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Deepak Kumar Yadav
Research Scholar, Department of Agronomy, I. Ag. Sc., BHU, Varanasi, Uttar Pradesh, India

Bandana Rani Barik
Research Scholar, Department of Agronomy, I. Ag. Sc., BHU Varanasi, Uttar Pradesh, India

Gourisankar Pradhan
Research Scholar, Department of Agronomy, I. Ag. Sc., BHU Varanasi, Uttar Pradesh, India

Rajesh Kumar Singh
Assistant Professor, Department of Agronomy, I. Ag. Sc., BHU Varanasi, Uttar Pradesh, India

Saroj Kumar Prasad
Assistant Professor, Department of Agronomy, I. Ag. Sc., BHU Varanasi, Uttar Pradesh, India

Correspondence
Deepak Kumar Yadav
Research Scholar, Department of Agronomy, I. Ag. Sc., BHU, Varanasi, Uttar Pradesh, India

Responses of crops plant to drought and its management for crop water availability: A review

Deepak Kumar Yadav, Bandana Rani Barik, Gourisankar Pradhan, Rajesh Kumar Singh and Saroj Kumar Prasad

Abstract
The drought prone area are seen frequently worldwide and increasing 14.30% during the period of 1902–1949 and 1950–2008 Wang *et al.* (2014) while Zhang *et al*., (2017b) also reported that the semi-arid region of Northern China are also facing drought frequently as the variability of annual and decadal precipitation and temperature. Harb *et al.* (2010) documented that due to the drought induced to plant resulting as changes at cellular level showing acclamatory responses through proliferation of cell wall in *Arabidopsis thaliana* as an early cop-out strategy under water scarcity. Drought induced plant having decrease in their specific leaf area resulting as reduction of cell expansion and finally thinner leaves (Liu and Stützel, 2004). A common finding reported from drought studies area as the enhancement of root-shoot ratio and finding the enhancement of more root biomass compare to shoot biomass under the water limited condition (Blum, 1996). Such finding are also reported by Erice *et al.* (2010) under water stress conditions as maintaining higher root-shoot ratio in alfalfa. The reason behind it as accumulation of solutes on the root tip in water limited condition and resulting as variation in potential between the surrounding soil and root hairs, which in turn attract more water to these root hairs/ root tips therefore able to maintain root turger pressure and growth (Liu and Stützel, 2004). Moreover reduction in the leaf area of *Jatropha curcas* L. seedling as 28% of total leaf biomass produced under water scarcity (Achten *et al*., 2010).

Keywords: Drought, Awn, RuBP, ABA

Introduction
Responses of plant to Drought
Morphological Responses
The deleterious effect of drought on the crop growth and development have been studied for different crops such as maize (Kamara *et al*., 2003; Monneveux *et al*., 2006) [19, 36], barley (Samarah, 2005) [44], rice (Lafitte *et al*., 2007; Manickavelu *et al*., 2006; Pantuwan *et al*., 2002; Tripathy *et al*., 2000) [25, 31, 39, 51], wheat (Loutfy *et al*., 2012) [29], *Amaranthus* spp. (Liu and Stützel, 2004) [28], soybean (Samarah *et al*., 2006; Specht *et al*., 2001) [45, 49] and cowpea (Turk *et al*., 1980) [52].

Water stress influence the crop resulting as some common morphological alteration such as:

- Injure germination and stand establishment is weakened (Harris *et al*., 2002) [14].
- There are reduction in seed vigour index is about 85.8% while germination percentage by 63.3% in different cultivars of wheat and reason behind it was osmotic stress induced as use polyethylene glycol (PEG-6000) as reported by Dhanda *et al*. (2004) [8].
- Decrease in the germination stress tolerance index, dry matter stress index and plant tolerance index while increment in root length stress under PEG-induced drought stress in sunflower (*Helianthus annuus*) seedlings (Ahmad *et al*., 2009) [2].
- Under the drought treatment there are reduction in plant height of wheat and pea are 11.7% and 14.5%, respectively (Alexieva *et al*., 2001) [3].
- Furthermore, the abortion of tiller and changing into the rooting pattern are also seen 3 upland rice cultivars which are as follow WAB56-104 (*O. sativa* tropical *japonica*, improved), WAB 450-24-3-2-P18-HB (CG14 × WAB56-104 hybrid and CG14 (*Oryza glaberrima*) under drought situations (Asch *et al*., 2005) [4].

Physiological Responses of Plants
Due to the severe drought conditions leads to cell contraction and resulting as reduction of cellular volume and finally increases the viscosity of cell (Farooq *et al*., 2009) [11]. Due to the increment in the cell viscosity as the high concentration of solute accumulation may prove to be detrimental effect on the normal plant function and photosynthesis mechanism

(Hoekstra *et al*., 2001) [15]. Under drought stress condition the limitation of stomata functioning are documented in various crop species such as wheat (Khan and Soja, 2003) [21], soybean (Liu *et al*., 2003; Ohashi *et al*., 2006) [27, 38], maize (Cochard, 2002) [7], kidney bean (Miyashita *et al*., 2005) [35] and rice (Praba *et al*., 2009) [41]. Besides stomatal closure, there is also documentation of reduction in stomatal size in moderate drought conditions (Farooq *et al*., 2012) [10]. Under moderate drought conditions there are reduction in photosynthesis due to stomatal closure and CO_2 deficient in strawberry cultivars (Klamkowski and Treder, 2008) [22] and such findings are also reported by Miyashita *et al*. (2005) [35], in kidney beans (*Phaseolus vulgaris* L.) because of photosynthesis and transpiration reduction as the limitation of stomata. Besides the reduction of stomatal conductance, stomatal limitation also should be considered as a major factor which determining the detrimental impact on carbon assimilation process under drought condition. Due to stomatal limitation in water scarcity, infleuencing to different metabolic processes which impaired Ribulose bi-sphosphate (RuBP) regeneration and adenosine tri-phosphate (ATP) resulting as photo- inhibition and disturbance of normal photochemistry (Flexas and Medrano, 2002) [12]. Photorespiration in cotton plant induced by drought condition reported by Massacci *et al*. (2008) [32], in which plant adapted the strategy to neutralise the over-excitation in the PSII (Farooq *et al*., 2012) [10].

Antioxidant Metabolism

Under water stress higher plants are often facing the reactive oxygen species (ROS) toxicity as the reduction in the CO_2/O_2 ratio in photosynthetic tissues and enhancement of photorespiration. As the uncontrolled production of ROS may result in leakiness of membrane and lipid per-oxidation and finally lead to malon di-aldehyde (MDA) production and vitiate the function of macromolecule such as DNA, lipid, nucleic acid, protein and chlorophyll pigments (Moussa and Abdel-Aziz, 2008) [37]. Free radical explode inside the cellular and sub-cellular components which promote the antioxidants enzyme production such as SOD, CAT, GR, APX, dehydroascorbate reductase (DHAR), POD and non-enzymatic antioxidants like AsA, flavonoids, anthocyanins, carotenoids and α-tocopherol in drought which inducing plant resistance at different growth stages against such abiotic environmental stress (Reddy *et al*., 2004) [42]. Sharma and Dubey (2005) [48] reported that the significant increasing od anti-oxidants enzyme like GR, MDHAR, APX, and DHAR unjdre drought treatment in oreder to control oxidative damage in rice seedlings. There are accumulation of proline inside the plant is important adaptive mechanism by plant under drought. Such finding are reported by Bandurska *et al*. (2017) [5] as there are increase of proline concentration in leaves and roots of the barley genotypes Syrian breeding line Cam/B_1/ C_I and the German cultivar Maresi. For improving drought tolerance mechanisom in plant there are accumulation of osmolytes like amino acid, sugar and protein is common which improving the capacity to cope with osmotic stress and maintenance of nutrient homeostasis (Iqbal *et al*., 2014) [17]. In leaves of peanut cultivars at pre-flowering stage under drought there was higher free proline content accompanied by free amino acid as well as soluble protein contributing to osmotic regulation and make plant to stand against drought condition Zhang *et al*. (2017b) [56]. Likewise, Moussa and Abdel-Aziz, 2008 [37] reported that enhancement of glycinebetain (GB) and free proline in maize highlights the safeguarding role of these non-enzymatic antioxidant molecules against detrimental effect from oxidative injury in water stress.

Yield Attributes under Drought Condition

Yield losses as the water scarcity in different crops are becoming serious concern in crop production in current scenario. Yield losses are directly correlated with the severity and duration period of stress during crop production such as wheat (Zhao *et al*., 2017) [58] maize, (Kamara *et al*., 2003) [19], barley (Samarah, 2005) [44], rice (Lafitte *et al*., 2007; Pantuwan *et al*., 2002) [25, 39] and chickpea (Mafakheri *et al*., 2010) [10]. Samarah (2005) [44], reported in barley crop at post-anthesis having detrimental effect on grain yield as the severity of stress. There is also reduction in grain filling spawn in barley crop as the scarcity of water compared to irrigated. Drought condition inducing the acceleration of maturity as the faster vraytev of grain filling has been reported in common beans (*Phaseolus vulgaris* L.) which shown a positive correlation with the seed yield, determining the drought adaptation strategy in the resistant cultivars (Rosales-Serna *et al*., 2004; Table) [43].

Table 1: Seed yield (g per plant) per growth habit average of two dry bean cultivars grown under three moisture conditions at two locations in Mexico, 2001

Growth habit	ID	TD	Irrigated	Mean
Texcoco				
Type I	11.2	15.1	36.0	20.8
Type III	18.9	26.0	45.4	30.1
Mean	15.1	20.6	40.7	25.5
CV (%)	22			
LSD $_{0.05}^{a}$	9.4			
LSD $_{0.05}^{b}$	3.7			
Cotaxtla				
Type I	NTc	10.5	18.6	14.6
Type III	NT	13.2	19.2	16.2
Mean	–	11.9	18.9	15.4
CV (%)	18			
LSD $_{0.05}^{a}$	6.2			
LSD $_{0.05}^{b}$	8.2			

a LSD value among growth habits.
b LSD value among moisture treatments.
c NT: treatment not tested in Cotaxtla.

Signalling and Drought Stress

Chemical signalling activity inside the plant inducing tolerance mechanism against stress which includes the involvement of ROS, Ca^{+2}, calcium regulated proteins and plant hormones by signal transduction pathways and also cell programming activities at the genetical level are shown in Figure 1.1.Under water scarcity condition there are plant hormone signalling act as a significant role in establishing stress tolerance mechanism by controlling stomatal movement (Sarwat and Tuteja, 2017) [47]. In water stress study highlighted the positive role of ABA and JA act in association with protein kinases and phosphates, which influences regulation (activation and deactivation) of ion channel in guard cell of plasma membrane in stressful situations (Kumar *et al*., 2013) [23]. Moreover there is accumulation of ABA in guard cell promoting the closure of stomata which is an adaptation strategy of plant to stand in the water stress, thereby reducing the water losses from stomatal cell (Miura and Tada, 2014) [34]. Due to drought there are inducing the plant as stomatal closure process involving activation of calcium permeable channel in plasma membrane in the presence of 1,4,5-triphosphate (IP3), which is secondary messanger molecule, mediating ABA signal, influencing depolarization of plasma membrane and subsequently stimulation of cytoplasmic calcium influx (Harrison, 2012) [14]. In continuation of these, Suh *et al*. (2016) [50] reported that hydrogen peroxide (H_2O_2) mediated the activation of calcium permeable channel in the plasma membrane, thereby indicating the indirect impact of H_2O_2 in controlling of stomatal aperture in limited water condition. Aquaporin is trans-membrane protein act as an important protein group which conferring drought tolerance in crop plants (Zargar *et al*., 2017) [54]. Different aquaporins are exist in plant but among them two different most important aquaporins are - plasma intrinsic aquaporins (PIP) localized in plasma membrane and tonoplast intrinsic aquaporins (TIP) localized in the vascular membrane are widely studied due to the role in water and solute transportation under limited water condition (Hove and Bhave, 2011) [16]. The major hormones during determining the drought stress signalling is ABA, which regulates so many PIP activities but the responses of PIP genes and ABA hormones are different in water limited condition. Such evidences are reported by Lian *et al*. (2006) [26] and Zargar *et al*. (2017) [54] as both ABA-dependent and ABA-independent PIP genes having different pathways regulation under water stress conditions. When plant cell exposed to osmotic stress there are several phospholipid systems are identified which are significantly involved in generation of array of messenger molecules (Farooq *et al*., 2009) [11]. Recently, evidenced a proportionate enhancement in the level of β-sitosterol, a major phytosterol, in rice seedlings with the severity of water scarcity in drought tolerant rice cultivar N22, inferring the importance of phytosterols in inducing drought tolerance signalling pathway (Kumar *et al*., 2015) [24]. Besides this, many studies have reported the significant role of phospholipase Dα (PLDα), a membrane phospholipid, in the abscisic acid signal transduction pathway, under osmotic stress resulting as stomatal closure (Sang *et al*., 2001; Zhang *et al*., 2004) [46, 57].

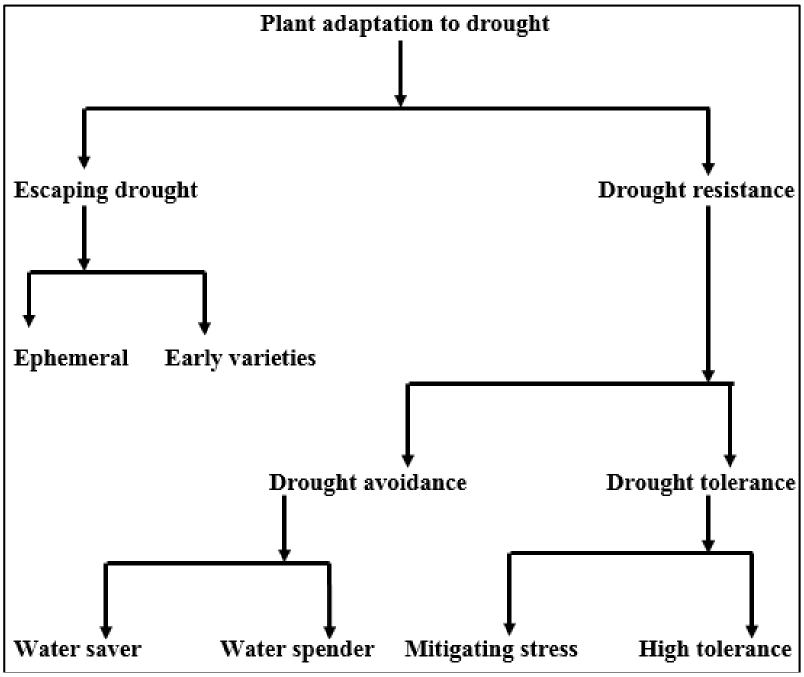

Fig 1: Schematic diagram of Plant adaptation to drought)

Escaping drought

It is a simplest means of adaptation of plants to drought. Most of the deserts plants are ephemeral plant. These plants complete their life cycle within a short period of time (5 to 6 weeks) before commencement of drought.

Drought resistance

Plant can adapt to drought either by avoiding stress or by tolerating stresses due to different mode of mechanisms.

Avoiding stress

It is the ability of plant to maintain water balance and turgidity in cell even exposed to drought conditions. The favourable water balance and turgidity can be gain by following way.

Mechanisms to conserve water

Stomatal mechanism

The drought resistance varieties remain closed their stomata when drought prevails and open their stomata in the early morning for reduction of less amount of water.

Increased photosynthetic efficiency

The C_4 plant have higher photosynthetic rate than C_3 plants. So C_4 plant are said to be drought resistant as they can grow even under moisture stress. The C_4 plant can also translocate photosynthate more rapidly. Eg. Maize, sorghum.

Lipid deposition on leaves

Some crop plant like Soybean, Sorghum etc. reduce the loss under moisture stress condition by depositing lipid on plant surface.

Reduction in leaf areas

Plant reduced transpiration by decreasing their leaf area of the plants. The size of individual leaf is reduced as leaf expansion is less under moisture stress. In some grass leaf becomes roll/scroll due to moisture stress, so reduced the area exposed to solar reduction results in low transpiration.

Leaf surface

Under moisture stress leaf becomes thick, waxy surface and spine thus reduced the water loss from leaf. Presence of pubescence on the leaf suface increases the reflectance and reduce solar radiation incidence.

Effects of awns

The variety that bears awns gives better performance under drought condition as compared to awn less varieties.

Mechanism to improve water uptake

This mechanism helps in extension of moisture from deeper layer of soil.

Efficient root system

The plant having deep root system, well branched and rapidly growing root helps in absorption of more moisture. This mechanism so much important that its help in drought tolerance without affecting productivity of crop.

Root-shoot ratio

If root is more than shoot than water balance can be maintained. It is an important mechanism of drought avoidance.

Increase in lipid phase conductance

It helps in maintain high water potential in plants. It can be achieved by lower the resistance to water or increase the diameter.

Drought tolerance

It can be achieved by mitigating stress and high degree of tolerance.

Mitigating stress

It can be done by resisting dehydration and maintainces of liquid phase by accumulating higher amount of solutes.

High degree of tolerance

Plant can escape drought by reducing both plastic and metabolic strain during drought period.

Management of crop water under drought

Management of water-limited cropping systems requires a precise knowledge of those subsystem properties and Management of crop water under drought processes that are responsible for a sub-optimum water use. The fundamental dependence of water dynamics on hydrological site conditions implies that agricultural interventions have to be adapted to the specificity of the drought environment.

Management measures

Soil-related measures

The soil subsystem is mainly influenced by the tillage system, which has both short- and long-term impacts. A second important management impact on soil processes and properties is crop rotation. Short term effects of soil management target the soil surface and the initial soil water depletion at the onset of main cropping season. Long-term effects comprise a number of changes in soil hydraulic properties.

Short-term measures

Mulching

Soil coverage can be achieved by crop residues (mulching), a living canopy cover (cover cropping, relay intercropping) or non-crop mulch material (plastic foil, geo-textile). Soil coverage is intended to reduce runoff and evaporation from bare soil surfaces. Kálmar *et al*. (2013) [18] studied post-harvest mulching on a chernozem soil in central Hungary with annual rainfall of 580 mm and mean temperature of 10 °C. They measured 8–11% higher soil water content in 0–65 cm soil depth for undisturbed mulch covered soil with 55–65% coverage Compared to a conventionally tilled soil without mulch cover.

Stubble tillage

A common measure to reduce post-harvest evaporation losses is stubble tillage. It is a measure applied during the fallow period between consecutive crops, while surface cover by mulch can potentially protect the soil surface during the whole year. As reported above, evaporation during prolonged dry periods is low and also other losses (runoff, drainage) are negligible during dry seasons in storage-driven and residual moisture ecosystems. Thus, stubble tillage for water conservation is mainly effective in supply-driven summer–rainfall agro-ecosystems. Several recent studies, however, questioned the water-saving potential of stubble tillage (Pekrun *et al*. 2011; Kálmar *et al*. 2013) [40, 18].

Initial depletion

Bare soil fallowing is a traditional measure for soil recovery. In water-limited ecosystems, it is mainly intended to replenish soil water storage before the subsequent main crop. Depending on the extent of drought and rainfall distribution, fallowing might extend from short duration of unplanted soil between two consecutive crops to a whole non-cropped vegetation period.

Long-term measures

Long-term soil management measures focus on improvement of soil water storage capacity. Storage capacity is strongly influenced by texture and profile depth, which are natural site constraints. However, two important soil properties related to water storage are essentially influenced by plant–soil interactions in the cropping system

Tillage systems

There is an extensive literature on tillage influences on soil hydraulic properties. A main effect of reduced tillage systems on water flow processes is related to residue cover, which has already been discussed above. Concerning soil properties, different intensity of mechanical disturbance changes the soil pore size distribution and pore geometry. Kay and Vanden Bygaart (2002) reviewed results from tillage experiments in Canada and confirmed the general trend of decreasing macropore and increasing storage pore volume in conservation tillage systems.

Organic matter input

The key influence of vegetation on soil hydraulic properties is largely recognised. It is a result of the soil structure–organic matter interaction. In spite of this, targeted plant based management of soil hydrology is still at its infancy. This is mainly due to the complex and dynamic, biologically mediated processes driving the feedback between plant and soil. For temperate climates, Miller *et al*. (2002) found significantly higher water retention and hydraulic conductivity in a clay loam soil with 17 g kg^{-1} total organic carbon (TOC) in a semi-arid continental climate of the Canadian Great Plains due to addition of cattle manure.

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