Review Article

Strategies for mitigation of moisture stress in maize (*Zea mays* L.) - A Review

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Abstract

Overexploitation of natural resources with substantial rise in population have exacerbated the temperature and carbon dioxide levels eventually disturbed the behavior of precipitation and posed the vulnerability of rainfed farming to huge risk. Thus, it is critically important to formulate and apply appropriate crop stress mitigation strategies. In this context, breeding stress tolerant cultivars seems potential approach but the constraints *viz.*, polygenic nature of stress tolerating genes and incidence of multiple stresses limits the practical implementation and demands a shift towards agronomic and soil conservation measures. Crop stresses induce certain growth, physiological, phenological and productivity alterations *viz.*, source to sink relationship, osmoregulation and overproduction of reactive oxygen species, ultimately inducing programmed cell death. Modern stress mitigation strategies focuses on understanding of endogenous stress ameliorating bio-molecules and processes followed by identifying the mechanisms for promoting the same through agronomic and crop management practices *viz.*, land use, mulching and supplementation of agrochemicals.

Keywords: Abiotic stress, antioxidative defence system, maize, maize responses, planting methods, stress mitigation

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Introduction

Increasing food grain production with sustainability to feed the ever-increasing human population is a foremost concern of today's agriculture research. According to Food and Agriculture Organization an estimated staggered yield increase by $\geq$ 140 per cent is essential to feed the forthcoming generations by 2050 [1]. This requires the development and implementation of high yielding technologies and modern crop cultivars adapted towards wider range of agro-climatic regions and suitable for intensive cropping. During green revolution, a huge rise in productivity levels have been observed from irrigated agriculture but opportunities for continual expansion of land under irrigation are limited and therefore attempts for sustaining the food grain demands have been increasing towards rainfed and dryland areas. Moreover, a huge gap between the irrigated and rainfed agriculture is also a key factor for inspiration in research towards rainfed areas.

Rainfed agriculture is practiced over 80 per cent world's area, serving as an important contributor for food and livelihood demands of several developing nations [2]. A large proportion of poor and hungry population lives in semi-arid and dry sub-humid countries where rainfed agriculture is predominant source of food [3]. With a substantial rise in temperature and carbon dioxide levels along with population and urbanization, the variation across rainfall patterns had increased, increasing the vulnerability of rainfed crops towards biotic and abiotic stresses and threatening the sustainability of rainfed agriculture [4]. The scenario is likely to exacerbate in future with projected climate change which is expected to raise the demand of water across South Asian countries [5]. It has been observed across recent three decades that distribution of rainfall over space and time had shown considerable reduction with increased number of extreme rainfall events (intensive rainfall events and dry spells) [5, 6]. The statement finds plentiful importance across developing and agrarian countries like India where 67 per cent of net sown area comes under rain shadow, contributing 44 per cent to the national food grain production and supports 40 per cent of population [7]. Scarce, intensive and unpredictable rains with high coefficients of variation are the common features and principal factors behind low water productivity of rainfed lands [8]. Lack of irrigation facilities coupled with highly degraded and eroded soils of undulating topographies with less adoption rate of improved agro-technologies due to bio-physical and socio-economic constraints are the principal factors responsible for prevalence of subsistence farming of low yielding, drought adapting and stress tolerating cereals *viz.*, maize, sorghum, pearl millet and pulses in these areas [9].

Maize is the second most important crop of world known for its photo-thermo-insensitive behaviour and highest yield potential, is a principal *kharif* crop of rainfed areas. It has C_4, day neutral and short duration character with diverse seasonal growing adaptation and thus emerged as an important alternative for non-traditional areas and seasons of world [10]. In India, average maize productivity level across rainfed regions is less than 2 tonnes ha^{-1} *vis-à -vis* the irrigated average productivity is greater than 4 tonnes ha^{-1}, indicating a huge unbridged gap between irrigated and rainfed agriculture [11]. Large productivity gaps exist across other rainfed crops too; unpredictable climatic conditions along with multiple stress factors are the major reasons for these [2]. There are regions where the cumulative annual rainfall is sufficient for supporting multiple cropping; however the uneven distribution of seasonal rainfall along with lack of improved water-harvesting and agronomic interventions are bottlenecks for crop production [3]. Growth and productivity of crop is highly deteriorated by environmental constraints, moisture and heat stress are the key factors affecting the productivity of maize. The crop finds susceptibility to drought as well as waterlogging. Degrees of crop losses depend up on the nature, intensity and stage of occurrence of stress [12], and thus understanding and characterization of plant's behaviour under varying stress conditions is critical for formulation of stress mitigation strategies [13]. For instance, incidence of moisture shortage during sowing reduces plumule and radicle growth restricting the growth of seedlings and resulting uneven plant stand [14], drought stress during vegetative or pre-anthesis stage reduces crop growth, duration and accelerates tasselling [15]. Moisture stress during flowering speeds up the tassel growth but restriction across silk development occurred, eventually widening the anthesis-silking interval and shortening the grain filling duration [16]. Prolonged moisture shortage under dry spells affects solubility and uptake of nutrients by disturbing the unloading mechanism, ion uptake and mineral nutrition, altering the crop physiological and biochemical responses and ultimately results low productivity levels. To tackle these problems, recent research advancements had come up with efficient technologies in order to improve the rain water use efficiency and stress tolerance traits of plants.

Among these efficient agro-technologies, involvement of defence inducing agrochemicals, nutrient solutions and plant growth promoting hormones had recently evolved as truly innovative and low external input and sustainable agriculture (LEISA) based system in which micro-dosing plant growth regulators and nutrient solutions are supplemented for amelioration of stressed crop plants [17]. The approach is typically based upon the understanding of physiological response of maize under stress where the plant inhibit several growth, physiological and biochemical alterations (overproduction of reactive oxygen species (ROS), osmoregulation), signalling the plant's defence system to perturb the unbalanced alterations [18]. This signalling response is associated with accumulation of several kinds of phytohormones (abscisic acid, salicylic acid, jasmonic acid, gibberellins, ethylene, auxins and cytokinin) and compatible solutes (sugars, proline and glycine-betaine) and activation of ROS scavenging enzymes (peroxidase, catalase, ascorbate peroxidase, and superoxide dismutase) whose accumulation rates and activity measures the stress tolerance ability of plant [19]. Amelioration of stress is possible by supporting the process of accumulation of signalling molecules, and compatible solutes and activity of enzymatic antioxidants through supplementation of exogenous plant hormones and plant growth inducing agrochemicals [17]. The adoption rate of supplementation of agrochemicals is rapidly growing across arid and semi-arid regions of world and the technique has huge scope in the field of stressed plant improvement. Additionally, the inclusion of agronomic interventions such as *in-situ* moisture conservation measures and land use techniques also had potential to add up with tolerance against multiple abiotic stresses. We resolutely deliberates that the approaches are revolutionizing agricultural systems for improvement of rainwater use efficiency of rainfed agriculture and amelioration of stressed crop plants across arid, semi-arid and problematic soils of world. Some excellent research studies with significant contributions have recently been conducted regarding the same and have not been summarized in scientific literature, thus limiting the application of technologies. Keeping the above facts in view, various research findings are reviewed in this manuscript to understand various physiological, phenological and biochemical mechanisms involved in the growth and development of maize under moisture stress conditions and to summarize various stress mitigation strategies for amelioration of maize yield under stressed environment.

Growth and physiological response of maize to moisture stress

Moisture stress is the most important ecological constraints of arid environment, seriously limiting the productivity of agricultural crops [20]. Maize, a major *kharif* crop of rainfed areas, is intolerant to lodging and nutrient deficient soils, its shallow rooting behaviour make it susceptible to drought as well as waterlogging [21]. Drought stress induced by dry spells obstructs crop growth, deteriorates each phase of crop and ultimately disturbs phenology and grain yield to serious extent. A general background of crop growth and physiological behaviour in response to stress is essential to understand the critical stages and processes involved for timing, formulation and application of stress amelioration strategies [22].

Physiology of maize as affected by moisture stress

The physiological behaviour of plants under various stresses (*viz.*, moisture stress, salt stress, heavy metal and heat stress) is more or less common. Turgor pressure, flux assimilation and light interception are important for growth of leaves. Moisture stress reduces cell division and cell elongation resulting into loss of turgidity from leaves [23] and wedge shaped motor cells present on leaf surface [24], eventually leading to folding of leaves and reductions in leaf area for photosynthesis [25]. Reduced leaf turgor, leaf water content and root oriented signals closes stomata that further retards transpiration, increases leaf temperature, inhibits activity of enzymes, gaseous diffusion and photosynthesis [26]. Carbon diffusion and stomatal conductance are directly related to stomatal movement, thus closing of stomata and reduction in carbon diffusion results reduced supply of carbon to RUBISCO [27]. Reduction in photosynthesis directs assimilate towards roots for their active elongation to improve the uptake of water by plants [28]. This increases root to shoot ratio by hampering stem growth and increasing root growth for active water uptake. Reduced leaf area in association with decreased carbon diffusion, reduced cell division and mitosis retards photosynthesis and chlorophyll formation, eventually leading to lower dry matter production in plant system [29]. Advanced phase of stress includes over reduction of electron with in the electron transport chain resulting into overproduction of ROS and oxidative damage in plant cells [30]. These ROS cause peroxidation of lipids, degradation of nucleic acids, inhibition of enzymes, oxidation of proteins and activation of programmed cell death pathway [31]. Although, ROS are the products of normal plant bio system but under normal conditions they get scavenged by a series of enzymatic and non-enzymatic antioxidants. Induction of stress, imbalance their production and scavenging resulting into perturbed equilibrium among two groups [32]. Although, increased production of ROS is also a preliminary response of plant against stress but survival of plant largely depends on detoxifying ability of antioxidants [33]. Improvement across activities of non-enzymatic antioxidants and ROS scavenging enzymes is possible through micro-dosing fertilizers, agrochemicals and phytohormones and the strategy has recently been utilized by many of the researchers for amelioration of crops from abiotic stresses [34-36].

Growth and productivity of maize as affected by moisture stress

Maize is a C_4, day neutral and short duration plant having energy efficient photosynthetic system. Based on seasonal and climatic variations the crop requires 400-450 mm of irrigation water during its life cycle [37]. A critical observation of the graph given by Pannar (2012) indicates the least water requirement during earlier phases of the maize growth, which increases progressively with advancements in crop age, achieves its peak during the flowering and then fall down as the crop reaches maturity [38]. Different phases of crop growth find their varying degrees of susceptibility to moisture stress and the extent of productivity losses depends upon stage and severity of stress [12]. Crop germination and vegetative development are crucial for plant stand development and overall plant growth. Although, maize crop has the highest germination index throughout cereals but soil moisture content around field capacity is considered essential for seed bed preparation and sowing. The crop has comparatively larger grain size over other cereals; therefore, it requires relatively more amount of moisture for maintaining the osmotic potential for starting the process of imbibition and metabolic activities to convert the stored food into consumable form in order to begin germination [14]. Failure and early cessation of seasonal rainfall result scarcity of moisture during sowing for activation of metabolic enzymes and processes causing reduced germination and uneven plant stand. On the other side, incidence of heavy rainfall events result waterlogging conditions; the situation further exacerbates under poor drainage and fine textured soils resulting into hindered seed germination and rotting of germinating seeds. Water deficit during early phases of crop growth affects crop establishment by inducing longer meristematic cells and hampered cell division that causes longer roots and dwarf plants [39]. Water deficit engender loss of cell turgor by disruption of moisture flow from xylem to the surrounding cells, limiting the photo-assimilation and metabolites essential for cell division. Reduced cell division, mitosis and cell expansion results hampered plant growth in terms of leaf area, plant height and crop growth rate [29]. In addition to this, prolonged water stress at this stage affects crop phenology resulting shortening of vegetative phase. Moisture deficit during seedling stage affects plumule and radicle growth [14] which further limits the nutrient and moisture uptake and ultimately the growth and productivity of crop. Prevalence of waterlogging and high temperature for few days from sowing to knee high stage can damage the whole plant as the growing point during these stages remain below or near ground level [40].

Yang *et al.*, (2004) reported that deficit moisture during flowering barrens ear emergence resulting into reduced grain weight per ear in wheat [41]. The sensitivity of flowering to moisture stress is explained by several researchers in majority of the crops because formation of reproductive organs hinder the translocation of assimilates from leaves to roots [42] and moisture stress engender a competition among translocation of assimilates from leaves to roots and reproductive organs [43]. Incidence of moisture stress signals root growth for active uptake of water resulting disturbed mobilization of photosynthetic assimilates towards developing sink organs [29]. Eghball and Maranville (1993) reported positive relationship between development of roots and corn yield (by moderate water stress) irrespective severe water stress conditions where decline in root growth takes place and reductions across crop yields were reported [44]. Pannar (2012) reported 14 days prior and after flowering as critical to moisture stress as all the leaves are unfolded but the critical stages of tassel and silk emergence are going to begin [38]. Intensity of moisture stress (at flowering) increases from top to bottom and therefore silk emergence is more vulnerable than tassel and pollen shedding. Moisture stress at silk elongation stage delays silking, thus affects number of ovules which develop silks. Prolonged dry spells during silk emergence and pollen shedding reduces the number of ovules to be fertilized and restricts the pollination process [40]. Significant reductions in crop productivity by moisture stress at tasselling stage have been reported by Anjum *et al.,* (2011) [45]. Release of pollens from tassel, followed by their proper landing on receptive silks are the basic necessities for pollination. Drought stress delays silk emergence and accelerates pollen shedding widening the anthesis-silking interval and affecting the number of ovules fertilized and finally number of grains per cob which even can't be recovered with rehydration [16]. Claassen and Shaw (1970) also confirmed reductions in number of matured kernels by imposition of stress at early ear shoot and ovule formation stages [12].

Grain yield is a factor of number of grains per unit area and 1000-grain weight [46]; grain number is determined by number of cobs per plant (which is a genetic character) and number of ovules fertilized (determined by extent of pollination). Weight of thousand grains is determined by source to sink relationship and duration of grain filling period. Grain development phase is also one of the critical periods during which final grain weight and grain yield per plant is determined. Moisture stress during early phases of grain filling deteriorates kernel quality and during late phases results premature hanging of cobs [38]. Its prevalence during post-flowering and grain filling stage results early maturation by earlier formation of black layer, reduced accumulation of starch, proteins and result small sized grains. Paucities of moisture during dough stage restrict uptake of nutrients (such as potassium) and result unfilled and chaffy grains [40]. Moony and Duplesis (1970) reported that increased leaf senescence during drought induces loss of leaf turgor which further reduces leaf area, chlorophyll formation, and leaf diffusion resulting in lesser photosynthesis and severe reductions across grain yield levels [47].

Ghooshchi *et al.,* (2008) carried out a field experiment to quantify the effect of moisture stress occurring at three different stages in maize (before silking, silking and grain filling) reported reduction in plant height (by 11.1 per cent, 15.0 per cent and 18.8 per cent), total leaf area (by 20.3 per cent, 28.7 per cent and 27.6 per cent), days to physiological maturity (by 17, 29 and 18 days), number of grains per cob (by 14.8 per cent, 24.8 per cent and 1.00 per cent), 1000-grain weight (by 8.84 per cent, 24.8 per cent and 32.7 per cent) and grain yield (by 12.5 per cent, 42.5 per cent and 15.0 per cent). They opined that yield declining effect of moisture stress as highest during silking followed by intermediate during grain filling and lowest during vegetative stages [20]. However, Chiarandha *et al.,* (1977) reported 29.0 per cent, 28.0 per cent, 29.0 per cent, and 22.0 per cent yield reduction in maize with prevalence of drought stress during tasselling, grain formation, milking and anthesis stage respectively [48]. Denmead and Shaw (1960) also reported decreased plant height, leaf area, cob length, grain yield, stover yield and assimilation of maize grown under moisture stress at different stages. They reported that early vegetative stress reduces the size of assimilatory surface during ear formation and stress imposed after ear emergence retards the assimilation to developing grains, causing the highest productivity losses with stress at silking (50 per cent) followed by vegetative (25 per cent) and lowest after ear formation stages [49]. Similarly, Moser *et al.,* (2006) also reported reductions across number of grains per cob, 1000-grain weight and grain yield with induction of pre-anthesis drought stress in maize. They further attributed the under development of grains to inadequate supply of assimilates to the growing region and reductions across number of endosperm cells and starch granules [46].

Role of plant growth regulators, nutrient solutions and Agronomic Interventions in stress mitigation of maize

Abiotic stresses had fashioned a huge unbridged gap between the productivity of rainfed and irrigated agriculture. According to an estimate by Clive, (2009) more than 30 genetically engineered crops over 300 million acres are being cultivated in 25 countries but the practical implementation and success in the field of stress mitigation and crop improvement is slender because stress tolerance is a polygenic and quantitative character and the plants under field conditions faces a combination of stresses where single stress tolerant cultivar fails because of lack of tolerance against multiple stresses [50, 17]. Apart from these, a general review of physiological response of maize towards major abiotic stress finds similarity (production of signalling molecules, osmoregulation, imbalance among ROS and safe detoxificants) and their reported management strategies are also more or less common (**Table 1**). Keeping in view the practical implementation of technology, inclusion of agronomic interventions such as crop establishment methods, *in-situ* moisture conservation measures and utilization of harvested rain water for deficit irrigation, foliar supplementation of plant growth regulators, hormones and nutrient solutions is finding a considerable scope in bridging the stress induced productivity gaps across rainfed areas.

Table 1 Plant Growth Regulators

Plant species	Plant growth regulator	Type of stress	Results	References
Triticum aestivum	Thiourea	Salinity & High temperature	Promotion of root growth & harvest index	[45]
Zea mays L. & *Glycine max*	Salicylic acid	-	Enhanced leaf area, shoot dry weight & photosynthesis	[62]
Brassica napus L.	Salicylic acid	Drought	Improved relative water content, photosynthetic & seed quality attributes	[63]
Zea mays L.	Salicylic acid	Drought	Improved growth, yield & yield attributes	[64]
Zea mays L.	Salicylic acid	Heat	Enhanced shoot length, osmolyte accumulation &antioxidative defence system	[65]
Zea mays L.	Salicylic acid	Drought	Retarded stomatal closure, leaf senescence & elevated antioxidative defence system	[66]
Zea mays L.	Thiourea	-	Improved stover & biological yield	[58]
Zea mays L.	Thiourea	-	Enhanced vegetative growth & grain yield	[67]
Zea mays L.	Thiourea	-	Improved vegetative growth, grain yield & biological yield	[68]
Zea mays L.	Thiourea	Different levels of soil moisture	Improved growth & productivity	[69]
Zea mays L.	Thiourea	-	Improved grain yield & yield attributes	[70]
Zea mays L.	Thiourea	Salinity	Enhanced shoot length, root length, dry weight, cell multiplication & chlorophyll synthesis	[71]
Zea mays L.	Thiourea	Cadmium	Improved photosynthetic rate, pigments & vegetative growth	[72]
Zea mays L.	Thiourea & Salicylic acid	Cadmium	Improved vegetative growth & osmo-protectants	[73]
Zea mays L.	Thiourea	Heat	Enhanced cell membrane stability, chlorophyll content, antioxidative enzymatic activity & quantum yield	[36]
Zea mays L.	Thiourea & Salicylic acid	Heat	Elevated antioxidative defence system	[74]
Zea mays L.	Ascorbic acid	Osmotic	Boosted malondialdehyde content, proline content & endogenous ascorbic acid	[75]
Zea mays L.	Proline	Drought	Improved antioxidative groups & quality attributes	[78]
Zea mays L.	Proline	Salt	Elevated antioxidative groups; reduced accumulation of sodium, chlorine, Hydrogen peroxide and lipid peroxidase.	[79]
Zea mays L.	Glycine-betaine	Salt	Improved Photosynthetic characters & antioxidative enzymes	[80]
Zea mays L.	Nitrogen, Phosphorous & Potassium	Moisture	Increased growth, phenological stages & yield attributes	[82]
Zea mays L.	Phosphorous & Zinc	Moisture	Increased growth, yield & yield attributes	[83]
Zea mays L	Calcium	Drought	Improved growth, photosynthetic pigments, osmolyte accumulation & plant water status; reductions across oxidative damage	[84]
Zea mays L.	Boron	Drought	Reductions across proline accumulation, free amino acids & soluble sugars; improvements in antioxidative defence system & photosynthetic capacity	[85]

Plant growth regulators

Stress tolerance ability of plant is governed by adaptations such as osmoregulation and ROS detoxifying ability of cell and its strength is correlated with attainment of thermo-tolerance [51]; induction of defence inducing agrochemicals *viz.*, thiourea, thiamine, ascorbic acid, putrescine etc. was observed pivotal in ameliorating the adverse effect of stress on plants [36]. Thiourea is an organosulfur compound having its chemical formula similar to that of urea with a slight difference of sulfur compound at carbon-oxygen bond, containing 42.2 per cent sulfur and 36.9 per cent nitrogen [52]. The compound has two functional groups, one is 'thiol' which is important for oxidative stress response and other is 'imino' which partly fulfils the nitrogen requirement. Firstly, the role thiourea was described as dormancy breaking hormone in potato and artichokes. Later on, concurrent results (as dormancy breaking hormone) were supported by different researchers in *striga* spp., peach, gladiolus and lettuce seeds [53].

Supplementation of thiourea may play considerable role in accumulation of starch, phloem transport of soluble sugars, stabilization of lipo-protein structure and production of less malondialdehyde thereby provide tolerance against stress [54, 55]. Significance of thiourea in termination of heat and drought stress in wheat was described by Asthir *et al.,* (2013) and Hassanein *et al.,* (2015) [56, 57]. Although, the actual mode of action of thiourea is still not well known, but several researchers revealed its role in translocation of photosynthetic assimilates and formation of tertiary complex in cereals. Thiourea have redox regulatory mechanisms to mitigate various kinds of stress in plants and its application had significantly increased vegetative growth, protein content and grain yield of maize plants [58]; similarly, foliar application of thiourea (10 mM) ameliorated the high temperature stress in wheat [45]. As per stress physiology, stress begins with certain physiological, morphological and biochemical changes in plant. This includes changes in leaf area, cell wall permeability, photosynthesis, reduced transpiration, stomatal movement, root length, fresh weight and ultimately over-production of ROS that results peroxidation of lipids, oxidation of proteins, nucleic acid damage, enzymes inactivation and activation of programmed cell death pathway [59]. Foliar spray of thiourea improves plant defence system through increased activity of non-enzymatic antioxidants and ROS scavenging enzymes that detoxify ROS and help the plant to ameliorate from adverse effects of stress.

Plant's adaptation towards abiotic stress involves accumulation of phenolic substances which provide tolerance against stress by working as structural components of cell wall [60], source of electrons and protons for ROS and functions as ameliorators of growth and productivity [61]. Salicylic acid is an important phenolic compound having considerable role in termination of stress through ion uptake and solute translocation, ethylene synthesis, glycolysis, stomatal regulation [62], enzyme activation, photosynthesis and protein synthesis [63]. Zamaninejad *et al.,* (2013) observed significant reductions across losses in growth, yield and yield attributes of drought stressed maize and foliar spray of salicylic acid (1 Mm) caused considerable improvements in different growth, yield and yield attributes of stressed plants [64]. Khanna *et al.,* (2016) conveyed concurrent results as significant improvements across shoot length, osmolyte accumulation and antioxidative defence system with foliar salicylic acid sprayed heat stressed maize seedlings [65]. Saruhan *et al.*, (2012) confirmed the positive role of salicylic acid as potential stress mitigating chemical in their pot experimental study from Turkey. Pre-treatment of salicylic acid prevented the loss of water by retarding stomatal closure, leaf senescence and rolling and boosted the antioxidative defence system of plant through increased activities of ROS scavenging enzymes (Catalase, ascorbate peroxidase, superoxide dismutase, glutathionine reductase, monodehydroascorbate reductase and malondialdehyde) [66].

Sahu and Solanki (1991) conducted a field experiment on foliar spray of three different sulfhydryl compounds (*viz.*, mercaptoethanol, mercaptoethylamine and thiourea) at the rate of 0.10 per cent during grain formation stage in maize and obtained significant increase in grain yield (34.1 per cent) and harvest index (13.9 per cent) with 0.10 per cent thiourea over the control treatments. However, a non-significant effect of different foliar sprays on stover and biological yield were observed [58]. Sahu *et al.*, (1993) continued the research for optimizing the levels of chemical with an objective of improving the growth and yield of maize. Significant increments in leaf area index (32.4 per cent), number of green leaves per plant (50.0 per cent), biological (35.7 per cent) and grain yield (40.6 per cent) were recorded in 1000 ppm thiourea whereas the highest plant height (12.7 per cent) was recorded in its combination with seed treatment of 500 ppm thiourea over control. The increased growth and yield parameters were attributed to the positive role of sulfhydryl group in reducing the leaf senescence and improving the photosynthetic efficiency that favoured the assimilation of photosynthates during grain filling [67]. Ram (2009) conducted another field experiment choosing two levels of foliar thiourea (1000 ppm and 2000 ppm) applied in couple of sprays at 35 and 55 days after sowing (DAS) and reported a significant increase in plant height (7.40 per cent and 8.50 per cent with 1000 ppm and 2000 ppm, respectively), dry matter accumulation (15.2 per cent and 17.4 per cent with 1000 ppm and 2000 ppm, respectively) and crop growth rate (18.6 per cent and 19.8 per cent with 1000 ppm and 2000 ppm, respectively) at harvest, leaf area index (5.50 per cent and 6.70 per cent with 1000 ppm and 2000 ppm, respectively) and chlorophyll content (6.90 per cent and 9.10 per cent with 1000 ppm and 2000 ppm, respectively) at 60 DAS resulting into significantly higher grain (11.7 per cent and 13.7 per cent with 1000 ppm and 2000 ppm, respectively) and biological yield (6.00 per cent and 7.60 per cent with 1000 ppm and 2000 ppm, respectively) over the water spray treatment [68].

Keeping in mind the positive role of thiourea, Meena (2014) conducted an experiment with foliar application of four different agrochemicals (*viz.,* brassinolide (0.5 ppm), benzyl adenine (45 ppm), thiourea (1000 ppm) and potassium chloride (1000 ppm) sprayed at 45 and 55 DAS) with an objective to find the most suitable agrochemical for mitigation of moisture stress in maize and observed concurrent results in terms of significantly higher plant height (5.09 per cent), dry matter accumulation (6.00 per cent), crop growth rate (56.0 per cent), grain yield (5.95 per cent) and stover yield (3.88 per cent) with 1000 ppm thiourea over control [69]. However, foliar application of 2000 ppm thiourea at grain filling stage was found effective in improving number of grains per cob (24.7 per cent), grain weight per cob (43.3 per cent) and grain yield (26.9 per cent) over control as reported by Ameta and Singh (2005) from a rainfed maize experiment [70].

Broadening the sphere of study of thiourea in mitigating other abiotic stresses, Sanaullah *et al.,* (2016) carried out a field experiment in salt stressed maize and reported significant increase in shoot length (12.0 per cent), root length (7.00 per cent), root fresh weight (49.0 per cent) and shoot dry weight (42.0-51.0 per cent) of salt stressed maize seedlings with medium supplementation of 400 µM thiourea and attributed it towards accelerated cell multiplication and chlorophyll biosynthesis in 400 µm medium supplemented thiourea plants [71]. Similarly, Perveen *et al.,* (2014) reported the role of thiourea in improving photosynthetic rate, chlorophyll and carotenoid synthesis which provide significant increment in shoot length, root length, plant dry weight, number of leaves and leaf area per plant in 0.25 mM medium supplemented thiourea in cadmium stressed maize from their pot experiment [72]. Javaid and Wahid (2019) also observed consistent results from their experiment on thiourea and salicylic acid medium supplementation in cadmium stressed maize in the form of improved plant dry weight, leaf area, and osmo-protectants (phenols, flavonoids and anthocyanin). They attributed the ROS scavenging ability of thiourea to improved growth and osmo-protectants in cadmium stressed maize [73]. A pot-cum field experiment was performed by Parmer (2017) to study the influence of foliar applied agrochemicals (*viz.,* thiourea and salicylic acid) on antioxidative defence system of heat stressed maize. They observed significant improvements in activities of enzymatic and non-enzymatic groups in foliar sprayed treatments under pot experiment and further sowing of genotypes under field experiment caused significantly higher number of grains per cob in maize [74]. Yadav *et al.,* (2017) comparing three different agrochemicals (putrescine (4.00 mM), thiourea (20.0 mM) and hydrogen peroxide (1.20 mM) reported that foliar spray of thiourea (20.0 mM) ameliorates heat stress by significantly enhancing cell membrane stability, chlorophyll content, antioxidant enzyme activity and quantum yield of plants [36]. Terzi *et al.,* (2015) while working on osmotic stress mitigation in maize with exogenous application of ascorbic acid also reported considerable improvements in terms of malondialdehyde content, proline content and endogenous ascorbic acid in osmotic stress mediated and foliar sprayed maize. Application of ascorbic acid scavenged the endogenous hydrogen peroxide, mitigated the peroxidation of lipids and accumulation of abscisic acid and osmolytes in osmotic stressed maize [75].

In addition to ROS scavenging activity, stress response cascade involves the production and accumulation of compatible solutes (such as proline and glycine-betaine) for maintenance of osmotic potential and turgidity of stressed tissue as for plant stress tolerance [59] and maintenance of balance across endogenous hormonal levels. Compatible solutes *viz.,* sugars (sucrose, fructose and glucose), sugar alcohols (mannitol, glycerol and methylated inositols), complex sugars (raffinose, trehalose and fructans), tertiary amines (1,4,5,6-tetrahydro-2-mehyl-4-carboxyl pyrimidine), quaternary amino acid derivatives (proline, glycine-betaine, alanine betaine, proline betaine) and sulfonium compounds (choline-*o*-sulfate and dimethylsulfoniopropionate) are present in cytoplasm and accumulates in higher concentration in plant cells suffering from moisture shortage by the process called osmoregulation [76]. Proline is protein-ogenic amino acid functions in primary metabolism, scavenging of free radicals, stabilization of sub-cellular structures and buffering of cell redox potential. Similarly, glycine-betaine is electrically neutral and water soluble, with non-polar hydrocarbon and methyl groups, interact with hydrophilic and hydrophobic domains of macromolecules (*viz.,* protein complexes and enzymes), stabilise their structures and activities, and maintain membrane integrity against the adverse effect of stress due to cold, heat and freezing [77]. While examining the effect of exogenous proline on drought stressed maize, Ali *et al.,* (2008) explored the considerable role of proline (30 mM) in terms of improvements across antioxidant compounds (phenols, flavonoids, carotenoids and tocopherols), seed sugar, protein, moisture, fiber and ash content [78]. Significant improvement across growth and antioxidative defence system of proline supplemented (30 mM) salt stressed maize seedling has also reported by Freitas *et al.,* (2018) [79]. Nawaz and Ashraf (2010) reported concurrent results with exogenous application of glycine-betaine on two maize cultivars grown under saline conditions. Considerable reductions among growth and photosynthetic capacity had reported across plants under saline conditions except foliar sprayed treatments where alleviation of stress was observed in terms of improvements across photosynthetic characters and activities of antioxidative enzymes [80].

Nutrient solutions

Injudicious use of fertilizers on eroded and poorly fertile light textured soils fails to meet the mineral nutrition requirement of rainfed crops causing the low productive potential. The situation is further worsened by exposure of plants to dry spells and extreme rainfall which erodes soil nutrient bank and limits the solubilisation, uptake and ionic movement resulting the under development of source and sink organs of crops. Foliar fertilization of nutrients had frequently observed as an efficient strategy for assimilation and utilization of nutrients in stressed plants and contaminated soils [81]. Amanuallah *et al.,* (2014) conducted a field experiment with foliar nitrogen, phosphorous and potassium (each at 2 per cent), sole and in various combinations on 30 and 60 DAS in moisture stressed maize. Considerable reductions across growth and productivity parameters were observed across unsprayed treatments. Significant improvements in terms of plat height, leaf area, number of grains per ear, grain weight, grain yield, biological yield, harvest index and days to physiological maturity were recorded among foliar sprayed treatments. The treatments in combined application of nitrogen and phosphorous; nitrogen, phosphorous and potassium in one split at 30 days or 60 days or in two equal splits (1 per cent each at 30 and 60 days) improved grain yield in maize [82].

Solubility and uptake of nutrients is slow in arid and semi-arid regions, particularly when the nutrient is immobile as in case of phosphorous. The diffusion coefficient of soil applied phosphorous is low and it becomes unavailable to plant. Fixation of soil applied phosphorous by micronutrients is well known. Keeping in view in finding the interaction among foliar phosphorous and zinc and active role of foliar applied KH_2PO_4 in delaying leaf senescence Amanullah *et al.,* (2016) conducted another field experiment with different levels of foliar phosphorous and zinc applied at boot and silking stage on dry land maize and reported significant reductions across growth and productivity in unsprayed treatments. Foliar spray of 3 per cent phosphorous and 0.3 per cent zinc resulted significant improvements in terms of plant height, leaf area index, grain yield, biological yield and shelling percentage in moisture stressed maize [83]. Naeem *et al.,* (2018a) reported optimistic role of foliar applied calcium (40 ppm) in termination of drought stressed maize plants. Two levels of moisture stress (100 per cent and 30 per cent of water holding capacity) were applied gravimetrically followed by foliar application of three different levels of calcium (20, 40 and 60 ppm) at 3rd and 6th week of seedling establishment. Foliar spray of 40 ppm calcium resulted marked degrees of tolerance towards drought by improvement across growth, photosynthesis, plant water status, chlorophyll pigments and osmolytes and reductions across oxidative damage in maize [84]. Concurrent results were also reported in case of boron, Naeem *et al.,* (2018b) confirmed the stress ameliorative role of foliar applied born (4 ppm) in terms of reductions across proline accumulation, total free amino acids, total soluble sugars, antioxidative defence system and photosynthetic capacity of maize grown under water limited conditions [85].

Agronomic interventions

Planting methods

An appropriate plant stand is the basic necessity of crop to realize the maximum productive potential, harvest solar energy and rescue the plant from vagaries of climate. Plant functions as a complete system having steadiness between shoot and root in capturing resources and assimilating them to organs for production of dry matter. Severity of maize to moisture stress is also explained earlier in this context as maize plant have relatively shallower root system making it intolerant to lodging and variety of biotic and abiotic factors. Failure of monsoon rains and manifestation of extreme rainfall events proved disastrous to crop emergence, on the contrary, mid-season dry spells affects anthesis-silking interval, pollination and grain filling. To overcome such problems an appropriate land use system is required which can efficiently control the run off and soil loss under excess rainfall events vis-a-vis conserve the rain harvested soil moisture under dry spells for supporting the growth of crop plants. Adoption of appropriate site specific land configurations such as sowing maize on ridges ensure better nutrient and water supply, provide support against lodging by winds and rain thereby provides better crop microclimate for enhancing root growth and thus can also be helpful in terminating the influence of moisture stress [86]. Apart from ridge sowing, flat sowing increases soil compaction, affecting root penetration and orchestrates the severity of waterlogging under extreme rain events [87]. A brief overview of research studies regarding different planting methods have been summarized in **Table 2**. Bakht *et al.,* (2007) compared three different planting methods (*viz.,* ridge sowing, broadcasting and flat sowing) and reported considerable increase in cob length (0.75 cm), number of grains per cob (6.54 per cent), 1000-grain weight (3.95 per cent), grain yield (9.77 per cent), and stalk yield (7.17 per cent) in ridge planted maize over the flat sowing. A comparable increase in harvest index (1.29 per cent) and bareness (3.36 per cent) was also observed but did not attain the level of significance [88]. Similarly, Raihan *et al.,* (2017) from Kandahar (Afghanistan) worked on sandy clay loam soil (pH-8.3) reported a significantly higher plant height (1.98 per cent), dry matter accumulation (6.50 per cent), crop growth rate (21.3 per cent), production efficiency (37.0 per cent) and water use efficiency (36.9 per cent) amongst ridge sown plots over the line sowing treatment. The improvements were attributed towards higher uptake of nutrients and moisture from deeper layers caused by proliferated root system under ridge sown treatments [89]. Widening the sphere of comparison of ridge, flat and bed planting, Kaur (2011) evaluated the ridge planting in comparison to flat and bed in august sown maize and concluded significant improvements across plant height (3.18 per cent), number of leaves per plant (6.3 per cent), leaf area index (10.3 per cent), dry matter accumulation (4.75 per cent), cob length (0.4 cm), cob girth (0.5 cm), number of grains per cob (8.16 per cent), grain yield (5.94 per cent) and stover yield (5.83 per cent) of ridge sown maize over the flat one and attributed the same to higher moisture content and better physical conditions in ridge and bed sown plot which enhanced crop growth and abled the assimilates to develop larger sink organs [90]. Similarly, Kaur and Kumar (2018) compared the same three planting methods (ridge, flat and bed sowing) on sandy loam (pH-7.8) soil and reported significantly higher plant height (7.89 per cent), number of leaves per plant (4.10 per cent), number of grains per cob (8.06 per cent), grain yield (8.93 per cent) and stover yield (6.95 per cent) in ridge sown *kharif* maize than that of flat sowing and attributed the same to improved aeration which leads to better initial crop growth resulting into more source size (leaves) that helped in achievement of larger sink organs (cobs) in ridge sown plots [91]. Although, the highest numerical increment was observed under bed sowing in both of the studies [90, 91] but the effect was statistically similar to ridge sown treatment. Khan *et al.*, (2012) conducted an experiment on sandy clay loam soil (pH-7.8) at for comparing the three planting methods (flat, ridge and bed sowing) and reported slightly varying results in terms of significantly higher plant population (8.07 per cent), grain yield (12.1 per cent) and biological yield (16.4 per cent) under ridge sowing whereas number of grains per cob (3.90 per cent) in bed sowing over flat sown ones [87]. Similarly, Mahitha (2013) evaluated flat, ridge and broad bed planting on sandy loam soil (pH-6.5) and reported significantly higher leaf area index (3.41 per cent), number of grain rows per cob (3.75 per cent), number of grains per cob (4.10 per cent), test weight (5.60 per cent), cob weight (0.53 per cent), grain yield (27.5 per cent) and straw yield (30.6 per cent) in ridge sowing as compared to flat sowing and attributed the same to more run off and water logging in flat sowing and facilitation of drainage of excess water and conservation of harvested rainwater in ridge sowing [92]. Kaur and Vashist (2015) and Brar *et al.,* (2016) reported concurrent results in bed and ridge sowing on growth and grain yield of spring maize. Growth parameters *viz.*, plant height, leaf area index, chlorophyll content index and dry matter accumulation at 30, 60 and 90 days after sowing were statistically similar in bed and ridge sowing [93] and days taken to reach different phenological stages, dry matter accumulation and grain yield were altered non-significantly with respect to bed and ridge sowing [94].

Table 2 Agronomic interventions and soil water conservation measures

Plant species	Intervention	Soil type	Yield gain (%)	References
Planting methods				
Zea mays L.	Ridge sowing & Bed sowing	loamy sand	5.94 % (ridge) & 10.8 % (bed)	[90]
Zea mays L.	Ridge sowing & Bed sowing	loamy sand	8.93 % (ridge) & 11.2 % (bed)	[91]
Zea mays L.	Ridge sowing	sandy clay loam	12.1 %	[87]
Zea mays L.	Ridge sowing	-	9.77 %	[88]
Zea mays L.	Ridge sowing	sandy clay loam	-	[89]
Zea mays L.	Ridge sowing	sandy loam	27.5 %	[92]
Zea mays L.	Ridge sowing	loamy sand	13.5 %	[95]
Zea mays L.	Ridge sowing	-	3.90 %	[96]
Zea mays L.	Trench sowing	loamy sand	24.9 %	[97]
Zea mays L.	Ridge sowing	sandy clay loam	19.6 %	[98]
Zea mays L.	Ridge sowing	sandy loam	7.48 %	[99]
Soil water conservation measures				
Zea mays L.	Gunny bags mulching	sandy loam	12.8 %	[92]
Zea mays L.	Sugarcane trash mulching	sandy loam	44.5 %	[104]
Zea mays L.	Mulching	loamy sand	14.8 %	[95]
Zea mays L.	Wheat residue mulching	sandy loam	12.0 %	[105]
Zea mays L.	Wheat residue mulching	deep black	15.8 %	[106]
Zea mays L.	Wheat straw mulching	-	17.3 %	[107]
Zea mays L.	Wheat straw mulching	sandy clay loam	22.1 %	[108]
Zea mays L.	*Dhaincha* live mulching	silty loam	12.0 %	[109]
Zea mays L.	Weed biomass mulching	sandy loam soil	11.9 %	[110]

Similar experiments for comparing ridge and flat planted *kharif* maize were conducted by Singh and Vashist (2015) and Gul *et al.*, (2015). Singh and Vashist (2015) reported a significant increase in growth parameters (*viz.*, plant height (8.64 per cent), leaf area index (16.6 per cent) and dry matter accumulation by (9.64 per cent at harvest), grain yield (13.1 per cent) and stover yield (16.1 per cent) in ridge sown maize as compared to flat sown crop and attributed it to improved moisture and root development that avoided moisture stress and waterlogging conditions and helped the crop to establish properly [95]. Gul *et al.,* (2015) reported significantly higher plant height (3.56 per cent), leaf area index (15.6 per cent), dry matter production (10.5 per cent), cob length (19.5 per cent), number of grains per cob (3.73 per cent), cob diameter (17.5 per cent), grain yield (3.90 per cent) and stover yield (2.12 per cent) and attributed it to loose and fertile soil under ridge sowing that improved moisture and nutrient availability and lead to more productive potential of crop [96].

Sharma and Saxena (2002) observed that trench sowing of maize provides better support to plant against lodging resulting into earlier establishment of seedlings, lesser moisture stress and highest grain yield (24.9 per cent) achievement over the flat sown plots during their study of comparison among flat, trench, ridge and raised bed sowing methods [97]. However, Rasheed *et al.,* (2003) recorded significantly taller plants (4.60 per cent) with earlier attainment of tasselling (2.44 days) and silking (2.16 days), higher number of grains per cob (4.55 per cent), 1000-grain weight (4.83 per cent), grain yield (19.6 per cent) and stover yield (13.2 per cent) in ridge sown plots as compared to flat planted rows [98]. Similarly, Kumar *et al.,* (2018) revealed the positive role of ridge sowing in terms of higher cob length (4.78 per cent), number of grains per cob (3.84 per cent), grain yield (7.48 per cent) and biological yield (7.92 per cent) of spring maize [99]. Concurrent to the results of Gul *et al.,* (2015) they also reported loose and fertile soil with more nutrient and water holding capacity of ridges in association with better aeration resulted improvement in yield and yield attributes of spring maize [96]. Ridge sowing mitigated the damaging effect of high temperature stress in spring maize through improvement of root density and conservation of soil moisture that orchestrated the relative water content and guaranteed the supply of assimilates and water to grain by enhancing photosynthesis during grain filling which caused widening of grain filling duration, rate of grain filling and ultimately grain yield and yield attributes of heat stressed spring maize [100]. Regardless, the significance of ridge sowing in improving the water use efficiency and stress tolerance of maize, ridge replenishing is associated with large degree of soil disturbance, temperature fluctuations and moisture loss which may exacerbate soil drought across dryland areas [101]. The technology further limits the process of germination and seedling growth under early season dry spells in which ridges find comparatively higher degrees of vulnerability to moisture loss caused by evaporation than the flat sowing plots. Considerable soil loss associated with ridge overtopping and water erosion from furrows between ridges under intensive rainfall events is also major bottleneck in adoption of ridge sowing under rainfed areas. In crux, soil and water erosion is important constraint for production of maize across rainfed areas and ridge sowing is partly sufficient to control the same, therefore in addition to ridge sowing optimized in-situ soil and moisture conservation measures are necessary for realising the maximum productive potential of rainfed farming.

Soil and water conservation measures

Occurrence of dry spell, limited stored soil moisture, high rates of evaporation, competition by weeds and other biotic pests at critical stages of crop growth result significant yield reductions and demands appropriate soil and water conservation measures.

Mulching is one of the most effective answer to the above statement, improve crop microclimate by conserving stored soil moisture by the way it transfers the evaporation losses into improved water uptake and transpiration of plant, reducing soil deterioration and weed growth, balancing soil temperature and enhancing soil microbial growth (improve soil nutrition) [102]. It has an effective role in manipulating crop growing environment for improvement of productivity of various crops, can be utilized in non-traditional areas and seasons with lesser available soil moisture and to overcome the crop from vagaries of rainfall. There are areas in the world that receive intensive rains in a short span of time which is sufficient to produce one to two crops during an year but the problem lies in its distribution and management. Lack of appropriate agronomic and watershed approaches is the reason for productivity gap between irrigated and rainfed areas. Wani (2009) also stated that "occurrence of meteorological drought is not a reason for famines and food shortages but it's the poor management and utilization of limited rain showers for productive green purpose". They exemplified Wana region where farmers utilized 45.0 - 55.0 per cent of rains for production of crops and reported 100 per cent increment in crop productivity [3].

Addition of locally available mulch materials on ridges proved efficient in reducing run off during high intensity rains [103] and thus, application can be used for improving rain water use efficiency and would be helpful in strengthening the probability of stress mitigation. An overview of various soil water conservation measures and mulch materials is summarized in Table 2. Mahitha (2013) carried out a research study with three different mulch materials (paddy straw, gunny bags and hydrogel) and reported significant increase in dry matter accumulation (4.50 per cent at harvest), number of grain rows per cob (8.10 per cent), number of grains per cob (3.84 per cent), test weight (7.10 per cent), cob weight (5.20 per cent) and grain yield (12.8 per cent) in gunny bags mulch application over control and attributed it to reduced weed growth and evaporation that improved moisture content in soil profile to cope up with dry spells [92]. Similarly, Vashisht *et al.,* (2013) compared another three locally available organic mulch materials (*sugarcane trash, basooti* and *subabul* leaves), applied two times during crop growth (after crop emergence and before recede of monsoon) and reported 7.42 per cent decrease in runoff, 80.8 per cent decrease in total soil loss and 43.7 per cent increase in water use efficiency that lead to increased grain yield up to 44.5 per cent with *sugarcane trash* followed by *subabul* (28.1 per cent) and *basooti* (18.1 per cent) applied plots over control. *Sugarcane trash* had comparatively more ground coverage and a slower rate of decomposition that helped more water to infiltrate in soil and improve crop growth, whereas *basooti* and *subabul* decompose fast and helps to build significantly higher organic carbon (increase of up to 20.0 per cent in *subabul* and 12.5 per cent in *basooti*) in field for succeeding crops [104]. Singh and Vashist (2015) supported the positive role of mulching (5 tons ha^{-1}) in *kharif* maize in terms of significantly higher plant height (7.80 per cent at harvest), number of leaves per plant (7.40 per cent at 60 DAS), dry matter accumulation (8.23 per cent at harvest), grain yield (14.8 per cent) and stover yield (15.3 per cent) which was attributed to favourable hydrothermal regimes caused by reduced run off and evaporation that has favourable impact on crop growth [95]. Similarly, Chatterjee *et al.,* (2017) working on *kharif* maize with sandy loam soil also observed positive role of mulch application in terms of higher profile water storage (caused due to reduced evaporation, improved infiltration and facilitates condensation of water during night), leaf area index (22.2 per cent at flowering and 16.3 per cent at grain filling over control), grain yield (12.0 per cent) and biomass yield (15.8 per cent) which resulted significantly higher agronomic water productivity (12.6 per cent) and economic water productivity (15.6 per cent) [105]. However, Kaur (2011) find contradictory results in terms of non-significant effect of mulch application on growth parameters *viz.,* plant height, number of leaves per plant, leaf area index, dry matter accumulation and days taken to different phenological stages), yield and yield attributes (number of cobs per plant, cob length, cob girth, bareness percentage, number of grains per cob and test weight) of august sown maize. The contradiction was justified with well distributed and sufficient rainfall during the crop season that failed the mulch to show its moisture conservative nature and resulted similar crop in mulched and control plots [90]. Priya and Shashidhara (2016) from their rainfed maize experiment on deep black soils also reported positive effect of mulching in terms of significantly higher test weight (13.1 per cent), cob length (14.7 per cent), grain weight per plant (8.50 per cent) and grain yield (15.8 per cent) of maize in mulched plots over control and attributed the same to improved moisture content in root zone [106].

Optimizing level of mulch in maize Khurshid *et al.,* (2006) and Pervaiz *et al.,* (2009) from University of Agriculture Faisalabad, Pakistan conducted field experiments, Khurshid *et al.,* (2006) evaluated three levels of mulch (*viz.,* 4, 8 and 12 Mg ha^{-1}) with control and reported significant increase in plant height (17.1 per cent), 1000-grain weight (8.35 per cent), plant biomass (29.3 per cent) and grain yield (17.3 per cent) at 8 Mg ha^{-1} mulch level (over the no mulch treatment) which was attributed to improved soil properties [107]. Similarly, Pervaiz *et al.,* (2009) quantified two levels of wheat straw mulch (*viz.,* 7 Mg ha^{-1} and 14 Mg ha^{-1}) and reported significantly higher soil moisture content (21.4 per cent) and soil organic matter content (103.5 per cent) which resulted significant improvement in nutrient uptake (*viz.,* N and P), plant height (5.40 per cent), biological yield (8.80 per cent) and grain yield (22.1 per cent) in 14 Mg ha^{-1} wheat straw mulch level over control treatment [108].

Apart from beneficial effect of mulching, the availability of mulch material is still questionable in some parts. Keeping in view Sharma *et al.,* (2010) conducted a field experiment with live mulching of legumes intercrops (*viz., sunhemp, dhaincha* and *cowpea* sown in maize and spread as mulch material at 30 and 45 DAS) observed that growing legume crops up to 30 days compete with weeds, reduce their growth, harvest nutrients and their further spreading enhanced moisture conservation by reducing run off, evaporation and improving infiltration resulting into significant improvement in plant height (4.70 per cent), number of cobs per plant (4.08 per cent), 1000-grain weight (10.2 per cent) and grain yield (12.6 per cent) in *dhaincha* mulch at 30 days spreading over clean cultivation [109]. Keeping in mind the objective of quantifying the role of mulching in dry spell mitigation, Hijam *et al.,* (2014) carried out a field experiment on sandy loam soil, reported significantly higher plant height (16.4 per cent), leaf area index (20.4 per cent), grain yield (11.9 per cent) and stover yield (16.4 per cent) in mulched plots over the non-mulched ones and credited it to higher availability of soil moisture in the root zone that caused better mineralization of plant nutrients and help to mitigate the period of dry spells during critical phases of crop growth [110].

Conclusions and future prospects

Poorly distributed uncertain rainfall, increasing number of droughts, extreme and untimely rainfall events and natural constraints such as land degradation and soil erosion had posed the vulnerability of rainfed farming and sustainability of food grains at high risk. Vagaries of seasonal rainfall, the ultimate source for crop production, had increased the incidence and frequency of biotic and abiotic stresses and created a large unbridged productivity gap between irrigated and rainfed areas. Advancements in agricultural and biochemistry research across previous decades had recorded considerable interventions approaching in bridging these gaps through reductions in terms of productivity and quality losses. Inclusion of plant growth regulators, antioxidative defence inducing and osmo-regulating agrochemicals (thiourea, salicylic acid, ascorbic acid, proline, glycine-betaine etc.), macro and micro nutrient solutions (nitrogen, phosphorous, potassium, zinc, calcium, boron) as foliar supplementation have been increased across last few decades. With substantial rise in frequency of stresses and advancements in the field of biochemistry and stress physiology, research advancements are expected to widen in future and the approach is tend to become a revolutionising agricultural system for mitigating the threat to world food security. Further research is required to focus on mechanisms involved under multiple stress factors and differential responses of plants towards varying degrees of stress under field conditions. In addition to optimization of productivity levels an eager and interactive response of plants under integrative effect of foliar supplementation, agronomic and soil moisture conservation measures on grain quality and bioactivity related traits is a future scope of interest. We hope that the paper would further strengthen and stimulate the efforts across mitigation of multiple stresses in maize along with bridging the productivity gaps, improvement of livelihood of poor and developing communities and pay considerable role in mitigating the threat of future food grain demands.

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