Chapter

Management of Abiotic Stress in Forage Crops

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Abstract

Forage plays a key role in rearing ruminants and protecting the environment. Apart from serving as the primary source of food for domestic and wild animals, forages also contribute to human civilization in different ways like protecting soil through crop over and fertility by addition of organic matter. It also provides habitat for wild animals. A survival strategy plays a more important role than a growth strategy to improve the sustainability of forage production, especially in extreme environmental conditions . Climate change is likely to affect the forage production and nutritional food security for domestic animals. Long-term rainfall data in India indicate that rainfed areas experience 3 to 4 years of drought in every 10 years. Of these, one or two of it occur in severe form. Forage crop production is largely affected by abiotic factors related stress such as drought, salinity, etc. There is need to adopt various conventional and genetic approaches to improve stress tolerance of forage crops.

Keywords: forage crops, abiotic stress, management, breeding and micronutrients

1. Introduction

In the agricultural context, stress has been defined as the conditions in which plants are prevented from fully expressing their genetic potential for growth, development, reproduction, and, ultimately, crop productivity [1]. Abiotic stress negatively affects the livelihoods of farmers and their families, the sustainability of livestock, as well as national economies and food security. Forages are generally described as plants and its parts consumed by domestic livestock. Forage plays a key role in rearing ruminants and protecting the environment. Apart from serving as the primary source of food for domestic and wild animals, forages also contribute to human civilization in different ways like protecting soil through crop over and fertility by addition of organic matter. It also provides habitat for wild animals. In the biological soil–plant–animal system, forage is highly demanded by livestock. Escalation in the human population in the coming decades will put the higher burden on land for food crops and fiber production. As a result, we may face forced forage cultivation in those areas having poorer soils regarding fertility and management [2]. The water use for irrigation is incredibly high and this trend could increase considerably in the future leading to shortage of water availability [3]. For perennial forage and natural vegetation, the ability to survive during adverse environmental periods is a life saving feature. A survival strategy plays a more important role than a growth strategy to improve the sustainability of forage production, especially in extreme environmental conditions [4]. Forage crop production is largely affected by abiotic factors related stress such as drought, salinity, etc. There is need to adopt various conventional and genetic approaches to improve stress tolerance of forage crops.

2. Forage status

Currently, India faces a critical imbalance in its natural resource base: around 18 percent of humans and 15 percent of the world's animal population are only served by 2.4 percent of the geographical area, 1.5 percent of forests and pastures, and 4.2 percent of water resources [5]. The three main sources of forage supply in India are crop residues, cultivated forage, and forage from common property resources such as forests, permanent pastures, and pastures. Due to the multiplicity of forage crops produced in different seasons and regions, the surplus and deficit in different regions, the non-commercial nature of crops and forage production with minimal inputs from degraded and marginal land, there has been a large gap in the availability and need for forage. Currently, the country faces a net deficit of 35.6 percent of green forage, 10.95 percent of residues from dry crops, and 44 percent of concentrated ingredients for animal feed [6]. Supply and demand for the forage scenario are presented in **Figure 1**. Furthermore, in the case of forage, regional and seasonal deficiencies are more important than national deficiencies, since it is not economical to transport forage over long distances. Furthermore, the available forages are of low quality and deficient in available energy, protein, and minerals. Farmers maintain large herds of animals to compensate for low productivity, adding pressure on forage and other natural resources [7]. Almost two-thirds of the total cost of animal production is due to food and fodder. Consequently, any attempt to improve the availability of food and fodder and save the cost of food would result in better remuneration for farmers. The area under cultivated forage is only 8.4 million hectares and has been static for the past two decades. The potential for further increases seems very small due to demographic pressure for food crops. Recent crop diversification, where cash crops replace traditional cereal crops, especially coarse grains, is likely to have an impact on the availability of crop residues for animal production [8]. Likewise, the productivity of certain important cultivated forages is highly variable. Among Kharif forages, sorghum, corn, cowpea, Napier-bajra hybrid, and guinea they have a wide range. However, during rabi, the choice is limited to oats, alfalfa, and berseem. Emphasis should be placed on new area-specific crops that can break down yield barriers and meet the challenges of the food deficit.

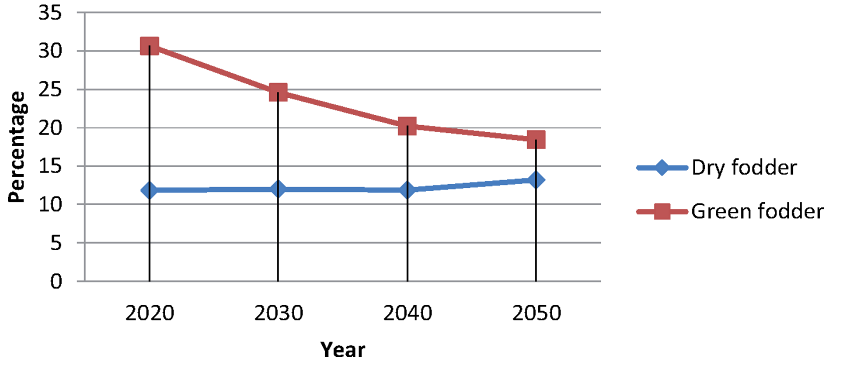

Figure 1.
*Deficient trend of fodder crop concerning future demand. *IGFRI vision, 2050.*

3. Different types of abiotic stress faced by crops

3.1 Temperature restriction

The tropical climate is cursed by higher temperatures and radiation that limit the growth and development of plants. High temperatures cause burns, sunburn, and discoloration of the leaves, reducing plant growth [9]. Limiting growth, metabolism, and performance potential due to exposure to a temperature below or above the thermal threshold for optimal biochemical, physiological, and morphological development is called thermal stress [10]. Plants are classified into psychophilic, mesophilic, and thermophilic according to their tolerance to low, medium, and high temperatures [1]. The adversity of heat stress varies with the duration, stage, and intensity of stress [11]. Increased heat stress adversely affects the spikelets number, the number of florets per plant in rice crop, and the seeds in forage crop like sorghum [12]. It also reduces quality due to reduced production of oil, starch, and protein [13]. Stress at low temperatures causes wilting, bleaching, darkening, necrosis, and death of plants [1]. Approximately 15percent of arable land is said to be affected by frost stress [14].

3.2 Moisture stress

About 28 percent of the world's land is too dry for agricultural support [15]. The estimated annual yield loss due to extraction in the tropics is almost 17 percent [16]. Increasing the draft with the changing climate scenario leads to a decrease in plant physiology, growth, and reproduction [17]. The moisture deficit causes greater transpiration and reduces the availability of water from the roots of the plants [18], which tends to balance the water on the negative side that affects growth, the relationship between nutrients and water, photosynthesis and assimilation of sharing and, ultimately, performance [19]. The stress response plan in plants varies according to the species according to its stages and other growth factors [20]. High-temperature stress affects enzyme activity, cell division in plants [21] and also changes the growth period and distribution of crops [22].

3.3 Heavy metal stress

Heavy metals are those metals that have a specific weight greater than 5 g cm^{-3} or an atomic mass greater than 20 and are generally toxic even at low concentrations [23]; some of heavy elements or metals are cadmium (Cd), lead (Pb), arsenic (As), silver (Ag), etc. Heavy metal contamination in the soil is mainly due to human activities such as mining, smelting, intensive agricultural practices, fuel production, electroplating, etc. [24] and may also be due to natural processes such as soil erosion, excessive weathering of rocks and minerals, and volcanic eruption. Among heavy metals, some have known physiological functions in the plant system called non-essential heavy metals, namely arsenic (As), lead (Pb), cadmium (Cd), mercury (Hg), and selenium. (Sc) and some are involved in different physiological functions of plants as a cofactor of enzymatic reactions [25] or role in redox reactions [26] called essential heavy metals, namely cobalt (Co), copper (Cu), manganese (Mn), zinc (Zn), iron (Fe), molybdenum (Mo) and nickel (Ni).

3.4 Salt stress

Crops are said to be subject to salt stress when they cannot express their full genetic potential in terms of growth, development, and reproduction, since the salinity of the soil exceeds the critical level [27] and dissolved salts in the soil and irrigation water vary from place to place [28]. The detrimental effect of soils affected by salt may be due to a high concentration of salt in the soil solution, i.e. osmotic effects or a high concentration of specific ions such as sodium or chloride that can damage sensitive crops, i.e. a specific ionic effect. The harmful effect of saline soil is due to the concentration of soluble salt, while the harmful effects of sodium soil are due to deterioration of the physical state of the soil [29]. The harmful effect of salt stress may be due to a specific ionic effect, that is, Na^+ and Cl^- [30] or to interact with other dynamics of mineral nutrients [31].

3.5 Nutritional stress

Several mineral elements contribute to the growth and development of a plant, 17 of which are called essential nutrients according to the essentiality criteria defined by Arnon and Stout. Since mineral nutrition is discipline independent of plant physiology [32, 33] divide essential minerals into four groups according to their biological structures and metabolic functions. There is some nutritional stress (deficiency or excess) reported by various scientists in different plants. Nitrate plays pivotal role cytokinin biosynthesis and transport, and a higher level of nitrate (NO^{3-}) inhibits root growth and the root: shoot ratio [34]. Phosphorus deficiency limits the lengthening of the primary roots and improves the formation of lateral roots, decreases the proportion of the dry weight of the roots of the shoots [35], reduces the leaves [36] and affects the reproductive organs formation [37], plants with potassium deficiency (K^+) are sensitive to lodging and airflow [38]. A sulfur deficiency decreased the net photosynthesis and the hydraulic conductivity of the roots [39], the reduction in the dry weight ratio of the roots of the shoots [40], an alteration in the metabolism of carbohydrates followed by an induced accumulation of starch [41].

4. Impact of abiotic stress on physiology of forage

4.1 Photosynthesis

Moderate stress in water deficit plants reduces photosynthesis which is accompanied by closing of stoma [42]. Measurement of the photosynthetic response and the activity of the ribosose bisphosphate carboxylase vifro (RUBISCO) in alfalfa (*Medicago sativa* L.) exposed to an increasing water deficit and found evidence of adverse osmotic effects [43].

4.2 Forage quality

The digestibility of legumes and their fiber have been largely affected by water availability [44, 45]. Drought affects the forage composition and quality by altering plant maturity and ratio of leaf mass to stem mass [46].

4.3 Establishment of seedlings in forages

Water availability highly affects the forage seedlings growth and maturity [47]. Seminal roots support seedlings for a short time. Seminal root system absorbs by the hydraulic conductivity of the suboptoptic internode. Redmann and Qi (1992) found that the diameter of the xylem vessels in warm-season grass seedlings that emerged from different planting depths and length of suboptoptic internode plays an important role in transport of water from the root to the shoot and reducing hydraulic conductivity.

5. Impact of climatic anomalies on forages in terms of stress

Climate change has become a serious threat to life on earth. There is also a global trend of increased storms on most lands. Glaciers are continuously melting, while daily high temperature with heat waves became more common [48]. Coping with climate variability is becoming a major challenge for human civilization. Higher seasonal variability regarding the distribution of precipitation, extreme events of temperature, and precipitation cause damage to crops and raise serious concerns about agricultural production. Among adverse weather events, drought is the major factor to directly affect the population. A warmer climate with increasing climatic variability will increase the risk of climatic extremes. Meteorological data analyzed over 5 decades from CRIDA's Gunegal research farm, a typical rain region, showed low precipitation. Climate change is likely to affect the forage production and nutritional food security for domestic animals. Long-term rainfall data in India indicate that rainfed areas experience 3 to 4 years of drought in every 10 years. Of these, one or two of it occur in severe form [49].

6. Abiotic stress management in major fodder crops

6.1 Sorghum

6.1.1 Water stress and its management

Sorghum with its persistent green character, well developed root system, higher water-use efficiency and epicuticular wax represents a good system for studying physiological features related to drought tolerance. Depending on stress development at any growth stage, sorghum shows a stress response before flowering and after flowering, respectively. All these different responses are affected by various genetic processes [50]. Pre-flowering stress affects plant biomass, panicle size, kernel quantity, and grain yield [51], whereas posttesthetic dryness leads to premature senescence of leaves and stems, lodging and the reduction of seed size [52]. Post-synthesis drought also increases plant sensitivity to biotic stress, such as charcoal rot (*Macrophomina phaseolina*) and fusarium stem rot (*Fusarium moniliforme*) [52]. For drought tolerance before flowering, six distinct genomic regions were Recombinant inbred sorghum lines (RIL) derived from the cross between the genotypes Tx7078 (tolerant before flowering, sensitive to post-flowering) and B35 (sensitive to pre-flowering, tolerant after flowering) [53]. The response to dryness after flowering is associated with the persistent green character of sorghum. Staying green is essentially the retention of the surface of mature green leaves (GLAM). Maintaining the remaining green character during the grain filling phase under stress conditions of soil water deficit constitutes an important element of drought tolerance [54].

6.1.2 Epicuticular wax

Epicuticular wax (EW) forms a glaucous upper coating that is visible on many cultivated plants called waxy bloom. Species, organ, stage of development, and environmental conditions are all those things that affect buildup of wax.

Composition and structure of epicuticular wax is very diverse which is considered a potential useful trait and has been related to resistance against different adverse environmental conditions [55]. Sorghum differs from other field crops in its ability to produce sufficient amount of EW that is placed on the leaf blade as well as leaf sheath generally during pre-flowering and stages of maturity. Sorghum leaf sheath bloom is composed of large amount of free fatty acids with a 16 to 33 carbon chain length [56].

6.1.3 Osmotic adjustment

Two traits named osmotic adjustment and antioxidant capacity have been related with drought tolerance mechanisms. Osmotic adjustment has been associated with sustained performance under water limiting conditions in many crops and is an inherited characteristic. Two major independent genes namely OA1 and OA2 in sorghum have been reported to control Osmotic adjustment inheritance.

6.1.4 Cold tolerance

Sorghum from the tropical and subtropical regions of Africa [57] is well adapted to warm growing conditions. Cool temperatures at the beginning of the growing season are therefore an important limitation for the growth of temperate sorghum areas [58]. Cross developed from local Chinese races, ShanQui Red (SQR, cold-tolerant), and SRN39 (cold-sensitive) was used for QTL analysis of early-season cold yields on sorghum [59].

6.2 Bajra

Bajra [*Pennisetum glaucum*] is a C4 plant with very high photosynthetic efficiency. Bajra also have high dry matter production capacity. It is generally cultivated under the most adverse agroclimatic conditions, where other crops such as sorghum and corn do not stand well.

6.2.1 Selecting genotypes is a good approach to managing abiotic stress

Pearl millet germplasm screening helped in the development of highly advanced breeding techniques, an improvement in the population, including OPVs, genetic pools and compounds, possible parental hybrids, and accessions of the high-throughput genetic material of cereals and forages, presumably with a high degree of salt tolerance (**Table 1**).

6.2.2 Low soil fertility

Soils in the areas where pearl millet is grown are often poor infertility because they contain a small amount of organic matter (0.05–0.40percent) due to low ground cover, coarse soil texture, and prevailing high temperatures [63]. Soils also contain low to moderate levels of available phosphorus (10–25 kg ha^{-1}). This problem was mainly solved through nutrient management. The possibilities of genetic improvement for the efficient use of nutrients are increasingly explored in some cultures [64]. Only recently has strategic research been launched at ICRISAT in the West and Central Africa region to identify QTL to increase the efficiency of phosphorus and examine the stability of its expression across genetic environments.

Abiotic stress	Genotypes	References
Drought	CZP 9802; 863B and PRLT 2/89-33ICMP 83,720	[60]
Heat	H77/833–2, H77/29–2 and CVJ 2–5–3-1-3, 77/371XBSECT CP1	[61]
Salinity	33, 10,876 and 10,878 (Sudan), 18,406 and 18,570 (Namibia), and ICMV93753 and ICMV 94474 (India); 863-B, CZI 98–11, CZI 9621, HTP 94/54	[62]

Table 1.
Available genotypes for abiotic stress tolerance in pearl millet.

6.3 Forage corn

Corn forage (*Zea mays* L.) has become an important component of ruminant rations in recent years. It is the only crop among non-leguminous forages that combines better nutritional quality. With a large amount of biomass [65]. Although the crop has great adaptability [66], it is the least tolerant of abiotic stress among cereals. Drought, salinity, and high temperatures are among the major abiotic stresses that negatively impact corn production in most regions of global corn production [67]. Soils with saline stress are present on all continents and in almost all climatic conditions. However, its distribution is relatively more extensive in arid and semi-arid regions than in humid regions [68]. Mohammed and Mohammed 2019 stated that the appropriate genotype based on stress selection is the inexpensive and manageable stress method based on salt, water, and heat or combined form and also concluded that the reduction in stress performance would be reduced to 20–40 parents.

6.4 Cowpea

The cowpea (*Vigna unguiculata*) is one of the most important legumes cultivated by subsistence farmers for human and animal consumption, mainly in the semi-arid regions of Africa and Brazil. In Africa, it is used for the livelihood of millions of people in the semi-arid regions of the West and Center [69] and is considered the most important grain legume crop in the sub-Saharan region.

6.4.1 Reproductive improvements

Cowpea is relatively drought tolerant. Despite this feature, however, drought can cause a considerable loss of performance. Efforts have been made to select the cowpea genetic material to identify lines with better drought tolerance than currently available varieties. According to Watanabe et al. [70], certain lines of genetic material, in particular, TVu 11,979 and TVu 14,914, were consistently very drought tolerant under real field conditions. Drought can occur at the beginning of the season, mid-season, or the crop development stage. Studies have shown that cowpea plants can show drought tolerance in the vegetative stage [71] and the reproductive stage [32]. Some cowpea lines exhibit a green persistence feature, also called delayed leaf senescence (DLS), which can help plants tolerate terminal and mid-season drought [32].

6.4.2 Gene selection

In cowpea plants, overexpression of the CPRD 8, CPRD12, CPRD14, CPRD22 and CPRD46 genes that confer tolerance to water stress [72], as well as the production of VusAPX genes connected to VucAPX, VupAPX and VutAPX of antioxidant enzymes [73], it is reported, in addition to the expression of the high level of the PvP5CS gene associated with the production of proline, an amino acid that fulfills the function of osmotic adjustment between species during drought.

6.5 Abiotic stress tolerance mechanism

Climate and soil determine many plant adaptations and the ecogeographic distribution of species and ecotypes show differences in physiology and development patterns that provide good evidence of adaptation mechanisms. Plants respond to environmental change as individuals through phenotypic plasticity and in populations through the selection and associated evolutionary processes. Determining the genetics underlying adaptation processes is not always easy because environmental factors can be complex or poorly defined. However, extreme environmental pressures, such as heavy metal contamination from the soil or harsh winter conditions [74] can produce detectable genetic changes. Multiple genes may be responsible for a response to a certain factor, or the same gene may be involved in different adaptive responses specific genetic interactions can be in a state of change or become fixed, limiting the possibilities for future evolution. Phenotypic plasticity acts as a buffer to prevent excessive gene flow in response to short-term changes.

7. Improving forages for abiotic stress response based on breeding techniques

7.1 Greater tolerance to stress through genetic transformation

Genetic improvement of forages through the selection of conventional plants is slow because most forage species are self-incompatible, limiting inbreeding to concentrate the desired genes to be used in the rapid development of new cultivars. Genetic transformation allows the direct introduction of desirable genes, thus offering new opportunities for forage molecular selection. Like many other crops, drought tolerance is an important goal in improving alfalfa. Since cuticle waxes play a central role in limiting the breathable loss of water from the plant surface, the genetic engineering of plant waxes is expected to eventually increase tolerance to environmental stress in crops such as agronomic importance [75].

7.2 Improvement of stress tolerance through intergeneric hybridization

Extensive hybridization with relative species followed by introgression of chromosomes and/or chromosome fragments has been considered an effective means of transferring salt and other stress tolerance genes to target species to extend the gene pool. Intergeneric hybrids between species of Lolium (Ryegrass) and Festuca (Fescue) have attracted much attention from forage breeders. Rye grasses are considered ideal grasses due to their fast establishment, their ability to resist intense grazing, their good palatability, and their high nutritional value [76].

Alfalfa (*Medicago sativa* L.) is widely cultivated in temperate and tropical regions for green forage, hay, silage, and grass. As a perennial forage plant, alfalfa is a fairly hardy species and has a relatively high level of drought tolerance compared too many other legume forage plants [77]. Alfalfa's increased drought tolerance is due in part to deeper roots and the ability to extract more available water from the root zone [78]. Detection of salt-sensitive proteins in two contrasting alfalfa cultivars using a comparative proteome approach revealed two new proteins, NAD synthetase, and biotin carboxylase-3, as being salt sensitive. These results provide new information on alfalfa salt stress tolerance [79]. The effects of rhizobia strains on the amino acid composition of alfalfa under salt stress indicate that proline, glutamine, arginine, GABA, and histidine accumulate significantly in salt-stressed nodules, suggesting increased production of amino acids associated with osmoregulation, nitrogen storage, or energy metabolism to counteract salt stress [80] is a widely allogeneous forage legume species distributed worldwide due to its wide range of climate adaptation [81]. But it is less drought tolerant than other temperate perennial forage legumes due to its shallow root system and its inability to effectively control transpiration [82]. Biochemical studies have indicated that when white clover was stressed by a water deficit, De novo synthesis of amino acids, including proline, has increased in both leaves and roots [83]. This phenomenon may serve as an adaptive response during the first days of drought since the transient increase in amino acid concentration has been followed by a decrease in protein synthesis that slows plant growth.

Cowpea (*Vigna unguiculata* L.) growing in a variety of environments from tropical to arid/semi-arid regions, increased tolerance to drought and heat would be desirable. The cowpeas (*Vigna marina*) that grow on sandy beaches in the tropical and subtropical regions closest to the sea have the potential to be a source of genes for breeding salt-tolerant cultivars. Chankaew et al., [84] first reported QTL mapping for salt tolerance in the *Vigna marina*, and multiple internal mapping consistently identified an important QTL that can explain 50 percent of the phenotypic variation. The flanking marker can facilitate the transfer of salt tolerance of this subspecies in related Vigna cultures.

8. Micronutrient stress management

8.1 Sorghum

Sorghum (*Sorghum bicolor*) is one of the important forage crops for high agricultural production and good nutritional value for animals. Nutrient requirements for growing sorghum are high; they are grown for forage, in part from organic sources, and are supplemented primarily with inorganic fertilizers. The growth, development, and biological yield of crops affected by balanced fertilization have shown positive effects. Micronutrients increase crop productivity and also maintain soil health. A very small amount is required. Soil application of micronutrients is preferable for what is desired. Choudhary et al. [85] observed that the combined application of micronutrients, that is, a considerably higher yield of cereals, stems, and organic, is obtained through a soil + leaf application. The results showed a significant increase in grain yield (14.15 and 12.13 percent), biological yields (11.37 and 9.31 percent), and in stem yield (10.75 and 8.60 percent) and through the combined spraying of soil and foliar on the soil and foliar application, respectively.

8.2 Pearl millet

Pearl millet (*Pennisetum glaucum* L.) is one of the main millet crops in arid and semi-arid areas. Weather. Due to the drought-tolerant nature, it grows well in poor sandy soils. Sustainable production of pearl millet can be achieved through the balanced use of nutrients in crops with the fusion of organic and inorganic sources. Intensive farming is followed in the current system, most farmers use high-yielding whole crop varieties, ultimately a significant removal of nutrients from the soil in recent years, and the consumption of fertilizers has remained well less than the elimination one. So that the qualitative and quantitative improvement of the crop yield goes through mineral fertilization and that its quality can be improved through adequate practices of nutrient management and soil cultivation [86].

8.3 Maize

The third most important cereal crop is maize (*Zea mays* L.) worldwide and India. It is cultivated in temperate and tropical regions of the world. It is the most important cereal for animal feed. In India, 45 percent of maize production is used in various forms of staple foods [87]. Corn, rice, and wheat are estimated to provide at least 30percent of food calories to more than 4.5 billion people in 94 developing countries. The demands for animal feed and biofuels can be met by increasing maize production [88]. The application of micronutrients can be carried out in several ways, such as seed treatment, soil and foliar application [89], which depends on the characteristics of the soil and the climate of the region. Corn productivity can be improved by applying Zn and B to the soil.

8.4 Cowpea

Cowpea (*Vigna unguiculata*) is a legume and is used as a forage crop that is grown during the Kharif season, requiring only an initial dose of nitrogen (15–25 kg N ha^{-1}). Most nitrogen requirements are met by symbiotic nitrogen fixation. The strong application of NPK fertilizers has led to micronutrient deficiencies in many parts of the country. To achieve high yields and maintain them over the years, it becomes highly relevant to predict emerging nutrient deficiencies and to develop appropriate breeding technologies. Balanced fertilization is inevitable to increase the productivity of the crop. Among the micronutrients, Zn, Fe, B, Mn, and Mo significantly improved yield, and micronutrient foliar spray is economical on legumes.

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References

[1] Levitt J. Responses of Plants to Environmental Stress. In Water, Radiation, Salt, and other Stress. New York: New York: Academic Press, 1980.

[2] Sanderson, M. A., D. W. Stair, and M. A. Hussey, 1997: Physiological and morphological response of perennial forages to stress. *Advances in Agron*., 59: 171-224.

[3] Breshears, D. D., N. S. Cobb, P. M. Rich, K. P. Price, C. D. Allen, R. G. Balice, W. H. Romme, J. H. Kastens,

[4] Eagles, C. F., H. Thomas, F. Volaire, and C. J. Howwarth, 1997: Stress physiology and crop improvement. In: Proc. XVIII Intl. Grassland Cong., B. R. Christie, (ed.). Canada

[5] Palsaniya DR, Singh R, Tewari R K, Yadav R S, and Dhyani S K 2012a. Integrated watershed management for natural resource conservation and livelihood security in Semi-Arid Tropics of India. *Indian J Agric Sci* 82(3): 241-47.

[6] IGFRI Vision 2050. Indian Grassland and Fodder Research Institute, Jhansi (UP).

[7] Palsaniya DR, Singh Ramesh, Tewari RK, Yadav RS, Dwivedi RP, Kumar RV, Venkatesh A, Kareemulla K, Bajpai CK, Singh Rajendra, Yadav SPS, Chaturvedi OP and Dhyani SK 2008. Socio-economic and livelihood analysis of people in Garhkundar-Dabar watershed of central India. *Indian J Agroforestry* 10(1): 65-72.

[8] Ghosh P K and Palsaniya D R 2014a. Crop diversification for sustainable intensification and carbon management. In *National Symposium on agricultural diversification for sustainable livelihood and environmental security*, PAU, Ludhiana, 18-20 November 2014, pp. 3-5.

[9] Vollenweider P, Günthardt-Goerg MS. Diagnosis of abiotic and biotic stress factors using the visible symptoms in foliage. Environ. Pollut. 2005; 137(3):455-465.

[10] Greaves J. The gender trap. Health Informatics J. 1996; 2(4):194-198

[11] Fahad S, Hussain S, Saud S, Khan F, Hassan S, Amanullah, *et al*. exogenously applied plant growth regulators affect heat-stressed rice pollens. J Agron. Crop Sci. 2016b; 202:139-150.

[12] Prasad PVV, Boote KJ, Allen LH. Adverse high temperature effects on pollen viability, seed-set, seed yield, and harvest index of grain-sorghum [*Sorghum bicolor* (L.) Moench] are more severe at elevated carbon dioxide due to higher tissue temperatures. Agric. For. Meteorol. 2006; 139(3-4):237-251.

[13] Maestri E, Klueva NK, Perrotta C, Gulli M, Nguyen H, Marmiroli N. Molecular genetics of heat tolerance and heat shock proteins in cereals.Plant Mol. Biol. 2002; 48:667-681

[14] Dudal R. Inventory of major soils of the world with special reference to mineral stress.-Plant Adaption to Mineral Stress in Problem Soils. Ed. M. J Wright. Cornell Univ. Agric. Exp. Stn. Ithaca, N.Y, 1976, 3-23.

[15] Kramer PJ, Boyer JS. Water relations of plants and soils. Academic Press, San Diego, 1995.

[16] Edmeades GOJ, Bolaoos, Lafitte HR. Progress in selecting for drought tolerance in maize. In D. Wilkinson (ed.), Proc. 47th Annual Corn and Sorghum Research Conference, Chicago, December 9ñ10. ASTA, Washington, 1992, 93n111.

[17] Barnabas B, Jager K, Feher A. The effect of drought and heat stress on reproductive processes in cereals. Plant, Cell & Environment. 2008; 31:11-38.

[18] Anjum SA, Xie XYU, Wang L, Chang Saleem MF, Man C, Lei W. Morphological, physiological and biochemical responses of plants to drought stress. African Journal of Agricultural Research. 2011; 6:2026-2032.

[19] Farooq M, Bramley H, Palta JA, Siddique KHM. Heat stress in wheat during reproductive and grain-filling phases. CRC. Crit. Rev. Plant Sci. 2011; 30(6):491-507.

[20] Demirevska K, Simova-Stoilova L, Fedina I, Georgieva K, Kunert K. Response of oryzacystatin I transformed tobacco plants to drought, heat, and light stress. Journal of Agronomy and Crop Science. 2010; 196:90-99.

[21] Smertenko A, Dráber P, Viklický V, Opatrný Z. Heat stress affects the organization of microtubules and cell division in *Nicotiana tabacum* cells. Plant, Cell Environ. 1997; 20(12):1534-1542.

[22] Porter JR. Rising temperatures are likely to reduce crop yields. Nature. 2005; 436:174.

[23] Rascio N, Navari-Izzo F. Heavy metal hyperaccumulating plants: how and why do they do it? And what makes them so interesting? Plant Sci. 2011; 180(2):169-181

[24] Ali H, Khan E, Sajad MA. Phytoremediation of heavy metals-concepts and applications. Chemosphere. 2013; 91(91):869-881.

[25] Mildvan AS. Metal in enzymes catalysis. Enzymes. 1970; 11(11):445-536.

[26] Yruela I. Copper in plants: acquisition, transport, and interactions. Funct. Plant Biol. 2009; 36(5):409-430.

[27] Grieve CM, Grattan SR, Maas EV. Plant Salt Tolerance. Agricultural Salinity. Assessment and Management (2nd Edition). 2012; 71:405-459.

[28] Tanji KK, Wallender WW. Nature and extent of agricultural salinity and sodicity. In: Wallender WW, Tanji KK (Eds.), Agricultural Salinity Assessment and Management. ASCE Manuals and Reports on Engineering Practice No. 71, second review New York, NY: American Society of Civil Engineers, 2012, 1-25

[29] Shainberg I, Singer MJ. Soil response to saline and sodic conditions. In: Wallender WW, Tanji KK (Eds.), Agricultural Salinity Assessment and Management. ASCE Manual and Reports on Engineering Practice No. 71, second Ed. New York, NY: American Society of Civil Engineers, 2012, 139-167.

[30] Munns R, Fisher DB, Tonnet ML. Na+ and Cl-transport in the phloem from leaves of NaCl-treated barley. Australian Journal of Plant Physiology. 1986; 13:757-766.

[31] Shabala S, Munns R. Salinity stress: Physiological constraints and adaptive mechanisms. In: Shabala S. (Ed.), Plant Stress Physiology. London, UK: CAB International, 2012.

[32] Hall, A. E., Singh, B. B., & Ehlers, J. D. (1997). Cowpea breeding. *Plant Breeding Reviews*, *15*, 215-274

[33] Mengel K, Kirkby EA. Principles of plant nutrition. Bern. Int. Potash Inst, 1978, 593.

[34] Zhang H, Jennings A, Barlow PW, Forde BG. Dual pathways for regulation of root branching by nitrate. Proc. Natl. Acad. Sci. The USA. 1999; 96:6529-6534.

[35] Fredeen AL, Rao IM, Terry N. Influence of phosphorus nutrition on growth and carbon partitioning in *Glycine max*. Plant Physiol. 1989; 89:225-230.

[36] Lynch J, Lauchli A, Epstein E. Vegetative growth of the common bean in response to phosphorus nutrition. Crop Sci. 1991; 31:380-387

[37] Barry DAJ, Miller MH. Phosphorus nutritional requirement of maize seedlings for maximum yield. Agron. J. 1989; 81:95-99.

[38] Lindhauer MG. Influence of K nutrition and drought on water relation and growth of sunflower (*Helianthus annuus* L.). Z. Pflanzenernahr. Bodenk. 1985; 148:654-669.

[39] Karmoker JL, Clarkson DL, Saker LR, Rooney JM, Purves JV. Sulphate deprivation depresses the transport of nitrogen to the xylem and the hydraulic conductivity of barley (*Hordeum vulgare* L.) roots. Planta.1991; 185:269-278

[40] Edelbauer A. Auswirkung von abgestuftem Schwefelmangel auf Wachstum, Substanzbildung und Mineralstoffgehalt von Tomate (*Lycopersicon esculentum* Mill.) In: Nahrlosungskultur. Die Bodenkultur. 1980; 31:229-241.

[41] Willenbrink J. Uber Beziehungen zwischen proteinumsatz und Schwefelver-sorgungder chloroplast. Z. Pflanzenphysiol. 1967; 56:427-438.

[42] Chaves, M. M. (1991). Effects of water deficits on carbon assimilation. J. *Exp. Bot.* 42, 1-16.

[43] Antolin, M. C., and Sinchez-Diaz, M. (1993). Effects of temporary droughts on photosynthesis of alfalfa plants. *J. Exp. Bot.* 44, 1341-1349.

[44] Petit, H. V., Pesant, A. R.. Barnett, G. M., Mason, W. N., and Dionne, J. L. (1992). Quality and morphological characteristics of alfalfa as affected by soil moisture, pH, and phosphorus fertilization. *Can.* J. *Plant Sci.* 72, 147-162.

[45] Sheaffer, C. C., Peterson, P. R., Hall, M. H., and Stordahl, J. B. (1992). Drought effects on yield and quality of perennial grasses in the north central United States. J. *Prod. Agric.* 5,556-561.

[46] Buxton, D. R., and Fales, S. L. (1994). Plant environment and quality. *In* "Forage Quality, Evaluation, and Utilization" (G. C. Fahey, Ed.), pp. 155-199. ASA-CSSA-SSSA, Madison, WI.

[47] Osmond, C. B., Austin. M. P., Berry, J. A., Billings, W. D., Boyer, J. S., Dacey, J. W. H., Nobel, P. S.. and Winner, W. E. (1987). Stress physiology and the distribution of plants. *Bioscience* 37,38-48.

[48] Agarawal, P.K. 2008. Global Climate Change and Indian Agriculture: Impacts, Adaptation, and Mitigation. *Indian J. Environ. Sci.*, 78(11): 911-919.

[49] Srinivasarao, Ch., and K.A. Gopinath. 2016. Resilient rainfed technologies for drought mitigation and sustainable food security. *Mausam* 67 (1), 169-182.

[50] Rosenow, D.T., Quisenberry, J.E., Wendt, C.W., and Clark, L.E. (1983) Drought tolerant sorghum and cotton germplasm. Agr. Water Manage., 7 (1-3), 207-222.

[51] Sanchez, A.C., Subudhi, P.K., Rosenow, D.T., and Nguyen, H.T. (2002) Mapping QTLs associated with drought resistance in sorghum (*Sorghum bicolor* L. Moench). Plant Mol. Biol., 48 (5-6), 713-726.

[52] Borrell, A.K., Hammer, G.L., and Henzell, R.G. (2000) Does maintaining green leaf area in sorghum improve yield under drought? II. Dry matter production and yield. Crop Sci., 40 (4), 1037-1048.

[53] Tuinstra, M.R., Grote, E.M., Goldsbough, P.B., and Ejeta, G. (1996) Identification of quantitative trait loci

associated with pre-flowering drought tolerance in sorghum. Crop Sci., 36 (5), 1337-1344.

[54] Blum, A. (2005) Drought resistance, water-use efficiency, and yield potential: are they compatible, dissonant, or mutually exclusive? Aust. J. Agric. Res., 56 (11), 1159-1168.

[55] Jenks, M.A., and Ashworth, E.N. (1999) Plant epicuticular waxes: function, production, and genetics, in Horticultural Reviews, vol. 23 (ed. J. Janick), John Wiley & Sons, Inc., New York, pp. 1-68.

[56] Jenks, M.A., Rich, P.J., Rhodes, D., Ashworth, E.N., Axtell, J.D., and Ding, C.K. (2000) Leaf-sheath cuticular waxes on bloomless and sparse bloom mutants of *Sorghum bicolor*. Phytochemistry, 54 (6), 577-584

[57] Doggett, H. (1988) Sorghum, 2nd edn, John Wiley & Sons, Inc., New York.

[58] Yu, J. and Tuinstra, M.R. (2001) Genetic analysis of seedling growth under cold temperature stress in grain sorghum. Crop Sci., 41 (5), 1438-1443.

[59] Knoll, J., Gunaratna, G., and Ejeta, G. (2008) QTL analysis of early-season cold tolerance in sorghum. Theor. Appl. Genet.,116 (4), 577-587.

[60] Yadav,O.P.(2004).CZP9802—a new drought tolerant cultivar of pearl millet. *IndianFarming* 54, 15-17.

[61] Yadav,R.S.,Hash,C.T., Bidinger,F.R.,Devos,K.M.,and Howarth,C.J.(2004). Genomic regions associated with grain yield and aspects of post-flowering drought tolerance in pearl millet across stress environments and testers backgrounds. *Euphytica* 136, 265-277. DOI: 10.1023/B: EUPH.0000032711. 34599.3a

[62] Ali, G.M. Khan, N.M., Hazara, R., and McNeilly,T.(2004). Variability in the response of pearl millet(*Pennisetumamericanum* (L.) Leeke)accessions to salinity. *ActaAgron. Hung.* 52, 277-286. DOI: 10.1556/ AAgr.52.2004.3.9

[63] Kumar P, Tarafder JC, Painuli DK, Raina P, Singh MP, Beniwal RK, Soni ML, Kumar M, Santra P, Shamsudin M (2009) Variability in arid soils characteristics. In: Kar A, Garg BK, Singh MP, Kathju S (eds) Trends in arid zone research in India. Central Arid Zone Research Institute, Jodhpur, pp 78-112.

[64] Hash CT, Schaffert RE, Peacock JM (2002) Prospects for using conventional techniques and molecular biological tools to enhance performance of 'orphan' crop plants on soils low in available phosphorus. Plant Soil 245:135-146.

[65] J.A. Cusicanqui, J.G. Lauer, Plant density, and hybrid influence on corn forage yield and quality, Agro. J. 91 (1999) 911-915.

[66] M. Koutsika- Sotiriou, Hybrid seed production in maize, in A.S. Basra (Ed.), Heterosis and hybrid seed production in agronomic crops, Food Products Press, NewYork, 1999, pp. 25-64.

[67] W. Schlenker, M.J. Roberts, Nonlinear temperature effects indicate severe damages to U.S. crop yields under climate change, Proc. Nat. Acad. Sci. USA. 106 (2009) 15594-15598.

[68] J.D. Oster, R. C. Reeve M. Fireman, Salt problems in relation to irrigation, In Irrigation of agricultural lands (ed. by R. M. Hagen), Agronomy J. 11 (1967) 988-1008.

[69] Langyintuo AS, Lowenberg-DeBoer J. Potential regional trade implications of adopting Bt cowpea in West and Central Africa. AgBioForum. 2006;9:111-20.

[70] Watanabe, I., Hakoyama, S., Terao, T., & Singh, B. B. (1997). Evaluation methods for drought tolerance of cowpea. In B. B. Singh, D. R. Mohan Raj, K. E. Dashiell, & L. E. N. Jackai (Eds.), *Advances in cowpea research* (pp. 141-146). Ibadan, Nigeria: IITA. Copublication of International Institute of Tropical Agriculture (IITA) and Japan International Research Center for Agricultural Sciences (JIRCAS).

[71] Singh, B. B., & Matsui, T. (2002). Cowpea varieties for drought tolerance. In C. A. Fatokun, S. A. Tarawali, B. B. Singh, P. M. Kormawa, & M. Tamo (Eds.), *Challenges and opportunities for enhancing sustainable cowpea production. Proceedings of the world cowpea conference III, 4-8 September 2000* (pp. 287-300). Ibadan, Nigeria: International Institute of Tropical Agriculture (IITA).

[72] Iuchi S, Yamaguchi-Shinozaki K, Urao T, Shinozaki K. Novel drought inducible genes in the highly drought-tolerant cowpea: cloning of cDNA and analysis of their gene expression. Plant Cell Physiology. 1996a;37(8):1073-1082. DOI: 10.1093/oxfordjournals.pcp.a029056

[73] D'arcy-Lameta A, Ferrari-Iliou R, Contour-Ansel D, Pham-Thi AT, Zuily-Fodil Y. Isolation and characterization are of four ascorbate peroxidase cDNA responsive to water deficit in cowpea leaves. Annals of Botany. 2006;97(1):133-140. DOI: 10.1093/aob/ mcj010

[74] Helgadottir, A., S. Dalmannsdottir, and R. P. Collins, 2001: Adaptational changes in populations of contrasting white clover cultivars selected under Icelandic conditions. *Annals of Bot.* 88: 771-780.

[75] Vogg, G., S. Fischer, J. Leide, E. Emmanuel, R. Jetter, A. A. Levy, and M. Riederer, 2004: Tomato fruit cuticular waxes and their effects on transpiration barrier properties: functional characterization of a mutant deficient in a very-long-chain fatty acid beta-ketoacyl-CoA synthase. *Journal of Experimental Botany*, 55: 1401-1410.

[76] Humphreys, M. W., P. J. Canter, and H. M. Thomas, 2003: Advances in introgression technologies for precision breeding within the *Lolium-festuca* complex. *Annals of Applied Biology*, 143: 1-10.

[77] Barnes, D. K., and C. C. Sheaffer, 1995: Alfalfa. In: Forages: An Introduction to Grassland Agriculture, R. F. Barnes, D. A. Miller, C. J. Nelson, (eds.). Iowa State University Press, Ames, Iowa, pp. 205-216.

[78] Hall, A. E., 2001: Crop responses to the environment. CRC Press, Boca Raton, FL, USA.

[79] Rahman, M.A., I, Alam, Y.G. Kim, N.Y.Ahn, S.H. Heo, P.G. Lee, G. Lu and B.H. Lee, 2015: Screening for salt responsive proteins in two contrasting alfalfa cultivars using a comparative proteome approach. *Plant Physiol. Biochem.*, 89: 112-122.

[80] Bernard, A., M, Bipfubusa, C, Dhont, F. P, Chalifour, P, Drouin and C. J. Beauchamp. 2016 : Rhizobial strains exert a major effect on the amino acid composition of alfalfa nodules under Nacl stress. *Plant Physiol. Biochem.*, 108 : 344-352.

[81] Pederson, G. A. 1995: White clover and other perennial clovers. In: Forages. I. An Introduction to Grassland Agriculture, R. F. Barnes, D. A. Miller, C. J. Nelson, (eds.). Iowa State University Press, Ames, Iowa, pp 205-216.

[82] Annicchiarico, P. and E. Piano, 2004: Indirect selection for root development of white clover and implications for drought tolerance. *Journal of Agronomy and Crop Science*, 190: 28-34.

[83] Lee, B. R., W. J. Jung, K. Y. Kim, J. C. Avice, A. Ourry, and T. H. Kim. 2005. Transient increase of *de novo* amino acid synthesis and its physiological significance in water-stressed white clover. *Functional Plant Biology*, 32: 831-838.

[84] Chankaew, S., T, Semura, K. Naito, O.E. Tanaka, N. Tomorka, P. Somta, A. Kaga, D.A. Vaughan, and Srinives, 2014: QTL mapping for salt tolerance and domestication related traits in *Vigna marina ssp. oblonga*. *Theor. Appl. Genet*., 127(3); 691-702.

[85] Choudhary, S. K., M. K. Jat, and A. K. Mathur. 2017: Effect of micronutrient on yield and nutrient uptake in sorghum. *Journal of Pharmacognosy and Phytochemistry*, 6(2): 105-108.

[86] Ali, S., K.A. Riaz, G.M. Mairaj, M. Arif, S. Fida, and Bibi. 2008: Assessment of different crop nutrient management practices for yield improvement. *Australian Journal of Crop Science*. 2(3):150-157.

[87] Prasanna, B. M., S. K. Vasal, B. Kassahun and N. N. Singh. 2001 : Quality protein maize. *Curr Sci.,* 81: 48-53.

[88] Chen, X. P., Z. L. Cui, P. M. Vitousek, K. G. Cassman, and P. A. Matson. 2011: Integrated soil-crop system management for food security. *Proc. Natl. Acad. Sci*., 108: 6399-6404.

[89] Rehim, A., M. Farooq, F. Ahmad, M. Hussain. 2012: Band placement of phosphorus improves the phosphorus use efficiency and wheat productivity under different irrigation regimes. *Int. J. Agri. Biol*. 14: 727-733.