of science for benevolence of humanity. For example, about 70 patents delayed benefit of highly innovative and nutrient-rich golden rice for the targeted population having no access to sufficient quantity and quality of food. In this context, the Public Sector Intellectual Property Resource for Agriculture (PIPRA; www.pipra.org) is trying to establish “best practices” encouraging the greatest commercial application of publicly funded research without compromising the rights of public institutions to fulfill their responsibilities toward the public at large. With hundreds of inventions related to drought tolerance in plants patented, significant utility is expected from PIPRA’s efforts to establish a database providing an overview of IPR currently held by public institutions, with up-to-date information on the licensing status of these IPRs. Further the crop improvement for drought-prone regions can get a boost if freedom to operate (FTO) for use of new invention is facilitated through “technology packages” of complementary patents. (Atkinson et al. 2003; Gepts 2004). Efforts should be made to avoid complex restrictions and obligations that may hinder the exchange of genetic materials, public research, and further innovation (Seyoum and Welch 2015).

While the focus is on genetic variability for drought improvement in staple food crops, the opportunity to cultivate other crop species is yet to gain momentum. The human population today derives most of its calories from a very narrow set of crops, with only about 30 species providing 95% of the global food energy (Prescott and Prescott 1990; FAO 2010) and just three major crops, viz., wheat, maize, and rice, provide over 60% of our food supply. On the contrary, over 7000 species are known as edible and are either partly or fully domesticated, suggesting that a large share of potential food sources is underutilized (Rehm and Espig 1991; Wilson 1992). These underutilized crops carry unrealized potential to contribute to human welfare, in particular for income generation for the world’s poor, food security and nutrition, and reduction of "hidden hunger" caused by micronutrient deficiencies resulting from uniform diets. It is increasingly felt that challenges of global climate change and food security can be addressed by rescuing and using more diversity in agricultural and food production systems, both in terms of crop as in terms of varieties within any given crop (PAR 2010; FAO 2011). Diverse agroecosystem, crop diversification, and dietary diversification should be assessed in specific context of drought for integrating qualitative and quantitative knowledge on underutilized crops for decision support system. Any efforts to choose the best combination of unexplored crops and the well-characterized drought-prone agroecosystem can greatly contribute to the drought management in agriculture.

3.5.7 Dryland Horticulture Technologies

Extensive studies have been conducted to understand the mechanisms underlying plant responses to soil moisture deficit. However, implementation of technologies except for micro irrigation is not gaining momentum. Plants strategy to survive and perform during and after stress needs to be exploited for those horticultural crops where information is available. There is a need to generate such information for other crops for productive use of scarce and poor quality water though these plants are apparently adapted to dry region. Future orchard management practices for dryland horticulture should consider the emerging basic knowledge that mechanisms of tolerance to drought in young leaf are different from that in mature leaves (Claeys and Dirk 2013). It is well know that pollination is critical to fruit production, but the interactions of pollination with plant resources on a plant's reproductive and vegetative features are largely overlooked (Klein et al. 2015). There is an indication that thermal imaging can explain the responses of plant to soil moisture levels (Lima et al. 2016). There is clear demonstration of benefits of simple techniques such as mulching with straw or plastic films in conserving soil moisture and enhancing water use efficiency in crops like peach in semiarid region (Wanga et al. 2015). Deficit irrigation techniques optimized and method adopted to optimize the same in orchard crops like grapes (Lanaria et al. 2015), papaya (Nunes de Limaa et al. 2015), and pomegranate (Catola et al. 2016; Parvizi et al. 2016) need to be extended to other fruit crops to save water without compromising the quality of fruits. Such optimizations are likely to be largely determined by the type of soil and precipitation events at a given agroecology. However, site preparation techniques, careful species selection, planting, and care during the initial and other critical stages of development are the versatile tools for sustaining orchards during drought period (Minhas et al. 2015). Recently the information on abiotic stress physiology of different horticulture crops has been compiled (Srinivasa Rao et al. 2016) which can further serve as guide for translation of scientific knowledge into management practices for better harvest and income for farmers of dry and drought-prone areas.

3.5.8 Efforts Beyond the Usual Business

Some of the unusual approaches such as artificial rains can help to cope during severe water scarcity periods. Managing clouds to get rains have been tried by human being since time immemorial, and cloud seeding has been demonstrated for enhancing precipitation. Recently, Chinese scientists have perfected this art of managing clouds. The science of cloud seeding involves introduction of small particles for promoting condensation of moisture from cloud by serving as a nuclei to start with and precipitate down as snow or rain. Since the world is at the verge of facing severe water crisis, such technologies are likely to evolve fast. If the art and science are made prefect for managing cloud to get precipitation at desired time, at desired place, and in amount optimum for agricultural activity, our strategy to manage drought-like situation should be reoriented.

Introduction of genetically engineered crops warrant altogether different crop production approaches to comply with the norms of biosecurity. In addition, these crops need high input use efficiency-driven resource management practices as the cost of seeds may be higher than usual traditionally bred crop varieties. On the other hand, introduction of new crops may need altogether different agronomic practices. Future research for drought-prone agriculture should consider these aspects. If inbuilt constraints such as economically unviable size of land holdings are addressed through institutional mechanisms, every piece of land can get benefit of appropriately integrated modern science and viable conventional approaches emerging from traditional wisdom.

3.5.9 Village Transformation Into Drought-Ready Community

To make community-level drought planning more widespread, there should be close linkages between key stakeholders, planners, researchers, and villagers. This needs additional resources to work with organizations and communities. This can be achieved by wider publicity of success stories emerged from model villages. To be qualified as drought ready, the villages should get a start well in time, gather information on drought, establish monitoring, involve in public awareness and education, and prepare for response to drought and recovery. Advances in information technology can be effectively employed to facilitate many of the components of drought-ready community. For example, it is often seen that the farmers face lack of sufficient seeds of desired quality following the drought episodes though the likelihood of better weather offer them to recover from the drought shocks. Such situations can be predicted and the provision can be made to arrange for seeds and other inputs from other places which remain unaffected by drought. Alternatively, there should be access to technology and infrastructure to preserve the seeds during drought phase of drought cycle. Similarly, there must be ways to save drying orchards by bringing water from other places wherever possible. The cost of such ventures will be lesser for the community relative to individual.

3.6 Conclusion

Both the natural resource management and crop improvement research have played significant role in improving the productivity of crops in drought-prone areas as evident from reduced impact of recent drought on overall agricultural production of the country. Implicitly, we cannot neglect regional adverse impact of drought that tends to continue miseries of farmer in drought-prone area. It is also recognized that the achievement so far in developing technologies is not sufficient to meet the future demand for food, improved livelihood, and for stable and descent income of the marginal farmers. Hence, there is a need for accelerated efforts to develop technologies that can reduce the cause of soil moisture deficit, minimize the impact of drought, and accelerate the recovery to normal after the drought event. There is a scope for enhanced capacity to understand drought-prone environment facilitated by remote sensing and GIS and instrumentation and automation to monitor moisture in soil and plant tissues. Our understanding of impact of conservation agriculture as well as advances in genomics, phenomics, and metabolomics for genetic improvement can provide new opportunities for developing novel mitigation and adaptation technologies for drought-prone agriculture. In addition to crop-based agriculture, integrated farming approaches involving livestock and agroforestry with improved mechanization of agricultural operation can transform agricultural landscapes in drought-prone areas and also the remunerations for the farmers. Such ventures should give due consideration for land use plan options. With improvement in monsoon forecast, these technologies can provide robust solutions for management of drought at smallest level of administration. While the scientific community will continue to advance the understanding about the science of tolerance to drought in crop plants, it will better serve crop improvement scientists by providing a more in-depth and clear understanding of the adaptation and mitigation solutions. The focus of search for solutions should be a major component of translational research by involving multidisciplinary teams. With the state-of-the-art facilities for high throughput genomics, phenomics, proteomics spread across the institution, interinstitutional collaboration can bring the expertise on one platform where communications will be robust enough to avoid duplication and to promote synergies in developing scientific solutions for management of agricultural drought.

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