Drought in Indian perspective, its impact on major crops and livestock and remedial measures

Alok Singh Jayara
Department of Agronomy, Govind Ballabh Pant University of Agriculture & Technology, Pantnagar, US Nagar, Uttarakhand, India.

K. Indudhar Reddy
Agroclimatic Research Centre, ARI, Professor JayashankarTelangana State Agricultural University, Rajendranagar, Hyderabad, Telangana, India.

Roshan Lal Meena
ICAR-NBSS&LUP, Regional Centre, Udaipur, Rajasthan, India.

Drought is one of the important natural disasters which lead to maximum severity to human among all others. The vulnerability increases with the resource poor nature of developing and under developing nations. Considering the extent of rainfed area in India, the vulnerability to drought is higher compared to other peer nations. It has implications on agriculture, livestock, fisheries, rural employment, human nutrition and health. However, the impact initiates with crop production and encompasses livestock in medium term which has severe economic implications for farmer. Therefore, it is desirable to present an extensive study on the impact of drought on major crops and livestock in India. Further, we have also emphasised on the remedial measures to be followed for crop production and livestock.

Introduction
Drought is one of the several atmospheric phenomena which has catastrophic implication for life and livelihoods of the particular country. It is defined in various contexts from shortage of rainfall compared to the long period average, reduction in soil moisture and levels of water resources to the shortfall in ET demands of the crops. Increased incidence of disasters is the new normal, and drought incidence (along with other weather and climate related disasters) frequency has quadrupled from average 40 per decade in 1970s to 150 in 2010s (FAO, 2021). Drought is among the other extreme meteorological events such as heat waves, storms etc which can worsen other high impact events such as flooding, landslides, wildfires and avalanches (WMO, 2020). Drought causes short and medium term water shortage and reduces yield of crop and livestock under extreme heat stress (FAO, 2021). Drought is an extreme climatic event whose intensity and duration increases slowly and can have hydrological and socio-economic impacts including wild-fires, loss of crops and livestock, water scarcity, migration, increase in food prices and health effects (Mukherjee et al., 2018). The severity of drought can be gauged from the fact that it is dependent on twin atmospheric conditions i.e. prevailing precipitation and the temperature. While the former supplements the water, later put a demand on it and thus balance of two determine the drought conditions. Historically, precipitation is considered as the major cause of drought, however, with global warming scenario, rising evaporative demand is considered as major cause of drought events (Zhao and Dai, 2015). Drought is classified as meteorological, hydrological, agricultural and socio-economic, depending on the extent and severity of its impact. At individual plant level, it can bring physiological and biochemical stress which is manifested in the form of reduced growth and yield and at crop level, it impacts the gross harvesting of solar radiation and consequent yields which ultimately disrupts the food security and economy of the nation(s). Drought has impacted parts of interior South America in 2020 with an
estimation of loss of $ 3 billion in agriculture in Brazil alone whereas in parts of South Africa, it is continued to persist (WMO, 2020); however, prolonged drought along with conflict has resulted in the famine in Somalia between October, 2010 to April, 2012 (FAO, 2017). Globally agriculture supports livelihood of 2.5 million peoples and on account of its direct interaction with the environment, reliance on natural resources for production and importance in socio-economic development of nation, urgent actions are needed to build resilient agricultural systems (FAO, 2021). If only impact of drought is considered agriculture share rose to 84% whereas it is upto 25% with climate related disasters (FAO, 2017). There are evidences of the shift in climatic regimes which has increased the vulnerability towards the drought. It is evident from the recent impact of climatic extremes that ecosystems and human lives are vulnerable to heat waves, drought, floods, cyclones and wildfires (IPCC, 2014). It is important to have a comprehensive strategy for the drought management as it starts as small event of precipitation deficit and affects the soil moisture, hydrology and agriculture of the particular place (Rajasivaranjan, 2015). To mitigate impacts of drought along with other extreme events, it is suggested to integrate crop production with livestock, horticulture, apiculture, fisheries and agro-forestry (MoEFCC, 2021).

Drought in Indian perspective

The importance of drought situation to the country as whole can be gauged from the trailing facts. Agriculture contributes around 16 % of gross value addition and supports 48 % of the employment. 68 % of the total agriculture is rainfed. Around 74 % of the total rainfall is obtained during the south west monsoon. Overall drought risk to agriculture is higher in India due to the deviated monsoon, depleted ground water and food demand of population of 1.252 billion (Zhang et al., 2017). The monsoon in India is characterized by its erratic behavior in terms of its spatial and temporal distribution. The monsoon has the impact of various atmospheric phenomena such as Rossby waves/ jet streams and El-Nino which are strong in reducing rainfall over Indian sub-continent. Most of the drought conditions of the Indian summer monsoon rainfall are associated with El Niño (13 of the 18 years) indicating that about 72% of the drought years are associated with the influence of Pacific Ocean (Varikoden et al., 2015). Though every El Nino year is not associated with drought, however, there is strong inverse relationship between strength of El Nino and monsoon occurrence which negatively impacts the Indian agriculture (Pandey et al., 2019). Drought has hardest impact on the Southern and Western regions, however, these states have better adaptations whereas it has significant impact on North and Central regions, but the adaptation level is lower (Amarsinghe et al., 2020). It is considered that frequency of drought is once in 15 years in North Eastern India, however, it has been reported by Parida and Oinam (2015) that in the period 2000-15, eight years has experienced meteorological drought in this region. In a prediction study of 48 years (2050-2099). Ojha et al. (2013) predicted increase in drought incidence in west central, peninsular, and central northeast regions of India. In a study on drought characterization in India over projected climatic scenario in different time frames.
i.e. near-future (2010–2039), mid-future (2040–2069), and far-future (2070–2099) in comparison with reference period (1976–2005), increasing trend in drought severity, duration, occurrences, and the average length of drought under warming climate scenarios was concluded (Bisht et al., 2018). Drought studies in India are important not only in context of her own food security but also for nations which are dependent on imports of food grain from India (Udmale et al., 2020).

**Impact on crop production**

Agriculture is mainstay of Indian economy and any prolonged drought condition can jeopardize food security and bring the famine conditions. Understanding the impact of drought on crop production is itself challenging as it is complex interaction of temperature, precipitation, vapour pressure and solar radiation (Leng and Hall, 2019). In the crop production, drought can have impact from preparation of field, sowing operations, weakening of standing crops, increased vulnerability to the pest incidence and final impact on the quantity and quality of yield obtained (Gautam and Bana, 2014). The reproductive stages of the crops are more sensitive to the drought stress than vegetative stages leading to reduced flowers, pods, fruit set and number of seeds and is more severe when accompanied with heat stress and these two will be more common in current and future climate change scenario (Sehgal et al., 2018). The impact of drought on the crop production shows fluctuations. In the twelve drought years, the loss in crop production when compared to previous years varied from 2.8 % in the year 1982-83 to 19 % in 1965-66 and 13.2 % in 2002-03 (Badatya, 2005). Average crop loss of 86.1 % (for both Kharif and Rabi) was reported in 2012 in Southern Maharashtra, which varied from 67.8 % in maize to 98.2 % in cotton (Udmale et al., 2015).

**The impact of drought among major crops of India is presented below**

**Rice**

In India around 42 percent of the total 44 mha area under rice cultivation is rainfed (Mention the area of which country or region) (Birthal et al., 2015) and drought is major constraint of rainfed rice production (Kumar et al., 2014; Sharma et al., 2016). Drought has been reported to reduce relative leaf water content, inhibition of cell enlargement leading to reduced leaf size, reduced tillering and plant height and increase in the mean root length (Sharma et al., 2016). Multi stage drought led to the 86% reduction in yield in rice along with reduction in yield attributes; and deterioration of physiological parameters including decrease in chlorophyll content, relative water content, photosynthesis, transpiration rate, starch content and increase in proline content and lipid peroxidation when compared to non-stress, however, differences exist among growth stages and genotypes (Kumar et al., 2020). Similar findings were reported by Nahar et al. (2018) in rice.

**Wheat**

Out of 29 mha under wheat cultivation in India, 3-5 mha is susceptible to drought (Sheoran et al., 2015). The vegetative stage of wheat is more sensitive to drought as the root growth is reduced consequently reducing the leaf area, leaf number per plant, leaf size and leaf longevity (Zhang et al., 2018). Drought reduces chlorophyll content, membrane stability, relative water content, reduction in chlorophyll fluorescence and the yield and yield components, reduction in NPK uptake and increased the catalase, peroxidase and superoxide dismutase content (Abdullah et al., 2011; Nawaz et al., 2012; Sheoran et al., 2015), however the effect was pronounced with late stage drought stress than early season (Nawaz et al., 2012). 57-59 per cent reduction occurs in iron and zinc content per hectare with drought stress in wheat (Velu et al., 2016).

**Sugarcane**

Drought stress significantly reduces the juice quality including decrease in sucrose percentage, purity coefficient, (=Sucrose%/ Brix), commercial cane sugar %{ = (1.022 × Sucrose %) – (0.292 ×⁰ Brix)}, total soluble solids or brix, marginal decrease in pH, increase in reducing sugar content (Hemprabha et al., 2004; Mishra et al., 2016). Increase in proline content, SOD and peroxidase enzyme activity and decrease in plant height, single cane weight, number of millable canes, cane yield, relative water content, chlorophyll and carotenoids content was recorded with drought stress (Pawar and Bhutkar, 2011; Jain et al., 2015; Santeshwari, 2021).

**Oil seeds**

The morphological and physiological impacts of drought on oilseeds will be similar as described
under rice and wheat. In oilseeds, drought can impact the fatty acid synthesis and can lead to increase in saturated fatty acid (palmitic and stearic acid) content and decrease in unsaturated fatty acids (linoleic and linolenic acid) (El Sabagh et al., 2019). Drought stress reduces rate of flower production, peg elongation rate, seed growth rate and its weight; number of mature pods; pod yield; shelling percentage; harvest index and adequate pod zone soil moisture is important for development of pegs into pods; also leads to reduction in oleic: linoleic acid ratio which reduces the keeping quality and increases aflatoxin content which was independent of the drought tolerance of genotypes (Kenchanagoudar et al., 2002; Reddy et al., 2003; Hamidou et al., 2014), however, Dwivedi et al. (1996) reported increase in oleic acid content with end season drought in groundnut. Oil content reduces under the end season drought, however, it was not affected by mid-season drought (Dwivedi et al., 1996; Kenchanagoudar et al., 2002). Drought stress reduces the growth parameters and isoflavone content in soybean (Akhita Devi and Giridhar, 2013). There had been varying impact of drought stress on the growth and physiological parameters, yield attributing characteristics and yield of mustard depending on the genotypes (Chauhan et al., 2007; Singh et al., 2009). Though sunflower is considered moderately drought tolerant, any incidence of drought at critical stages can reduced photosynthesis, water potential, xylem and phloem transport, nutrient uptake, reduced capitulum diameter, number of achene per capitulum, achene weight per capitulum and ultimately achene yield, reduced oil content depending on the intensity of drought and its fatty acid composition (Nezami et al., 2008; Jaleel et al., 2009; Hussain et al., 2018). The bud initiation stage is more critical for drought stress than seed filling in sunflower (Jaleel et al., 2009).

**Pulses**

Pulses are generally grown under the rainfed conditions in India, therefore, more susceptible to the drought conditions. Chickpea being grown under residual moisture conditions, therefore, susceptible to terminal drought or moisture stress situations causing 40-50% global yield losses (Basu et al., 2004; Jha et al., 2014; Devasirvatham and Tan, 2018; Muruiki et al., 2018; Sinha et al., 2019). Drought stress leads to stunted growth, non-uniform plant stand, pale colored lower leaves, early senescence, reduction in days to maturity, chlorophyll content, Rubisco activity, sucrose synthesis, average reduction of 23% in number of seeds per pod, upto 54% reduction in seed size and increased incidence of dry root rot and black root rot (Kumar, 1997; Awasthi et al., 2014; Sinha et al., 2019). Though there had been reduction in the relative water content, photosynthetic apparatus was not impacted showing ability of chickpea to maintain turgor even under water stress conditions (Basu et al., 2004). Drought stress in pigeonpea led to reduction in relative water content, stomatal conductance, transpiration rate, total chlorophyll content, enhancement in proline content, superoxide dismutase, malondialdehyde and peroxidase activity, reduction in specific nitrogenase activity and leghaemoglobin content (Nandwal et al., 1991; Kumar et al., 2011; Vanaja et al., 2015). Flowering stage is most sensitive stage for drought stress in pigeonpea leading to 48% reduction of yield and upto 62% when combined with drought at pre-flowering (Lopez et al., 1996; Nam et al., 2001). Pigeonpea owing to its long duration nature will see least reduction in area under drought incidence as its sowing can be adjusted according to receipt of rainfall (Kumar et al., 2014). Moisture stress at seed filling in lentil significantly reduced above ground biomass, pod number, pod weight, seed number by 41%,71%,71%,77%, respectively (Sehgal et al., 2017). In greengram and blackgram, drought stress leads to reduced leaf number, plant height, shoot and root biomass, leaf area index, leaf water potential, protein content, yield and increased proline, anthocyanin, flavnoids (Baroowa and Gogoi, 2015; Baroowa and Gogoi, 2016).

**Impact on livestock**

Livestock has an important role in the Indian agriculture. This is more important in dryland areas where the crop yields are unpredictable and these serve as a income assurance during stress period. Drought incidence reduces the availability of the green forage as well as the dry reservoirs makes a scarcity of water for the livestock. Around 113.5 million bovines were affected in nine states of India, with seven states facing fodder shortage (except Odisha and Tamil nadu) in drought year of
2002 (Patil, 2012). Purchase of fodder and crop residues like legume hays, rice straw and sorghum stover increases with simultaneous increase in fodder cost and there is reduction in purchase of concentrate feed and rice bran (Biradar and Sridhar, 2009; Chand and Biradar, 2017). During drought years there is decrease in feed intake, loss of body weight, decline in fertility, disturbance in reproductive performances, average lactation length and yields, worsening of milk to adult female cattle ratio, increase in dry and unproductive cattle, decrease in livestock population probably due to animal death due to lack of quality fodder, distress sale of cattle and unbearable cost of livestock; it also leads to migration of livestock especially cattle and sheep (Patil, 2012; Maurya and Tripathi, 2013; Mishra, 2017; Kanwal et al., 2020). To lessen the drought impact, farmers practice distress sale of cattle fetching lower prices than normal (Toulmin, 1986; Biradar and Sridhar, 2009; Udmale et al., 2014; Chand and Biradar, 2017).

Mitigation measures

Agriculture is the foremost sector where mitigation should receive the priority. Singh et al. (2011) concluded that Indian food grain production is more vulnerable to drought than floods and among the two major seasons, kharif food grain production is more vulnerable than rabi season. Various agronomic measures for drought proofing includes availability of quality seeds, optimizing plant population, spray of anti-transpirants, application of polymers e.g. Pusa hydrogel, practicing life saving irrigation, nutrient management, practicing conservation tillage, intercropping to reduce runoff losses, selection of efficient varieties, shifting sowing according to expected rainfall pattern, mulching and in-situ moisture conservation, use of zero till seed drill to accomplish late sowing of wheat (Gautam and Bana, 2014; Tyagi et al., 2020). Application of pusa hydrogel had improved growth and physiological parameters in rice; significantly higher yields in cotton; pusa hydrogel @ 2.5 kg/ha + organic mulch @ 5 tonnes/ha in pigeonpea recorded highest yields and net return (Sen et al., 2019; Ashraf et al., 2020; JadHAV et al., 2020). Krishna and Ramanjaneyulu (2012) reported effectiveness of life saving irrigation through sprinkler, ridge and furrow method over flatbed method and intercropping of Castor+redgram (1:1) in terms of yield and net returns. Some of the critical stages for irrigation in pulses are given table 1. However, the drought areas should have supplementary irrigation scheduled on the basis of incidence of dry spell rather than critical stage concept, generally 10-15 days depending on the soil texture (Reddy and Reddy, 2016). Water harvesting for this supplemental irrigation can be done by construction of some feasible system like earthern dam on gully head, community tanks, small tanks for individual farmers preferably located at the lowest point of the catchment, with capacity to completely full at the end of monsoon, maximum volume with minimum exposed surface so as to reduce evaporation losses and lining for reducing the seepage losses (Verma, 1981). Mulching is effective under drought stress. Yield levels were significantly higher with plastic mulch under 75% moisture stress in capsicum; with double mulching with organic material for crops in rotation with maize; fruit yield in ber with black polythene or date palm leaves mulch along with supplementary irrigation; 24-28% higher okra yields with organic mulches compared to no mulch under moisture stress; mulching with crop residues along with compartmental bunding reported highest groundnut yield and water use efficiency (Thakur et al., 2000; Bahadur et al., 2013; Meghwal and Kumar, 2014; Ngangom et al., 2020; Pandian et al., 2020). Insitu water conservation measures involving alteration in land configuration also proved successful in enhancing yield in drought prone rainfed areas (Table 2).

Mineral nutrition has an important role in inducing drought tolerance in plants. The metabolic role of nutrients is presented in table 3. Moderate nitrogen supply in maize enhanced drought tolerance through enhanced nitrate concentration, nitrate reductase activity, abscisic acid content; higher N supply increased cell membrane stability in soybean; foliar application of N at flowering increased seed yield and protein content under terminal drought stress in chickpea; moderate dose of nitrogen recorded highest wheat yield under drought stress (Palta et al., 2005; Premachandra et al., 2009; Song et al., 2019; Sedri et al., 2019). Phosphorus application enhanced relative water content, photosynthetic rate and yield of mothbean under drought stress; grain yield was compensate by application of P, Fe and Si under moisture stress with that of irrigated rice crop; number of tubers
Table 1: Critical stages for various pulses for yield maximization under limited irrigation water availability (Praharaj et al., 2016)

| Pulse crop     | Critical stage                                                                 |
|----------------|--------------------------------------------------------------------------------|
| Chickpea       | 1 irrigation at 50% flowering/ pod development stage; 2 irrigations at branching and pod formation. |
| Pigeonpea      | 2 irrigations at branching and pod formation.                                    |
| Fieldpea       | 50% flowering.                                                                  |
| Lentil          | Early pod filling stage.                                                        |
| Rabi pigeonpea | 25 days crop stage.                                                             |

Table 2: Yield gain by practicing various in-situ moisture conservation practices under drought conditions

| Conservation measures | State and crop | Yield gain over control (%) | Reference               |
|-----------------------|----------------|-----------------------------|-------------------------|
| Trenching             | Uttarakhand; Rice | 32.9-58.4                   | Kumar et al., 2014      |
| Continuous Trenching  | Maharashtra; Mandarin | 29.2                        | Panigrahi et al., 2009  |
| Modified Crescent bund| Karnataka; Cashew | 32.2                        | Rejani and Yadukumar, 2010 |
| Scooping              | Karnataka; Sorghum | 11-12                       | Mishra and Patil, 2008  |
| Field Bunding         | Rajasthan; Chickpea | 18                          | Regaret et al., 2010    |
| Field Bunding         | Rajasthan; Sorghum | 10.5                        | Rao et al., 2010        |
| Paired row planting with conservation furrow between two rows | Telangana; Pigeonpea | 34.25                      | Rao et al., 2018        |

Table 3: Specific metabolic functions of various mineral nutrients under drought stress in plants (Hawkesford et al., 2012; Broadley et al., 2012)

| Nutrient     | Specific metabolic functions under drought conditions. |
|--------------|--------------------------------------------------------|
| Nitrogen     | Synthesis of betaine which act as compatible solute and counteracts high vacuolar concentration of inorganic ions like Na⁺ and Cl⁻ which inhibits Cytoplasmic metabolism. |
| Potassium    | Regulates the stomatal movement by changing turgor of guard cells; maintaining osmotic pressure in vacuole; avoidance of oxidative stress; pH stabilization of chloroplast stroma. |
| Sulphur      | Strong disulphide bridge (-SH group) in proteins which provides cellular resistance to dehydration caused by drought. |
| Magnesium    | Deficiency leads to impairment of root growth and thus impacting drought resistance. |
| Calcium      | Increase in cytosolic Ca concentration act as signal under drought stress. |
| Manganese    | Mn SOD induces enhanced drought tolerance.             |
| Molybdenum   | Component of aldehyde oxidase enzyme which causes conversion of abscisic aldehyde to abscisic acid (ABA) which is important for inducing drought tolerance in plants. |

and yield was increased with P application under moisture stress (Garg et al., 2004; Motalebfard et al., 2013; Kumar et al., 2019). Spray of 2% KCl at flowering and siliqua formation stage in toria recorded significantly higher yields and yield attributes under rainfed conditions (Sarma et al., 2015); ameliorating effect of K application on relative water content and chlorophyll in sugarbeet (Aksu and Altay, 2020); K application at pre-flowering and pod development stage improved mungbean performance under drought (Umar et al., 2019); split K application improved yield parameters in groundnut under drought stress (Patro et al., 2018); enhanced seed yield of mustard and sorghum under drought stress with higher K dose and of groundnut under moderate K dose (Umar, 2006). Crop diversification can be practiced in form of crop rotation and intercropping/ mixed cropping. Mixed/ intercropping have variable adaptations to
climate threats and can enhance the productivity in extreme weather and low input farms whereas crop rotation can reduce soil degradation, can improve water use efficiency and can enhance productivity (Patel et al., 2020). Substituting maize with sorghum, sesame, blackgram, groundnut, greengram, clusterbean under low and erratic rainfall pattern proved efficient increasing maize equivalent yields, rain water use efficiency and can enhance productivity (Patel et al., 2020). Substituting maize with sorghum, sesame, blackgram, groundnut, greengram, clusterbean under low and erratic rainfall pattern proved efficient increasing maize equivalent yields, rain water use efficiency and can enhance productivity (Patel et al., 2020). Substituting maize with sorghum, sesame, blackgram, groundnut, greengram, clusterbean under low and erratic rainfall pattern proved efficient increasing maize equivalent yields, rain water use efficiency and can enhance productivity (Patel et al., 2020).

Strip cropping was most suited for pearl millet + legumes compared to their mixed and intercropping under severe moisture stress giving yields greater or at par to the sole pearl millet and LER value > 1 (Singh and Joshi, 1994). Selection of genotypes has a larger role in mitigation. A drought tolerant variety developed by IRRI, released as Sahbhagidhan in India, is short duration variety, have genetic drought tolerance and more efficient in extracting moisture (Dar et al., 2020) and its short duration nature escapes high temperature and allow farmer to grow another crop after harvest (Yamano et al., 2018). Some other drought tolerant varieties developed are CR Dhan 201, CR Dhan 801 an CR Dhan, 802 for rice (MoEFCC, 2021). Birthal et al. (2012) reported 23 per cent yield advantage with ICGV91114 compared to dominant groundnut variety TMV-2 in Ananthpur district. Among eight varieties, SPV-1591 and among six hybrids, CSH 15R had significantly higher yields under rainfed rabi season at Bellary (Patil, 2007). Among the fifteen wheat varieties, NI-5439, WH-1021, HD-2733 found to be best suited for moisture stress conditions (Meena et al., 2015). Livestock has important role to play in drought prone regions, some of the important breeds of dry areas are Thar parkar, Rath, Kankrej (Cattle); Marwari, Jaisalmeri, Patanwadi, nail (sheep); Marwari, kutchi (goats) and Bikaneri, Jaisalmeri (camel) (Patil et al., 2006). The various measures suggested for feed maintenance are thinning of the crop to increase their vegetative growth, increasing grass production in fallow and community areas, maximum utilization of the green herbage and agro-industrial waste, chaffing of forage, feeding of chopped forage for better digestion, hay making, enriching forage with urea treatment (Mishra, 2017). Some other important measures for livestock management includes controlled grazing, introduction of high yielding perennial grasses, silvipastoral system for areas having rainfall < 200 mm, strategic feeding of cattle includes preferential feeding to productive stock such as pregnant and lactating cattle, feed supply for maintenance of minimum body weight, urea/ammonia treated straw saves the cost of concentrate feed; multienutrient bricks/ blocks of molasses, urea, mineral and vitamins as lick for large animals and feed for small ruminants (Patil et al., 2006).

Conclusion
Drought has serious implications for the agriculture and livestock sector and thus, can disrupt the life in vulnerable areas. It is possible to avert the dark consequences of spontaneous drought through the preparedness in form of early warning and drought proofing. Drought has varying impact on production of crops depending on the adaptation of the particular state. In the drought year of 2009, there was rainfall deficit of 23, 34 and 35 % for the Jharkhand, Punjab and Haryana respectively, however, Punjab and Haryana has shown a net increase of paddy production (6.6 and 5.8 respectively) from triennium (2006-08) average and Jharkhand had witnessed reduction of 52.6 % owing to only 8 % of net sown area under irrigation compared to 86 and 98 % in Haryana and Punjab, respectively. Though we have discussed the specific impacts of drought on agriculture and livestock, it is needed to have holistic approach in its management considering availability of timely credit, other non farm employment, food grain supply. Long term area wide planning in form of water shed, water harvesting structures etc are necessary, however, short term mitigation measures such as availability of drinking water, fodder and concentrates, seed and technical inputs, government intervention are equally desirable.

Conflict of interest
The authors declare that they have no conflict of interest.

References
Abdullah, F., Hareri, F., Naaesan, M., Ammar, M.A., & Zuher Kanbar, O. (2011). Effect of drought on different physiological characters and yield component in different varieties of syrian durum wheat. Journal of Agricultural Science, 3(3), 127-130.
Drought in Indian perspective, its impact on major crops

Akithe Devi, M.K., & Giridhar, P. (2013). Variations in physiological response, lipid peroxidation, antioxidant enzyme activities, proline and isoflavones content in soybean varieties subjected to drought stress. Proceedings of National Academy of Sciences, India, Section B-Biological Sciences, 85(1), 35-44.

Aksu, G., & Altay, H. (2020). The effects of potassium applications on drought stress in sugar beet. Sugar Tech.

Amarsinghe, U., Amarnath, G., Alahacoon, N., & Ghosh, S. (2020). How do floods and drought impact economic growth and human development at the sub-national level in India? Climate, 8(11), 123.

Ashraf, A.M., Raghvan, T., & Begum, S. N. (2020). Influence of in-situ soil moisture conservation practices with pusa hydrogel on physiological parameters of rainfed cotton. International Journal of Bio-resource and Stress Management, 11(6), 548-557.

Awasthi, R., Kaushal, N., Vadez, V., Turner, N.C., Berger, J., Siddique, K.H.M., & Nayyar, H. (2014). Individual and combined effects of transient drought and heat stress on carbon assimilation and seed filling in chickpea. Functional Plant Biology, 41(11), 1148-1167.

Badatya, K. C. (2005). Managing risks of drought in Indian agriculture: role of credit institutions. Agricultural Economics Research Review, Agricultural Economics Research Association (India) Conference, 18.

Bahadur, A., Singh A.K., & Chaurasia, S.N. S. (2013). Physiological and yield response of okra (Abelmoschus esculentus Moench.) to drought stress and organic mulching. Journal of Applied Horticulture, 15(3), 187-190.

Baroowa, B., & Gogoi, N. (2015). Changes in plant water status, biochemical attributes and seed quality of blackgram and greengram genotypes under drought. International Letters of Natural Science, 42, 1-12.

Baroowa, B., & Gogoi, N. (2016). Morpho-physiological and yield responses of black gram (Vignamungo L) and green gram (Vigna radiata L) genotypes under drought at different growth stage. Research Journal of Recent Sciences, 5(2), 43-50.

Basu, P. S., Ali, M., & Chaturvedi, S. K. (2004). Adaptation of photosynthetic components of chickpea to water stress. In 4th international crop science congress, September.

Biradar, N., & Sridhar, K. (2009). Consequences of 2003 drought in Karnataka with particular reference to livestock and fodder. Journal of Human Ecology, 26(2), 123-130.

Birthal, P. S., Negi, D. S., Khan, M. T., & Agarwal, S. (2015). Is Indian agriculture becoming resilient to drought? Evidence from rice production systems. Food Policy, 56, 1-12.

Birthal, P. S., Negam, S. N., Narayanan, A. V., & Kareem, K. A. (2012). Potential economic benefits from adoption of improved drought-tolerant groundnut in India. Agriculture Economic Research Review, 25(1), 1-14.

Bisht, D.S., Sreedhar, V., Mishra, A., Chatterjee, C., & Raghuvanshi, N. S. (2018). Drought characterization over India under projected climate scenario. International Journal of Climatology, 39(4), 1889-1911.

Broadley, M., Brown, P., Cakmak, I., Rengel, Z., & Zhao, F. (2012). Function of nutrients: micronutrients. In Marschner's mineral nutrition of higher plants (pp. 191-248). Academic Press.

Chand, K., & Biradar, N. (2017). Socio-economic impacts of drought in India. In: Kumar, S., Tanwar, S. P. S. Singh, A. (Eds.), Drought mitigation and management. Scientific Publishers, New Delhi, 245-263.

Chauhan, J.S., Tyagi, M.K., Kumar, A., Nashaat, N.I., Singh, M., Singh, N.B., Jakhar, M.L., & Welham, S. J. (2007). Drought effects on yield and its components in Indian mustard (Brassica juncea L.). Plant Breeding, 126, 399-402.

Dar, M.H., Waza, S.A., Shukla, S., Zaidi, N.W., Nayak, S., Hussain, M., Kumar, A., Ismail, A.M., & Singh, U. (2020). Drought tolerant rice for ensuring food security in eastern India. Sustainability, 12, 2214.

Devasirvatham, V. & Tan, D.K. Y. (2018). Impact of high temperature and drought stress on chickpea production. Agronomy, 8, 145.

Dwivedi, S.L., Nigam, S.N., Rao, R.C.N., Singh, U., & Rao, K.V. S. (1996). Effect of drought on oil, fatty acids and protein contents of groundnut (Arachis hypogaea L.) seeds. Field Crops Research, 48, 125-133.

EL Sabagh, A., Hossain, A., Barutçułar, C., Gormus, O., Ahmad, Z., Hussain, S., Islam, M.S., Alharby, H., Bamagoos, A., Kumar, N., Akdeniz, A., Fahad, S., Meena, R.S., Abdelhamid, M., Wasaya, A., Hasanuzzaman, M., Sorour, S., & Saneoka, H. (2019). Effects of drought stress on the quality of major oilseed crops: implications and possible mitigation strategies—a review. Applied Ecology and Environmental Research, 17, 4019-4043.

FAO. (2017). The future of food and agriculture – Trends and challenges. Rome.

FAO. (2021). The impact of disasters and crises on agriculture and food security. Food and Agriculture Organization, Rome.

Garg, B.K., Burman, U., & Kathju, S. (2004). The influence of phosphorus nutrition on the physiological response of mothbean genotypes to drought. Journal of Plant Nutrition and Soil Science, 167, 503-508.
Kanwal, V., Sirohi, S., & Chand, P. (2020). Effect of drought on livestock enterprise: Evidence from Rajasthan. *Indian Journal of Animal Sciences, 90* (1), 94–98.

Kenchanagoudar, G., Nigam, S.N., & Chennabyregowda, M. V. (2002). Effect of drought on yield and yield attributes of groundnut. *Karnataka Journal of Agricultural Sciences, 15*(2), 364-366.

Kishore, A., Joshi, P. K., & Pandey, D. (2014). Droughts, distress, and policies for drought proofing agriculture in Bihar, India. *IFPRI Discussion Paper*, 01398.

Krishna, A., &Ramanjaneyulu, A.V. (2012). Impact of land configuration, life saving irrigation and intercropping on yield and economics of major rainfed crops in southern Telangana zone of Andhra Pradesh, India. *International journal of Bio-resource and Stress Management*, 3(3), 317-323.

Kumar, A., Nayak, A.K., Pani, D.R., & Das, B. S. (2019). Application of phosphorus, iron, and silicon reduces yield loss in rice exposed to water deficit stress. *Soil Fertility and Crop Nutrition*, 111, 1-10.

Kumar, M., Singh, K.P., Srinivas, K., & Reddy, K. S. (2014). In-situ water conservation in upland paddy field to improve productivity in north-west Himalayan region of India. *Paddy Water Environment*, 12, 181-191.

Kumar, P., Joshi, P. K., & Agarwal, P. (2014). Projected effect of droughts on supply, demand, and prices of crops in India. *Economic and Political Weekly XLIX*, (52), 54-63.

Kumar, R.R., Karajol, K., & Naik, G. R. (2011). Effect of polyethylene glycol induced water stress on physiological and biochemical responses in pigeonpea (*Cajanus cajan* L. *Millsp.*). *Recent Research in Science and Technology*, 3(1), 148-152.

Kumar, S., Mishra, A. K., Pramanik, S., Mamidanna, S., & Whitbread, A. (2020). Climate risk, vulnerability and resilience: Supporting livelihood of smallholders in semiarid India. *Land Use Policy*, 97, 104729.

Leng, G., & Hall, J. (2019). Crop yield sensitivity of global major agricultural countries to droughts and the projected changes in the future. *The Science of the total environment*, 654, 811–821.

Lopez, F.B., Johansen, C., & Chauhan, Y. S. (1996). Effects of timing of drought stress on phenology, yield and yield components of short-duration pigeonpea. *Journal of Agronomy and Crop Science, 177*, 311-320.

Maurya, R.K., & Tripathi, H. (2013). Impact of drought on productive and reproductive performance of goats in Bundelkhand region of Uttar Pradesh. *The Indian Journal of Small Ruminants*, 19(1), 92-94.

Meena, R., Tripathi, S., Chander, S., Chookar, R., Verma, M., & Sharma, R. (2015). Identifying drought tolerant wheat varieties using different indices. *SAARC Journal of Agriculture*, 13(1), 148-161.
Drought in Indian perspective, its impact on major crops

Meghwal, P. R., & Kumar, P. (2014). Effect of supplementary irrigation and mulching on vegetative growth, yield and quality of ber. *Indian Journal of Horticulture*, 71(4), 571-573.

Misra, A. K. (2017). Livestock Management in drought. *Drought Mitigation and Management* (Eds. S Kumar, SPS Tanwar and A Singh). *Scientific Publishers*, Jodhpur, 209-217.

Mishra, P. K., & Patil, S. L. (2008). In situ rainwater harvesting and related soil & water conservation technologies at the farm level. *Water Harvesting*, 12.

Mishra, V., Solomon, S., & Ansari, M. I. (2016). Impact of drought on post-harvest quality of sugarcane crop. *Advances in life science*, 5(20), 9496-9505.

MoEFCC, India. (2021). Third biennial update report to the United Nations framework convention on climate change. *Ministry of Environment, Forest and Climate Change, Government of India*.

Motalebifard, R., Najafi, N., Oustan, S., Nyshabouri, M. R., & Valizadeh, M. (2013). The combined effect of phosphorus and zinc on evapotranspiration, leaf water potential, water use efficiency and tuber attributes of potato under water deficit conditions. *Scientia Horticulturae*, 162, 31-38.

Mukherjee, S., Mishra, A., & Trenberth, K. E. (2018). Climate change and drought: a perspective on drought indices. *Current Climate Change Reports*, 4(2), 145-163.

Muruiki, R., Kimurto, P., Vandez, V., Gangarao, N.V.P.R., Silim, S., & Siambi, M. (2018). Effect of drought stress on yield performance of parental chickpea genotypes in semi-arid tropics. *Journal of Life Sciences*, 12(3), 159-168.

Nahar, S., Sahoo, L., & Tanti, B. (2018). Screening of drought tolerant rice through morpho-physiological and biochemical approaches. *Biocatalysis and Agricultural Biotechnology*, 15(1), 150-159.

Nam, N.H., Chauhan, Y.S., & Johansen, C. (2001). Effect of timing of drought stress on growth and yield of extra short duration pigeonpea lines. *Journal of Agricultural Science*, Cambridge 136, 179-189.

Nandwal, A.S., Bharti, S., Sheoran, I.S., & Kuhad, H.S. (1991). Drought effects on carbon exchange and nitrogen fixation in pigeonpea (*Cajanus cajan* L.). *Journal of Plant Physiology*, 138, 125-127.

Nawaz, F., Ahmad, R., Waraich, E.A., Naseem, M.S., & Shabbir, R. N. (2012). Nutrient uptake, physiological responses, and yield attributes of wheat (*Triticum aestivum* L.) exposed to early and late drought stress. *Journal of Plant Nutrition*, 35(6), 961-974.

Nezami, A., Khazaei, A.R., Rezazadeh, B., & Hosseini, A. (2008). Effects of drought stress and defoliation on sunflower (*Helianthus annus*) in controlled conditions. *Desert*, 12, 99-104.

Ngangom, B., Das, A., Lal, R., & Idapuganti, R.G. (2020). Double mulching improves soil properties and productivity of maize-based cropping system in eastern Indian Himalayas. *International Soil and Water Conservation Research*, 8(3), 308-320.

Ojha, R., Kumar, D.N., Sharma, A., & Mehrotra, R. (2013). Assessing severe drought and wet events over India in a future climate using a nested bias-correction approach. *Journal of Hydrologic Engineering*, 18, 760-772.

Palta, J.A., Nandwal, A.S., Kumari, S., & Turner, N. C. (2005). Foliar nitrogen applications increase the seed yield and protein content in chickpea (*Cicer aritinum* L.) subject to terminal drought. *Australian Journal of Agricultural Research*, 56(2), 105-112.

Panigrahi, P., Srivastava, A.K., & Huchche, A.D. (2009). Influence of in-situ soil and water conservation measures on performance of Nagpur mandarin. *Journal of Agricultural Engineering*, 46(3), 37-40.

Parida, B.R., & Oinam, B. (2015). Geospatial perspective of drought in India and agriculture. *16th Esri India User Conference*.

Patel, S.K., Sharma, A., & Singh, G. S. (2020). Traditional agricultural practices in India: an approach for environmental sustainability and food security. *Energy, Ecology and Environment*.

Patil, V. N. (2012). Drought: Impact on agriculture and livestock, major nutritional strategies to overcome ill effects in livestock. In Patil, N.V., Mathur, N.K., Patel, A.K., Patidar, M., Mathur, A.C. (Ed) *Feeding and Management of Livestock during Drought and Scarcity*, 59.

Patil, N.V., Mathur, B.K., Patel, A.K., Patidar, M., & Mathur, A.C. (2006). Feeding of livestock during drought and scarcity (A short course from 01th to 10th Nov., 2006). *Division of Animal Sciences, CAZRI, Jodhpur*.

Patil, S. L. (2007). Performance of sorghum varieties and hybrids during post rainyr season under drought situations in...
vertisol in Bellary, India. *Journal of SAT Agricultural Research*, 5(1).

Patro, H.K., Sahoo, G., & Behera, B. (2018). Effect of potassium application regime on productivity and drought tolerance parameters of groundnut (*Arachis hypogea* L.) in Odisha, India. *Electronic International Fertilizer Correspondent*, 53, 25-35.

Pawar, M.W., & Bhutkar, A. S. (2011). Yield and yield attributes of sugarcane genotypes under moisture stress. *Bioinfolet*, 8(3), 262-265.

Prahraj, C.S., Singh, U., Singh, S.S., Singh, N.P., & Shivay, Y. S.(2016). Supplementary and life-saving irrigation for enhancing pulse production, productivity and water use efficiency in India. *Indian Journal of Agronomy* 61 (4th IAC Special issue) S249-S261.

Premachandra, G.S., Saneoka, H., & Ogata, S.(2009). Cell membrane stability as indicator of drought tolerance, as affected by applied nitrogen in soybean. *The Journal of Agricultural Science*, 115(1), 63-66.

Rajasivaraj, T.(2015). Crop specific drought monitoring and yield loss assessment by integrating geospatial, climatic and crop modeling. *M. Tech. Thesis. Andhra University, Vishakapatnam*.

Rao, K.V., Vijayakumar, S., & Srinivas, I. (2018). On farm study of in-situ soil water conservation practices for enhancing productivity of pigeonpea. *Indian Journal of Dryland Agriculture Research and Development*, 33(2), 10-13.

Rao, S.S., Regar, P.L., & Singh, Y. V.(2010). In-situ rainwater conservation practices in sorghum (*Sorghum bicolor*) under rainfed conditions in arid region. *Indian Journal of Soil Conservation*, 38(2), 105-110.

Reddy, T. Y. & Reddy, G.H. S.(2016). *Principles of Agronomy*, 4th Ed, Kalyani Publishers, New Delhi-110002, 372.

Reddy, T.Y., Reddy, V.R., & Anbumozhi, V. (2003). Physiological responses of groundnut (*Arachis hypogea* L.) to drought stress and its amelioration: a critical review. *Plant Growth Regulation*, 41, 75-88.

Regar, P.L., Rao, S.S.,& Joshi, N. L.(2010). In-situ rainwater conservation practices on productivity of Chickpea (*Cicer arrietinum*) in the rainfed conditions of arid Rajasthan, India. *Indian Journal of Soil Conservation*, 38(2), 111-115.

Rejani, R., & Yadukumar, N.(2010). Soil and water conservation techniques in cashew grown along steep hill slopes. *Scientia Horticulturae*, 126, 371-378.

Samra, J. S.(2004). Review and analysis of drought monitoring, declaration and management in India. Working Paper 84. Colombo, Sri Lanka: *International Water Management Institute*.

Sarma, P.K., Hazarika, M. Sarma, D., & Saikia, P. (2015). Effect of foliar application of potassium on yield, drought tolerance and rain water use efficiency of toria under rainfed upland situation of Assam. *Indian Journal of Dryland Agriculture Research and Development*, 30(1), 55-59.

Santeshwari, Mishra, V., & Mall, A. K.(2021). Sucrose and commercial cane sugar attributes of sugarcane genotypes under drought conditions. *Virtual National Conference on “Strategic Reorientation for Climate Smart Agriculture” (V-AGMET 2021)*, March 17-19th, 2021, Punjab Agricultural University, Ludhiana, 94-98.

Sedri, M.H., Amini, A., & Golchin, A.(2019). Evaluation of nitrogen effects on yield and drought tolerance of rainfed wheat using drought stress indices. *Journal of Crop Science and Biotechnology*, 22, 235-242.

Sehgal, A., Sita, K., Kumar, J., Kumar, S., Singh, S., Siddique, K.H.M., & Nayyar, H.(2017). Effect of drought, heat and their interaction on the growth, yield and photosynthetic function of lentil (*Lens culinaris Medikus*) genotypes varying in heat and drought sensitivity. *Frontiers in plant science*, 8, 1776.

Sehgal, A., Site, K., Siddique, K.H.M., Kumar, R., Bhogireddy, S., Varshney, R.K., Hanumantharao, B., Nair, R. M., Prasad, P.N.V., & Nayyar, H.(2018). Drought or/and heat-stress effects on seed filling in food crops: impacts on functional biochemistry, seed yields, and nutritional quality. *Frontiers in Plant Science*, 9, 1705.

Sen, A., Singh, R. K., Yadav, D., & Kumari, P. (2019). Effect of Trichoderma and hydrogel on growth, yield and yield attributes of direct seeded rice (*Oryza sativa*) under rainfed conditions. *Indian Journal of Agricultural Sciences*, 89(2).

Sharma, B., Basumutary, N. R., Nahar, S., & Tanti, B.(2016). Effect of drought stress on morpho-physiological traits of in some traditional rice cultivars of Kokrajhar district, Assam, India. *Annals of plant sciences*, 5(8), 1402-1408.

Sheoran, S., Thakur, V., Narwal, S., Turan, R., Mamrutha, H.M., Singh V., Tiwari, V., & Sharma, I. (2015). Differential activity and expression profile of anti-oxidant enzymes and physiological changes in wheat (*Triticum aestivum L.*) under drought. *Applied Biochemistry and Biotechnology*, 177(6), 1282-1298.

Singh, A., Phadke, V. S., & Patwardhan, A. (2011). Impact of drought and flood on Indian food grain production, in challenges and opportunities in agrometeorology. *Springer Berlin Heidelberg*, 421-433.

Singh, M., Chauhan, J.S., & Meena, S. S.(2009). Drought induced changes in water use efficiency and other morpho-physiological characters in Indian mustard (*Brassica
Drought in Indian perspective, its impact on major crops

Singh, M., & Joshi, N. L. (1994). Performance of pearl millet-based intercropping systems under drought conditions. *Arid Soil Research and Rehabilitation, 8*(3), 277-283.

Sinha, R., Irulappan, V., Mohan-Raju, V., Suganthi, A., & Senthil-Kumar, M. (2019). Impact of drought stress on simultaneously occurring pathogen infection in field grown chickpea. *Scientific Reports, 9*, 5577.

Sinha, R., Irulappan, V., Mohan-Raju, V., Suganthi, A., & Senthil-Kumar, M. (2019). Impact of drought stress on simultaneously occurring pathogen infection in field grown chickpea. *Scientific Reports, 9*, 5577.

Sonawane, S. T., Patil, A.M., & Patil, N. K. (2016). Impact of drought on Indian agriculture and economy. *International Journal of Innovative Research in Science, Engineering and Technology, 5*(12), 21210-21213.

Song, Y., Li, J., Liu, M., Meng, Z., Liu, K., & Sui, N. (2019). Nitrogen increases drought tolerance in maize seedling. *Functional Plant Biology, 46*(4), 350-359.

Thakur, P.S., Thakur, A., & Kanaujia, S. P. (2000). Reversal of water stress effects. I. mulching impact on the performance of *Capsicum annum* under water deficit. *Indian Journal of Horticulture, 57*(3), 250-254.

Toulmin, C. (1986). Drought and the farming sector: Loss of farm animals and post-drought rehabilitation. *ALPAN – African Livestock Policy Analysis Network* Network Paper No. 10.

Tyagi, V., Nagargade, M., & Singh, R. K. (2020). Agronomic interventions for drought management in crops. In Rakshit, A., Singh, H.B., Singh, A.K., Singh, U.S., Fraceto, L. (Eds) New frontiers in stress management for durable agriculture. *Springer, Singapore*, 461-476.

Udamale, P., Ichikawa, Y., Manandhar, S., Ishidaira, H., & Kiem, A.S. (2014). Farmers' perception of drought impacts, local adaptation and administrative mitigation measures in Maharashtra state, India. *International Journal of Disaster Risk Reduction, 10* (A), 250-269.

Udamale, P., Ichikawa, Y., Ning, S., Shrestha, S. & Pal, I. (2020). A statistical approach towards defining national-scale meteorological droughts in India using crop data. *Environmental Research Letters, 15*, 094090.

Umar, S. (2006). Alleviating adverse effects of water stress on yield of sorghum, mustard and groundnut by potassium application. *Pakistan Journal of Botany, 38*(5), 1373-1380.

Umar, S., Anjum, N.A., Ahmad, P., & Iqbal, M. (2019). Drought-induced changes in growth, photosynthesis, and yield traits in mungbean: Role of potassium and sulfur nutrition. In *Crop Production Technologies for Sustainable Use and Conservation*. Apple Academic Press, 75-86.

Vanaja, N., Maheshwari, M., & Sathish, P. (2015). Genotypic variability in physiological, biomass and yield response to drought stress in pigeonpea. *Physiology and Molecular Biology of Plants, 21*(4), 541-549.

Varikoden, H., Revadekar, J.V., Choudhary, Y., & Preethi, B. (2015). Droughts of Indian summer monsoon associated with El Niño and Non-El Niño years. *International Journal of Climatology, 35*, 1916–1925.

Velu, G., Guzman, C., Mondal, S., Autrique, E., Huerta, G., & Singh, R. (2016). Effect of drought and elevated temperature on grain zinc and iron concentrations in CIMMYT spring wheat. *Journal of Cereal Science, 69*.

Verma, H. N. (1981). Water harvesting for life saving irrigation of rainfed crops in the sub-mountain region of Punjab. *Journal of Agricultural Engineering Research, 18*, 64-72.

WMO. (2020). Provisional report on state of global climate. *World Meteorological Organization*.

Yamano, T., Dar, M.H., Panda, A., Gupta, I., Malabayabas, M.L., & Kelly, F. (2018). Impact and adoption of risk reducing drought tolerant rice in India. *3ie Impact Evaluation Report 72*. New Delhi, *International Initiative for Impact Evaluation (3ie)*.

Zhang, J., Zhang, S., Cheng, M., Jiang, H., Zhang, X., Peng, C., Lu, X., Zhang, M., & Jin, J. (2018). Effect of drought on agronomic traits of rice and wheat: A meta-analysis. *International Journal of Environmental Research and Public Health, 15*, 839.

Zhao, T., & Dai, A. (2015). The magnitude and causes of global drought changes in the twenty first century under a low-moderate emission scenario. *Journal of Climate, 28*(11), 4490-4512

**Publisher's Note**: ASEA remains neutral with regard to jurisdictional claims in published maps and figures.