Understanding the Impact of Drought on Forest Ecosystems: A Comprehensive Review of Physiological Responses and Management Strategies

Astha Singh[1], Dr. K. K. Chandra[2]

[1]Department of Forestry, Wildlife & Environmental Sciences,
Guru Ghasidas Vishwavidyalaya, Koni, Bilaspur, Chhattisgarh(495009), India
Email: 111singhastha[at]gmail.com

[2]Department of Forestry, Wildlife & Environmental Sciences,
Guru Ghasidas Vishwavidyalaya, Koni, Bilaspur, Chhattisgarh(495009), India
Email: kkckvk[at]gmail.com

Abstract: ***This review study investigates the possible effects of altered precipitation patterns, particularly drought, on forest ecosystems and emphasizes forests' critical role in the global carbon cycle. It analyses drought stress and how it affects plant development in local and global environments, including tropical forests and India. Review concerns include stomatal conductance, relative water content, electrolyte leakage, and photosynthesis-related to the physiological and biochemical reactions to drought stress. The reported effects on tropical plants are also addressed, with a focus on tree susceptibility and changes in the composition of forests. It describes experimental models for researching drought stress, including soil- and hydroponic-based aqueous culture-based models. The emphasis of the work then switches to the difficulties in forecasting drought community and landscape reaction levels, highlighting the intricate nature of forest ecosystems. Tree mortality is believed to occur during short-term droughts, although long-term trends may favor species that can withstand drought. Strategies for management are discussed, including the use of satellite sensors for surveillance and fire safety. To predict future effects in tropical forest areas, it is critical to comprehend the mechanisms combining hydraulic failure and drought stress. The conclusion emphasizes the necessity of carefully designed experimental programs to improve tolerance to abiotic stressors, particularly drought.***

Keywords: Drought Stress, Drought Models, Tropical Forest, Biotic and Abiotic Stressor

1. Introduction

Since forest ecosystems store 75% of the total carbon in plant biomass (Pan et al., 2011) and trade around 8% of the CO_2 stock in the atmosphere each year (Malhi et al., 2002). The way both water and carbon are exchanged within forests may be significantly impacted by changes in precipitation patterns and the resulting dryness or reduction of soil moisture in the root zone. This might modify the rate at which these forests develop and thrive as well as the conditions in the surrounding areas (Hartmann, 2011). There have been reports of extensive forest mortality in several places around the globe in the past several decades because of protracted and severe drought occurrences (Allen et al., 2010). Current research on regional and worldwide precipitation patterns points to a rise in severe droughts that occur in eastern North America (Sheffield & Wood, 2008) and other parts of the world between periods of comparably higher precipitation (Bréda et al., 2006). According to the IPCC (2007), there is a higher probability of short-periodic, extreme drought events taking place in the future. These short-lived droughts may alter the level of evapotranspiration, soil water, and carbon balance, which might have a major influence on the survival and growth of ecosystems of woodland in the affected region. The impacts of short drought episodes on stand-level carbon and water dynamics are the subject of very few research in the literature (Granier et al., 2007).

1.1 Drought stress

A functional modification caused by an environmental circumstance is called stress. Plant growth and development are impeded when environmental conditions fall short of or surpass optimal levels. Abiotic stressors include conditions like heat, oxidative stress, radiation, heavy metal toxicity, drought, cold, salt, and interactions between plants and diseases, insects, and microbes. The two types of stresses are biotic and abiotic. Each biotic and abiotic factor's effect on plants is conditional upon its magnitude, intensity, duration, and mode of application. The meteorological word "drought" refers to a time when plant production is restricted due to a lack of substantial rainfall. Since agriculture depends heavily on freshwater supplies, drought stress is becoming a serious problem for agricultural output as water availability decreases. Water stress results in a greater loss in agricultural productivity than all other factors combined (Ansari et al., 2018). Plants under drought stress undergo various interactive modifications. These consist of the following: (1) modifications to the expression levels of genes involved in their survival (up, down, or co-expression)(Batlang et al., 2013); (2) modifications to the production and breakdown of proteins that harm plants or serve as a defensive mechanism to protect them from the effects of drought(Mohammadi et al., 2012); and (3) modifications to the metabolic pool to direct the investigation of new substances with related biochemistry

Paper ID: SR24216203544 DOI: https://dx.doi.org/10.21275/SR24216203544

that could provide resistance to drought stress (Kumari et al., 2013).

1.2 Current state of plant interactions and drought stress

Drought may affect around 16% of India's land area, which is mostly dry, semi-arid, and sub-humid. Roughly 68% of the 140 million hectares of arable land are at risk of drought(GOI, 2013). Three significant droughts have affected India since 2001: in 2002, in 2004, and 2009. These events have harmed the nation's general economic growth as well as other industries. Drought resistance is the outcome of coordinated cellular and molecular physiological and biochemical changes. In recent decades, there has been a substantial advancement in understanding the genetic, pharmacological, and physiological foundations of plant stress tolerance.

1.3 Droughts in Tropical Forests

Despite making up just 10% of the planet's surface, tropical forests are an essential component of the global carbon cycle, contributing 25% of the earth's overall carbon stock and one-third of net primary production (Aragão et al., 2014). The Amazon forest's function shifted from net sink to net source in 2010 because of a drought (van der Laan-Luijkx et al., 2015). Droughts can also harm biodiversity since tropical forests are habitats for over half of all species of terrestrial plants and animals (Poorter et al., 2015), including 96% of the species of trees (Kreft &Jetz, 2007). These species have the largest diversities in regions with consistent rainfall. Considering that multi-year climatic cycles are often associated with tropical droughts, it is difficult to identify long-term patterns due to inter-annual variance (García-García &Ummenhofer, 2015). However, according to several model forecasts, for the remainder of this century (Chadwick et al., 2016), there may be an increase in the frequency and severity of droughts in certain tropical forest regions. The last index has the most relevance to ecological effects since model forecasts consistently raise the likelihood of severe droughts in the tropics due to the influence of strong warming predictions on Polyethylene Terephthalate (Klein et al., 2015). Droughts will be more stressful for plants due to rising temperatures, even if rainfall levels stay the same. Furthermore, because decreasing evapotranspiration eliminates the cooling effect of higher albedo models, deforestation raises regional temperatures, and forest fragmentation increases the rate at which forest canopies desiccate during the dry season.

1.4 The impact of drought stress on anatomical features

- **Modifications in phenotype**

Because of the low turgor pressure, drought stress is widely recognized as a major factor affecting Plant establishment and growth. This includes plant elongation and expansion growth. Osmotic control helps pearl millet plants survive even in very drought-stressed environments by preserving cell turgor (Shao et al., 2008). The stem length of Abelmoschus esculentus was also shown to be significantly impacted. Photosynthesis and dry matter output depend on the growth of the ideal leaf area. Many plant species, including populous (Wullschleger et al., 2005), soybeans (Zhang et al., 2004), and many others (Farooq et al., 2009), have decreased leaf growth while under drought stress. When two sympatric Populus species are stressed by drought, there are significant interspecific differences in the total leaf biomass, overall number of leaves, and total area of leaves. During a drought, a strong relationship was seen among the outside dry mass and the impact of the root system. An increase in the ratio of roots to shoots in an environment susceptible to drought has been associated with the ABA content of roots and shoots. A typical adverse effect of water stress on crop plants is a reduction in the amount of fresh and dry biomass produced. (Farooq et al., 2009). The way that the chemical signals combine may affect how drought stress affects the shoot in the root zone. Plant growth decrease is recognized to be an adaptive stress response rather than a side effect of resource margination (Rollins et al., 2013). Crop resilience to drought stress is based on the interactions between phenology and water usage patterns (Sekhon et al., 2010). Plants restrict the number of tillers on their shoots to save water consumption under drought conditions. One key element that may contribute to lower production is the reduction in stomatal conductance and plant growth, which is a response to stress (Deikman et al., 2012).

- **The effect of drought on forest growth**

The forest's annual stem growth decreased by 17% duringthe drought, and its drought plot had an earlier growth termination date than the reference plot. Changes in stem development are important for overall carbon absorption since stem biomass makes up approximately 69% of the total biomass of trees. Globally, other forests have demonstrated comparable declines in growth under drought. According to some studies, the whole effect on tree stem development may not become apparent until the year after the drought. At the location, there was no lag effect in transpiration; nevertheless, the drought plot signified a modest increment in growth, indicating that trees had evolved to survive. The study emphasizes that when evaluating the climate change effects on ecosystems of forest, precipitation distribution rather than simply yearly totals must be taken into consideration.

1) Physiological markers impacted by the stress of drought

- **Stomatal conductance**

Numerous physiological indices, including electron transfer rate, WUE, CO_2 diffusion, transpiration, and respiration are closely correlated with stomatal conductance. Differential stomatal motions are seen by plants that respond to water constraints including drought-tolerant and drought-sensitive species. Drought-sensitive crops are found to have maintained stomatal conductance and carbon absorption even when the water potential falls (Pinheiro & Chaves, 2011). By evaporating (transpiring) water via the stomatal pores, plants lose almost 95% of their water content. Due to the influence of their open stomatal pores, plants must be able to maintain a balance of CO_2 that is introduced into the plant with the amount of water that is evaporating. A reduction in the exchange of gases inside the leaf and its surroundings results from drought stress-induced Plants' stomatal closure. In a state of drought stress, Pirouz had the lowest stomatal conductance and seed production (Sapeta et al., 2013).

- **Relative water content**

Plants need water at every stage of their growth and development. It is a vital component of plants. Leaf water content, which shows the proportion of water contained in plant tissues, is a helpful measure of plant homeostasis. The measurement of the greatest quantity of water that tissue can contain is called relative water content (Boyer, 1968). This measurement has preferred removal over measurements of water content reported on a dry or fresh weight basis for tissue. One of the best indicators of a plant's water condition considering the physiological consequences of a deficiency in cellular water is relative water content. RWC and water relations both decline as soon as abiotic stress causes plants to grow (Grover, 2004). In contrast to the water potential attained by plants during drought stress mitigation, relative water content (RWC), which is adversely impacted by stressors, particularly drought stress is thought to be a better predictor of water status. Several research suggest that a decrease in RWC is caused by a water shortage (Singh & P.K., 2015).

- **Leakage of electrolyte**

Measured Leakage of electrolyte as a sign of plant cell stress response. Reactive oxygen species levels rise in response to stress-induced electrolyte leakage, which commonly leads to PCD (programmed cell death) (Demidchik et al., 2014). Plants that go through stress are often assessed for stress tolerance using electrolyte leakage as a gauge. Unstressed or undamaged plant cells retain the electrolytes necessary for healthy cell activity inside the cell membrane (Lee & Zhu, 2010). The relative conductivity of the lost ions in water may be used to gauge how well they have been maintained structurally and steadily. In several crop species, EL (electrolyte leakage) has been suggested as a useful metric for identifying stress-tolerant cultivars (Rolny et al., 2011).

- **Photosynthesis**

Drought stress affects photosynthesis like other physiological factors. Enzymes, membranes, and photosynthetic machinery are all negatively impacted by drought. Additionally, a significant portion of photosynthesis is impacted by changes in organelle mobility brought on by drought. It has been shown that plants under drought stress cause hormonal imbalances, which lead to a decline in the concentrations of several essential photosynthesis-related enzymes. Drought stress lowered the water potential of leaves and RWC which in turn reduced stomatal conductance and subsequently decreased the CO_2 molar percentage in chloroplasts, the rate of photosynthesis, and CO_2 assimilation. When plants experience drought stress, one of their first reactions is stomatal closure, which is generally thought to be the primary cause of the decline in photosynthesis brought on by the drought (David et al., 2007).

2) Biochemical responses to stress caused by drought

The metabolic profile of a plant's tissues may be altered by drought stress; a number of these biochemical characteristics are discussed below.

- **Proline**

Plant drought stress is closely linked to proline, and it may significantly increase free proline levels in crops and other plants during this period (Flexas et al., 2008). Plant cells may store large amounts of proline as an osmo protectant without damaging the cellular structure. When plants faced environmental stressors, proline accumulation was crucial for osmotic adjustment, detoxification of ROS, and membrane integrity (Lee et al., 2009). Proline has been suggested to play functions other than osmotic adjustment, such as hydroxyl radical scavenger, supply of carbon and nitrogen, energy sink or decreasing power, and protection of plasma membrane integrity. Elevated proline levels help plants hold onto their low water potential.

- **Hydrogen peroxide (H2O2)**

The age of the plants, the length of the water shortage, and genotype-specific variations in the responses to drought stress on H_2O_2 production all had a significant impact. In plants, H_2O_2 has a dual function: at low concentrations, it functions as a signaling molecule, at high concentrations that causes apoptosis. Produced by the univalent reduction of O_2. Additionally, H_2O_2 was a major regulator of senescence, photosynthesis and photorespiration, growth, development, cell cycle, and stomatal movement (Gill & Tuteja, 2010).

- **Lipid peroxidation**

Lipid peroxidation is the most harmful metabolic process that happens in all living things when they are under stress. Lipid peroxidation is the most dependable criterion used to determine whether a genotype is resistant or vulnerable to stress. The byproduct of lipid peroxidation is malondialdehyde The Reactive Oxygen Species level is above the threshold limit, causing lipid peroxidation in the membranes of cells and organelles. This produces lipid-derived radicals, which contribute to oxidative stress and impair regular cellular activity (Garg & Manchanda, 2009). All genotypes demonstrated an increase in lipid peroxidation in response to an increase in NaCl content, while salt-tolerant genotypes showed a smaller increase than sensitive genotypes.

- **Photosynthetic pigments**

The most crucial component of chloroplasts for photosynthesis is thought to be chlorophyll, and the rate of photosynthetic activity is positively correlated with the relative concentration of chlorophyll. Reduced chlorophyll concentration is caused by pigment photooxidation, and chlorophyll breakdown brought on by the loss of chloroplast membranes during drought stress (Kannan & Kulandaivelu, 2011). Damage to photosynthetic pigments and thylakoid membranes are both severe outcomes of drought stress. Chlorophyll b declines more than chlorophyll a decline in plants that experience water constraint, which tips the ratio in favour of chlorophyll a. Carotenoids, sometimes referred to as “Cars”, are essential for the photo Défense process of photosynthesis and are necessary for a plant's development under both biotic and abiotic stress. Drought stress altered the proportion of carotenoid to chlorophyll “a” and “b”. Under conditions of water deficiency, a considerable lowering in the chlorophyll content of Vaccinium myrtillus and sunflower was also observed (Jaleel et al., 2009).

3) Observed Impacts of Droughts

Dryness-induced declines in tropical plants are common and have been seen in controlled experiments without rainfall as well as in wild settings. During a drought, certain trees may die in a matter of years; these trees' vulnerability varies depending on several factors, such as species, size, age, growth rate, and location. Big, long-lived trees are very vulnerable, which negatively impacts both biological services and carbon emissions and storage (Aubry-Kientz et al., 2015). Vulnerability is more common in seasonal rainforests with occasional dry periods, especially in wet microhabitats and amid trees. Tree trunk growth rates are adversely impacted by droughts, with the biggest trees being most severely affected. Amazonian drought, reductions in photosynthesis and carbon absorption may lead to slower growth rates (Aragão et al., 2014). More frequent and severe droughts are inevitably correlated with a shift in the kind of trees that do well in forests. While species that are vulnerable to drought decrease, those that are resistant to drought gain greater dominance. The interplay of fires, fragmented forests, and droughts speeds up the process of forest degradation in dry locations. Fires preferentially affect smaller sub-canopy trees, and they are exacerbated by dryness, which raises carbon emissions. However, by scattering radiation, fire-related aerosols may increase forest productivity. The complex interactions between fires, droughts, and forest composition changes in tropical regions have a significant impact on ecosystem dynamics and carbon balance (van der Laan-Luijkx et al., 2015).

4) Drought Stress Experimental Models

These approaches may all be classified as agar based, soil-based or aqueous culture-based based on their basic structure, even though there are many different types of drought models available.

- **Drought Models Based on Soil**

This experimental strategy has a major benefit in that it simulates actual drought circumstances in agriculture and the natural world by gradually reducing or abruptly stopping plant irrigation (Todaka et al., 2017). These models accurately simulate short-term droughts, which are common in European agriculture because of erratic weather patterns (Vinocur& Altman, 2005). Nevertheless, because of the model's high-waterintake and outflow rates, there are restrictions on researching long duration responses to drought, such as the buildup of osmo-protective metabolites or proteins and alterations to cell walls (Verslues et al., 2006). An improved version considers longer plant responses to dryness and permits gentler drought conditions by using foil-sealed containers to stop water loss (Farooq et al., 2009;Thompson et al., 2004). According to Totaka et al., (2017), the use of an automated irrigation system improves the accuracy of water schedules and real-time soil water content monitoring. However, a problem in long-term research carried out under well controlled laboratory circumstances is the need for significant plant material for periodic soil and leaf measurements. Another technique to solve this is to grow transgenic or mutant plants in the same container as their wild-type counterparts, with the wild-type plants acting as reference points for assessing stress signals. By monitoring the soil's water content after the dehydration phase, this method makes it easier to quantify the effects of drought stress and permits damage-free root removal for the purpose of examining oxidative process, changes in water potential, and metabolic activities at the level of the roots (Seminario et al., 2017). On inert substrates, research on how drought affects legume-rhizobial nodule symbiosis may also be done (Staudinger et al., 2016).

- **Drought Models Based on Hydroponic Aqueous Culture**

To replicate drought duress in plants, a multitude of techniques are utilized (Ito et al., 2006). One method simulates severe dehydration by submerging roots in the air for a maximum of eight hours; the intensity of the simulated drought is determined by the duration of submersion (Zhou et al., 2013). Alternatively, nutrient solutions are supplemented with osmolytes, which are osmotically active substances, to simulate arid conditions by inducing osmotic stress (Ji et al., 2014). In drought stress models, physiologically inert polymeric osmolytes are preferred, specifically polyethylene glycol (PEG), which has a molecular weight of 6000 Da or greater(Hellal et al., 2018). The medium water potential is substantially diminished by PEG, which disrupts the assimilation of water by plant roots (Amist& Singh, 2016). In recovery studies utilizing PEG-based models, plants are transferred or substituted to a solution devoid of PEG(Munns, 2002 and, Hohl & Schopfer, 1991). Aqueous PEG models are additionally employed in the screening of phyto-effectors, which are compounds that augment drought tolerance(Zhong et al., 2018). Water-suppressing small molecules frequently impedes plant-response enzymes(Chutia & Borah, 2012). A model based on Lemna minor culture that employs microtiter plates containing PEG6000 or PEG8000 enables the rapid screening of such compounds(Liu et al., 2017). However, solutions containing PEG and high viscosity may induce hypoxia, necessitating further aeration(Rissel et al., 2017). The impact of unintended root malfunction in media containing PEG on leaf dehydration underscores the criticality of preventing root injury associated with PEG(Blum, 2017).

- **Agar-Based Drought Model**

Plants cultivated on agar prevent or reduce hypoxia. Agar-based models are commonly employed in plant biology because Arabidopsis thaliana seedlings are useful for drought stress research (van der Weele et al., 2000). Agar that has hardened (filled Petri plates) and Skoog and Murashige medium augmented with PEG8000 over two days is used to infuse PEG (Smith et al., 1985). Adding PEG Adding directly to the agar medium during preparation hinders solidification (Conn et al., 2013). PEG dissolves from an intensive layering solution into preformed, hardened agar to create a wild agar media. After 24 hours of diffusion (van der Weele et al., 2000), changing the overlay solution concentration achieves wild type equilibrium between the agar and the aqueous overlay medium. Plants may be transplanted to PEG-free media after recovery. Stress application involves placing seedlings on PEG-containing agar medium. Numerous plants and fungi have been infected using the agar-based PEG infusion paradigm (Blum, 2017). A comparable setup that included 10% w/v PEG6000 in the overlay medium investigated how water stress affected the germination and development of rapeseed (Brassica napus) seedlings. According to Verslues et al., 2006 and colleagues, the arrangement was limited to early plant ontogenesis, seed germination, and seedling development (Verslues et al., 2006). This technique could not treat mature plants or later ontogenetic stress responses. The results we obtained mainly supported prior findings that older plants are more susceptible to dryness than seedlings (Yang et al., 1998). Different species have different stress thresholds (Verslues et al., 2006). Wild-type plants treated below 0.6 MPa lost seven days of life, in contrast to seedlings. However, plants that received wild-type treatments below 0.4 MPa displayed proteome and metabolome alterations, indicating redox metabolism and metabolic adjustment (Yang et al., 1998; Frolov et al., 2017). An agar-based model demonstrated that soybeans were more resistant to osmotic stress and could endure eight and sixteen (w/v) PEG pre- and post-flowering treatments for two weeks (Hamayun et al., 2010).

5) Assuming Future Responses at the Landscape Level and Community

In the event of a net loss of carbon at the landscape and community levels, the death of a single tree lowers the forest's ability to store carbon. Given that forests consist of more than simply the individual trees inside them, it is challenging to predict how multispecies communities will react to drought. This is because using effective drought-response techniques at the tree level is made more difficult by the competition between individual trees for the limited quantity of soil moisture (Manzoni et al., 2015). Additionally, it is expected that microsite variability and tree variety will both help to slightly reduce the impact of droughts on communities across larger geographic scales (Allen et al., 2015). It seems that short-term droughts often result in tree death, but long-term drying trends alter the species makeup of the ecosystem, favoring drought-tolerant species (Hofhansl et al., 2014). The specific reaction will depend on how severe the drought is in comparison to the long-term factors that influenced the existing species mix. Selection within the regional species pool will be the primary source of changes in species composition as drought-tolerant species increase and drought-sensitive species decrease. However, over time, plant movement will expand the pool from which species are chosen (Corlett & Westcott, 2013). Considerable variety in drought tolerance has been observed among several nontropical tree species, suggesting that population-level adaptation may be possible without requiring migration. Depending on changes in the diversity of species and functional features of the forest, ongoing shifts in carbon sequestration may have a decreasing or increasing influence on the carbon cycle. Extended periods of drought may provide advantages to tree species that can withstand fire, as well as grass invasion in areas where people live. This is because the connection between drought and fires, which are exacerbated by human activities such as logging, may be advantageous (Devisscher et al., 2016). As a result, in regions where the climate is conducive to either, forests may quickly transform into savannahs (Staal et al., 2015).

6) Management Strategies for Drought Resilience

Wet seasons are those that fall outside of a region's usual rainfall patterns, such as insufficient precipitation or drought conditions. Overall, agricultural output may be adversely affected by weather extremes like droughts and floods. To build resilient agricultural systems against climate variability, it is essential to comprehend these implications and implement practical adaptation strategies. Drought impacts may be identified and tracked using passive and active satellite sensors, such as visual refraction, electromagnetic scattering, thermal warnings, gravity fields, near-surface humidity levels, and atmospheric CO2 concentrations (Fatichi et al., 2016). The difficulty is in integrating various information sources in almost real-time (hours) and extrapolating them from ever-sparser data (decades) to be calibrated against ground observations. Preventing land-management fires from spreading into nearby woods is the first objective after a drought starts to occur (Alencar et al., 2015). Even though most efforts to do this have failed, enough research has been done to indicate that proper fines for starting fires during droughts, together with satellite detection combined with ground-based enforcement and firefighting, should be effective (Lee et al., 2016).

2. Conclusion

As the detailed connection that exists between dry stress and plant ecosystems, which is particularly visible in tropical regions and forested areas, has substantial ramifications for the recycling of carbon, the preservation of biodiversity, and the overall resilience of ecosystems, it is important to note that this relationship is particularly noticeable in tropical settings. The effects that have been recorded, the affects that have been defined on the physiological signs, and the biochemical responses all bring to light the fact that a significant number of plant species are very sensitive to variations in the patterns of precipitation. Using experimental models that replicate drought stress, we can make a significant contribution to our understanding of these processes. Soil-based, agar-based, and hydroponic aqueous culture are some of the types that are now available. There is an immediate need to put into action comprehensive management strategies for drought resilience. This is because future reactions at the landscape and community levels are intrinsically unpredictable. As a result, there is a crisis. This is done with the intention of minimizing the potential biological and environmental harm that might be brought about by prolonged drought conditions. The introduction of preventive measures, such as fire prevention and satellite monitoring, is one way in which this may be done.

References

[1] Alencar, A. A., Brando, P. M., Asner, G. P., &Putz, F. E. (2015). Landscape fragmentation, severe drought, and the new Amazon forest fire regime. *Ecological Applications*, *25*(6), 1493–1505. https://doi.org/10.1890/14-1528.1

[2] Allen, C. D., Breshears, D. D., & McDowell, N. G. (2015). On underestimation of global vulnerability to

tree mortality and forest die-off from hotter drought in the Anthropocene. Ecosphere, 6(8), 1–55. https://doi.org/10.1890/ES15-00203.1

[3] Allen, C. D., Macalady, A. K., Chenchouni, H., Bachelet, D., McDowell, N., Vennetier, M., Kitzberger, T., Rigling, A., Breshears, D. D., Hogg, E. H., Gonzalez, P., Fensham, R., Zhang, Z., Castro, J., Demidova, N., Lim, J. H., Allard, G., Running, S. W., Semerci, A., & Cobb, N. (2010). A global overview of drought and heat-induced tree mortality reveals emerging climate change risks for forests. Forest Ecology and Management, 259(4), 660–684. https://doi.org/10.1016/j.foreco.2009.09.001

[4] Amist, N., & Singh, N. B. (2016). PEG imposed water deficit and physiological alterations in hydroponic cabbage. Iran. Journal of Plant Physiology, 8, 1653–1658.

[5] Ansari, W. A., Atri, N., Singh, B., Kumar, P., & Pandey, S. (2018). Morpho-physiological and biochemical responses of muskmelon genotypes to different degrees of water deficit. Photosynthetica, 56(4), 1019–1030. https://doi.org/10.1007/s11099-018-0821-9

[6] Aragão, L. E., Poulter, B., Barlow, J. B., Anderson, L. O., Malhi, Y., Saatchi, S., Phillips, O. L., & Gloor, E. (2014). Environmental change and the carbon balance of Amazonian forests. Biological Reviews of the Cambridge Philosophical Society, 89(4), 913–931. https://doi.org/10.1111/brv.12088

[7] Aragão, L. E., Poulter, B., Barlow, J. B., Anderson, L. O., Malhi, Y., Saatchi, S., Phillips, O. L., & Gloor, E. (2014b). Environmental change and the carbon balance of Amazonian forests. Biological Reviews of the Cambridge Philosophical Society, 89(4), 913–931. https://doi.org/10.1111/brv.12088

[8] Aubry-Kientz, M., Rossi, V., Boreux, J. J., &Hérault, B. (2015). A joint individual-based model coupling growth and mortality reveals that tree vigor is a key component of tropical forest dynamics. Ecology and Evolution, 5(12), 2457–2465. https://doi.org/10.1002/ece3.1532

[9] Batlang, U., Baisakh, N., Ambavaram, M. M., & Pereira, A. (2013). Phenotypic and physiological evaluation for drought and salinity stress responses in rice. Methods in Molecular Biology, 956, 209–225. https://doi.org/10.1007/978-1-62703-194-3_15

[10] Blum, A. (2017). Osmotic adjustment is a prime drought stress adaptive engine in support of plant production. Plant, Cell and Environment, 40(1), 4–10. https://doi.org/10.1111/pce.12800, PubMed: 27417527

[11] Blum, A. (2017b). Osmotic adjustment is a prime drought stress adaptive engine in support of plant production. Plant, Cell and Environment, 40(1), 4–10. https://doi.org/10.1111/pce.12800, PubMed: 27417527

[12] Boyer, J. S. (1968). Measurement of the water status of plants. Annual Review of Plant Physiology, 9, 351–364.

[13] Bréda, N., Huc, R., Granier, A., & Dreyer, E. (2006). Temperate forest trees and stands under severe drought: A review of ecophysiological responses, adaptation processes and long term consequences. Annals of Forest Science, 63(6), 625–644. https://doi.org/10.1051/forest:2006042

[14] Chadwick, R., Good, P., Martin, G., & Rowell, D. P. (2016). Large rainfall changes are consistently projected over substantial areas of tropical land. Nature Climate Change, 6(2), 177–181. https://doi.org/10.1038/nclimate2805

[15] Chutia, J., & Borah, S. P. (2012). Water stress effects on leaf growth and chlorophyll content but not the grain yield in traditional rice (Oryza sativa Linn.) genotypes of Assam, India II. Protein and proline status in seedlings under PEG-induced water stress. American Journal of Plant Sciences, 3, 971–980. https://doi.org/

[16] Conn, S. J., Hocking, B., Dayod, M., Xu, B., Athman, A., Henderson, S., Aukett, L., Conn, V., Shearer, M. K., Fuentes, S., Tyerman, S. D., &Gilliham, M. (2013). Protocol: Optimising hydroponic growth systems for nutritional and physiological analysis of Arabidopsis thaliana and other plants. Plant Methods, 9(1), 4. https://doi.org/10.1186/1746-4811-9-4

[17] Corlett, R. T., & Westcott, D. A. (2013). Will plant movements keep up with climate change? Trends in Ecology and Evolution, 28(8), 482–488. https://doi.org/10.1016/j.tree.2013.04.003

[18] David, T. S., Henriques, M. O., Kurz-Besson, C., Nunes, J., Valente, F., Vaz, M., Pereira, J. S., Siegwolf, R., Chaves, M. M., Gazarini, L. C., & David, J. S. (2007). Water-use strategies in two co-occurring Mediterranean evergreen oaks: Surviving the summer drought. Tree Physiology, 27(6), 793–803. https://doi.org/10.1093/treephys/27.6.793

[19] Deikman, J., Petracek, M., & Heard, J. E. (2012). Drought tolerance through biotechnology: Improving translation from the laboratory to farmers fields. Current Opinion in Biotechnology, 23(2), 243–250. https://doi.org/10.1016/j.copbio.2011.11.003

[20] Demidchik, V., Straltsova, D., Medvedev, S. S., Pozhvanov, G. A., Sokolik, A., & Yurin, V. (2014). Stress-induced electrolyte leakage: The role of K+-permeable channels and involvement in programmed cell death and metabolic adjustment. Journal of Experimental Botany, 65(5), 1259–1270. https://doi.org/10.1093/jxb/eru004

[21] Devisscher, T., Malhi, Y., Rojas Landívar, V. D., & Oliveras, I. (2016). Understanding ecological transitions under recurrent wildfire: A case study in the seasonally dry tropical forests of the Chiquitania. Bolivia. Forest Ecology and Management, 360, 273–286. https://doi.org/10.1016/j.foreco.2015.10.033

[22] Farooq, M., Wahid, A., Kobayashi, N., Fujita, D., & Basra, S. M. A. (2009). Plant drought stress: Effects, mechanisms and management. Agronomy for Sustainable Development, 29(1), 185–212. https://doi.org/10.1051/agro:2008021

[23] Farooq, M., Wahid, A., Kobayashi, N., Fujita, D., & Basra, S. M. A. (2009b). Plant drought stress: Effects, mechanisms and management. Agronomy for Sustainable Development, 29(1), 185–212. https://doi.org/10.1051/agro:2008021

[24] Farooq, M., Wahid, A., Kobayashi, N., Fujita, D., & Basra, S. M. A. (2009b). Plant drought stress: Effects, mechanisms and management. Agronomy for Sustainable Development, 29(1), 185–212. https://doi.org/10.1051/agro:2008021

[25] Fatichi, S. et al. (2016). Modeling plant–water interactions: An ecohydrological overview from cell to global scale. WIREs water Published online November 19, 2015. http://doi.org/10.1002/wat2.1125
[26] Flexas, J., Ribas-Carbó, M., Diaz-Espejo, A., Galmés, J., & Medrano, H. (2008). Mesophyll conductance to CO2: Current knowledge and future prospects. Plant, Cell and Environment, 31(5), 602–621. https://doi.org/10.1111/j.1365-3040.2007.01757.x
[27] Frolov, A., Bilova, T., Paudel, G., Berger, R., Balcke, G. U., Birkemeyer, C., &Wessjohann, L. A. (2017). Early responses of mature Arabidopsis thaliana plants to reduced water potential in the agar-based polyethylene glycol infusion drought model. Journal of Plant Physiology, 208, 70–83. https://doi.org/10.1016/j.jplph.2016.09.013, PubMed: 27889524
[28] García-García, D., &Ummenhofer, C. C. (2015). Multidecadal variability of the continental precipitation annual amplitude driven by AMO and ENSO. Geophysical Research Letters, 42(2), 526–535. https://doi.org/10.1002/2014GL062451
[29] Garg, n., & Manchanda, G. (2009). rOS generation in plants: Boon or bane. Plant Biosys, 143, 81–96.
[30] Geissler, T., &Wessjohann, L. A. (2011). A Whole-plant microtiter plate assay for drought stress tolerance-inducing effects. Journal of Plant Growth Regulation, 30(4), 504–511. https://doi.org/10.1007/s00344-011-9212-1
[31] Geissler, T., &Wessjohann, L. A. (2011b). A Whole-plant microtiter plate assay for drought stress tolerance-inducing effects. Journal of Plant Growth Regulation, 30(4), 504–511. https://doi.org/10.1007/s00344-011-9212-1
[32] Gill, S. S., & Tuteja, N. (2010). Reactive oxygen species and antioxidant machinery in abiotic stress tolerance in crop plants. Plant Physiology and Biochemistry, 48(12), 909–930. https://doi.org/10.1016/j.plaphy.2010.08.016
[33] GoI. (2013), 'Reserve Bank of India Annual report (pp. 2012–2013). Government of India.
[34] Granier, A., Reichstein, M., Bréda, N., Janssens, I. A., Falge, E., Ciais, P., Grünwald, T., Aubinet, M., Berbigier, P., Bernhofer, C., Buchmann, N., Facini, O., Grassi, G., Heinesch, B., Ilvesniemi, H., Keronen, P., Knohl, A., Köstner, B., Lagergren, F., . . . Wang, Q. (2007). Evidence for soil water control on carbon and water dynamics in European forests during the extremely dry year: 2003. Agricultural and Forest Meteorology, 143(1–2), 123–145. https://doi.org/10.1016/j.agrformet.2006.12.004
[35] Grover, A. (2004). Genetic improvement for abiotic stress responses. Plant Breeding. Springer Netherlands, 167–193.
[36] Hamayun, M., Khan, S. A., Shinwari, Z. K., Khan, A. L., Ahmad, N., & Lee, I.-J. (2010). Effect of polyethylene glycol induced drought stress on physio-hormonal attributes of soybean. Abstracts of papers, 42, 977–986.
[37] Hartmann, H. (2011). Will a 385 million-year struggle for light become a struggle for water and for carbon? How trees may cope with more frequent climate change type drought events. Global Change Biology, 17(1), 642–655. https://doi.org/10.1111/j.1365-2486.2010.02248.x
[38] Hassan, N. S., Shaaban, L. D., Hashem, E. S. A., & Seleem, E. E. (2004). In vitro selection for water stress tolerant callus line of Helianthus annus L. cv. Myak. International Journal of Agriculture and Biology, 6, 13–18.
[39] Hellal, F. A., El-Shabrawi, H. M., Abd El-Hady, M., Khatab, I. A., El-Sayed, S. A. A., &Abdelly, C. (2018). Influence of PEGinduced drought stress on molecular and biochemical constituents and seedling growth of Egyptian barley cultivars. Journal, Genetic Engineering and Biotechnology, 16(1), 203–212. https://doi.org/10.1016/j.jgeb.2017.10.009
[40] Hofhansl, F., Kobler, J., Ofner, J., Drage, S., Pölz, E., & Wanek, W. (2014). Sensitivity of tropical forest aboveground productivity to climate anomalies in SW Costa Rica. Global Biogeochemical Cycles, 28(12), 1437–1454. https://doi.org/10.1002/2014GB004934
[41] Hohl, M., & Schopfer, P. (1991). Water relations of growing maize coleoptiles: Comparison between mannitol and polyethylene glycol 6000 as external osmotica for adjusting turgor pressure. Plant Physiology, 95(3), 716–722. https://doi.org/10.1104/pp.95.3.716, PubMed: 16668045
[42] Ito, Y., Katsura, K., Maruyama, K., Taji, T., Kobayashi, M., Seki, M., Shinozaki, K., & Yamaguchi-Shinozaki, K. (2006). Functional analysis of rice DREB1/CBF-type transcription factors involved in cold-responsive gene expression in transgenic rice. Plant and Cell Physiology, 47(1), 141–153. https://doi.org/10.1093/pcp/pci230, PubMed: 16284406
[43] Jain, M., Tiwary, S., & Gadre, R. (2010). Sorbitol-induced changes in various growth and biochemical parameters in maize. Plant, Soil and Environment, 56(6), 263–267. https://doi.org/10.17221/233/2009-PSE
[44] Jaleel, C. A. P., Manivannan, A., Wahid, M., Farooq, r., & Somasundaram, P. (2009). Drought stress in plants: A review on morphological characteristics and pigments composition. International Journal of Agriculture and Biology, 11(100), 105.
[45] Ji, H., Liu, L., Li, K., Xie, Q., Wang, Z., Zhao, X., & Li, X. (2014). PEG-mediated osmotic stress induces premature differentiation of the root apical meristem and outgrowth of lateral roots in wheat. Journal of Experimental Botany, 65(17), 4863–4872. https://doi.org/10.1093/jxb/eru255, PubMed: 24935621
[46] Kannan, n. D., &Kulandaivelu, G. (2011). Drought-induced changes in physiological, biochemical and phytochemical properties of Withaniasomnifera Dun. Journal of Medicinal Plants Research, 5, 3929–3935.
[47] Klein, T., Randin, C., & Körner, C. (2015). Water availability predicts forest canopy height at the global scale. Ecology Letters, 18(12), 1311–1320. https://doi.org/10.1111/ele.12525
[48] Kreft, H., &Jetz, W. (2007). Global patterns and determinants of vascular plant diversity. Proceedings of the National Academy of Sciences of the United

States of America, 104(14), 5925–5930. https://doi.org/10.1073/pnas.0608361104

[49] Kumari, S., Roy, S., Singh, P., Singla-Pareek, S. L., & Pareek, A. (2013). Cyclophilins: Proteins in search of function. Plant Signaling and Behavior, 8(1), e22734. https://doi.org/10.4161/psb.22734

[50] Lee, B. R., Jin, Y. L., Avice, J. C., Cliquet, J. B., Ourry, A., & Kim, T. H. (2009). Increased proline loading to phloem and its effects on nitrogen uptake and assimilation in water-stressed white clover (Trifolium repens). New Phytologist, 182(3), 654–663. https://doi.org/10.1111/j.1469-8137.2009.02795.x

[51] Lee, B., & Zhu, J. K. (2010). Phenotypic analysis of Arabidopsis mutants: Electrolyte leakage after freezing stress. Cold Spring Harbor protocols, 4970.

[52] Lee, J. S. H., Jaafar, Z., Tan, A. K. J., Carrasco, L. R., Ewing, J. J., Bickford, D. P., Webb, E. L., & Koh, L. P. (2016). Toward clearer skies: Challenges in regulating transboundary haze in Southeast Asia. Environmental Science and Policy, 55, 87–95. https://doi.org/10.1016/j.envsci.2015.09.008

[53] Liu, J., Yang, H., Gosling, S. N., Kummu, M., Flörke, M., Pfister, S., Hanasaki, N., Wada, Y., Zhang, X., Zheng, C., Alcamo, J., & Oki, T. (2017). Water scarcity assessments in the past, present, and future: REVIEW ON water SCARCITY ASSESSMENT. Earth’s Future, 5(6), 545–559. https://doi.org/10.1002/2016EF000518, PubMed: 30377623

[54] Malhi, Y., Meir, P., & Brown, S. (2002). Forests, carbon and global climate. Philosophical Transactions. Series A, Mathematical, Physical, and Engineering Sciences, 360(1797), 1567–1591. https://doi.org/10.1098/rsta.2002.1020

[55] Manzoni, S., Vico, G., Thompson, S., Beyer, F., & Weih, M. (2015). Contrasting leaf phenological strategies optimize carbon gain under droughts of different duration. Advances in Water Resources, 84, 37–51. https://doi.org/10.1016/j.advwatres.2015.08.001

[56] Meher, S., Shivakrishna, P., Ashok Reddy, K. A., & Manohar Rao, D. M. (2018). Effect of PEG-6000 imposed drought stress on RNA content, relative water content (RWC), and chlorophyll content in peanut leaves and roots. Saudi Journal of Biological Sciences, 25(2), 285–289. https://doi.org/10.1016/j.sjbs.2017.04.008, PubMed: 29472779

[57] Mohammadi, P. P., Moieni, A., & Komatsu, S. (2012). Comparative proteome analysis of drought sensitive and drought-tolerant rapeseed roots and their hybrid F1 line under drought stress. Amino Acids, 43(5), 2137–2152. https://doi.org/10.1007/s00726-012-1299-6

[58] Munns, R. (2002). Comparative physiology of salt and water stress. Plant, Cell and Environment, 25(2), 239–250. https://doi.org/10.1046/j.0016-8025.2001.00808.x, PubMed: 11841667

[59] Pan, Y., Birdsey, R. A., Fang, J., Houghton, R., Kauppi, P. E., Kurz, W. A., Phillips, O. L., Shvidenko, A., Lewis, S. L., Canadell, J. G., Ciais, P., Jackson, R. B., Pacala, S. W., McGuire, A. D., Piao, S., Rautiainen, A., Sitch, S., & Hayes, D. (2011). A large and persistent carbon sink in the world’s forests. Science, 333(6045), 988–993. https://doi.org/10.1126/science.1201609

[60] Pinheiro, C., & Chaves, M. M. (2011). Photosynthesis and drought: Can we make metabolic connections from available data? Journal of Experimental Botany, 62(3), 869–882. https://doi.org/10.1093/jxb/erq340

[61] Poorter, L., van der Sande, M. T., Thompson, J., Arets, E. J. M. M., Alarcón, A., Álvarez-Sánchez, J., Ascarrunz, N., Balvanera, P., Barajas-Guzmán, G., Boit, A., Bongers, F., Carvalho, F. A., Casanoves, F., Cornejo-Tenorio, G., Costa, F. R. C., de Castilho, C. V., Duivenvoorden, J. F., Dutrieux, L. P., Enquist, B. J., . . . Peña-Claros, M. (2015). Diversity enhances carbon storage in tropical forests. Global Ecology and Biogeography, 24(11), 1314–1328. https://doi.org/10.1111/geb.12364

[62] Rasool, S., Ahmad, A., Siddiqi, T. O., & Ahmad, P. (2013). Changes in growth, lipid peroxidation and some key antioxidant enzymes in chickpea genotypes under salt stress. Acta Physiologiae Plantarum, 35(4), 1039–1050. https://doi.org/10.1007/s11738-012-1142-4

[63] Rissel, D., Heym, P. P., Thor, K., Brandt, W., Wessjohann, L. A., & Peiter, E. (2017). No silver bullet-Canonical poly(ADP-ribose) Polymerases (PARPs) are no universal factors of abiotic and biotic stress resistance of Arabidopsis thaliana. Frontiers in Plant Science, 8, 59. https://doi.org/10.3389/fpls.2017.00059, PubMed: 28220129

[64] Rollins, J. A., Habte, E., Templer, S. E., Colby, T., Schmidt, J., & von Korff, M. (2013). Leaf proteome alterations in the context of physiological and morphological responses to drought and heat stress in barley (Hordeum vulgare L.). Journal of Experimental Botany, 64(11), 3201–3212. https://doi.org/10.1093/jxb/ert158

[65] Rolny, N., Costa, L., Carrión, C., &Guiamet, J. J. (2011). Is the electrolyte leakage assay an unequivocal test of membrane deterioration during leaf senescence? Plant Physiology and Biochemistry, 49(10), 1220–1227. https://doi.org/10.1016/j.plaphy.2011.06.010

[66] Sapeta, H., Costa, J. M., Lourenço, T., Maroco, J., van der Linde, P., & Oliveira, M. M. (2013). Drought stress response in Jatropha curcas: Growth and physiology. Environmental and Experimental Botany, 85, 76–84. https://doi.org/10.1016/j.envexpbot.2012.08.012

[67] Sekhon, H. S., Singh, G., Sharma, P., & Bains, T. S. (2010). Water use efficiency under stress environments. In S. S. Yadav & D. L. Mc. Neil (Eds.), Climate change and management of cool season grain legume crops. redden, and S.A. Patil). Springer Press, Dordrecht Heidelberg-London-new York.

[68] Seminario, A., Song, L., Zulet, A., Nguyen, H. T., González, E. M., &Larrainzar, E. (2017). Drought stress causes a reduction in the biosynthesis of ascorbic acid in soybean plants. Frontiers in Plant Science, 8, 1042. https://doi.org/10.3389/fpls.2017.01042, PubMed: 28663755

[69] Shao, H. B., Chu, L. Y., Shao, M. A., Jaleel, C. A., & Mi, H. M. (2008). Higher plant antioxidants and redox signaling under environmental stresses. Comptes

Rendus Biologies, 331(6), 433–441. https://doi.org/10.1016/j.crvi.2008.03.011

[70] Sheffield, J., & Wood, E. F. (2008). Projected changes in drought occurrence under future global warming from multi-model, multi-scenario, IPCC AR4 simulations. Climate Dynamics, 31(1), 79–105, Ar.4. https://doi.org/10.1007/s00382-007-0340-z

[71] Singh, G., & P. K. (2015). rai, n. rai, K.K., Tiwari. Changes in Free Radical Generation, Metabolites and Antioxidant Defense Machinery in Hyacinth Bean (Lablab purpureus. L) in response to high temperature stress. Acta Physiol Plant., 37, 37–46.

[72] Smith, R. H., Bhaskaran, S., & Miller, F. R. (1985). Screening for drought tolerance in Sorghum using cell culture. In Vitro Cellular Amp; Developmental Biology, 21(10), 541–545. https://doi.org/10.1007/BF02620883

[73] Staal, A., Dekker, S. C., Hirota, M., & van Nes, E. H. (2015). Synergistic effects of drought and deforestation on the resilience of the south-eastern Amazon rainforest. Ecological Complexity, 22, 65–75. https://doi.org/10.1016/j.ecocom.2015.01.003

[74] Staudinger, C., Mehmeti-Tershani, V., Gil-Quintana, E., Gonzalez, E. M., Hofhansl, F., Bachmann, G., &Wienkoop, S. (2016). Evidence for a rhizobia-induced drought stress response strategy in Medicago truncatula. Journal of Proteomics, 136, 202–213. https://doi.org/10.1016/j.jprot.2016.01.006, PubMed: 26812498

[75] Su, J., & Wu, R. (2004). Stress inducible synthesis of proline in transgenic rice confers faster growth under stress conditions than with constitutive synthesis. Plant Science, 166(4), 941–948. https://doi.org/10.1016/j.plantsci.2003.12.004

[76] Thompson, A. J., Thorne, E. T., Burbidge, A., Jackson, A. C., Sharp, R. E., & Taylor, I. B. (2004). Complementation of notabilis, an abscisic acid-deficient mutant of tomato: Importance of sequence context and utility of partial complementation. Plant, Cell and Environment, 27(4), 459–471. https://doi.org/10.1111/j.1365-3040.2003.01164.x

[77] Todaka, D., Zhao, Y., Yoshida, T., Kudo, M., Kidokoro, S., Mizoi, J., Kodaira, K. S., Takebayashi, Y., Kojima, M., Sakakibara, H., Toyooka, K., Sato, M., Fernie, A. R., Shinozaki, K., & Yamaguchi-Shinozaki, K. (2017). Temporal and spatial changes in gene expression, metabolite accumulation and phytohormone content in rice seedlings grown under drought stress conditions. Plant Journal: For Cell and Molecular Biology, 90(1), 61–78. https://doi.org/10.1111/tpj.13468, PubMed: 28019048

[78] Todaka, D., Zhao, Y., Yoshida, T., Kudo, M., Kidokoro, S., Mizoi, J., Kodaira, K. S., Takebayashi, Y., Kojima, M., Sakakibara, H., Toyooka, K., Sato, M., Fernie, A. R., Shinozaki, K., & Yamaguchi-Shinozaki, K. (2017b). Temporal and spatial changes in gene expression, metabolite accumulation and phytohormone content in rice seedlings grown under drought stress conditions. Plant Journal: For Cell and Molecular Biology, 90(1), 61–78. https://doi.org/10.1111/tpj.13468, PubMed: 28019048

[79] van der Laan-Luijkx, I. T., van der Velde, I. R., Krol, M. C., Gatti, L. V., Domingues, L. G., Correia, C. S. C., Miller, J. B., Gloor, M., van Leeuwen, T. T., Kaiser, J. W., Wiedinmyer, C., Basu, S., Clerbaux, C., & Peters, W. (2015). Response of the Amazon carbon balance to the 2010 drought derived with CarbonTracker South America. Global Biogeochemical Cycles, 29(7), 1092–1108. https://doi.org/10.1002/2014GB005082

[80] van der Laan-Luijkx, I. T., van der Velde, I. R., Krol, M. C., Gatti, L. V., Domingues, L. G., Correia, C. S. C., Miller, J. B., Gloor, M., van Leeuwen, T. T., Kaiser, J. W., Wiedinmyer, C., Basu, S., Clerbaux, C., & Peters, W. (2015b). Response of the Amazon carbon balance to the 2010 drought derived with CarbonTracker South America. Global Biogeochemical Cycles, 29(7), 1092–1108. https://doi.org/10.1002/2014GB005082

[81] van der Weele, C. M., Spollen, W. G., Sharp, R. E., & Baskin, T. I. (2000). Growth of Arabidopsis thaliana seedlings under water deficit studied by control of water potential in nutrient-agar media. Journal of Experimental Botany, 51(350), 1555–1562. https://doi.org/10.1093/jexbot/51.350.1555, PubMed: 11006306

[82] van der Weele, C. M., Spollen, W. G., Sharp, R. E., & Baskin, T. I. (2000b). Growth of Arabidopsis thaliana seedlings under water deficit studied by control of water potential in nutrient-agar media. Journal of Experimental Botany, 51(350), 1555–1562. https://doi.org/10.1093/jexbot/51.350.1555, PubMed: 11006306

[83] Verslues, P. E., Agarwal, M., Katiyar-Agarwal, S., Zhu, J., & Zhu, J. K. (2006). Methods and concepts in quantifying resistance to drought, salt and freezing, abiotic stresses that affect plant water status. Plant Journal: For Cell and Molecular Biology, 45(4), 523–539. https://doi.org/10.1111/j.1365-313X.2005.02593.x, PubMed: 16441347

[84] Verslues, P. E., Agarwal, M., Katiyar-Agarwal, S., Zhu, J., & Zhu, J. K. (2006b). Methods and concepts in quantifying resistance to drought, salt and freezing, abiotic stresses that affect plant water status. Plant Journal: For Cell and Molecular Biology, 45(4), 523–539. https://doi.org/10.1111/j.1365-313X.2005.02593.x, PubMed: 16441347

[85] Vinocur, B., & Altman, A. (2005). Recent advances in engineering plant tolerance to abiotic stress: Achievements and limitations. Current Opinion in Biotechnology, 16(2), 123–132. https://doi.org/10.1016/j.copbio.2005.02.001, PubMed: 15831376

[86] Wullschleger, S. D., Yin, T. M., DiFazio, S. P., Tschaplinski, T. J., Gunter, L. E., Davis, M. F., & Tuskan, G. A. (2005). Phenotypic variation in growth and biomass distribution for two advanced generation pedigrees of hybrid poplar. Canadian Journal of Forest Research, 35(8), 1779–1789. https://doi.org/10.1139/x05-101

[87] Yang, C. J., Zhang, X. K., Zou, C. S., Cheng, Y., Zhen, P. Y., & Li, G. Y. (1998). Effects of drought simulated by PEG-6000 on germination and seedling growth of rapeseed (Brassica napus L.). Chinese Journal of Oil Crop Sciences, 29, 425–430. Crossref

[88] Zhang, M., Chen, Q., & Shen, S. (2011). Physiological responses of two Jerusalem artichoke cultivars to drought stress induced by polyethylene glycol. Acta Physiologiae Plantarum, 33(2), 313–318. https://doi.org/10.1007/s11738-010-0549-z

[89] Zhang, M., Duan, L., Zhai, Z., Li, J., Tian, X., Wang, B., He, Z., & Li, Z. (2004). Effects of plant growth regulators on water deficit-induced yield loss in soybean. In Proceedings of the 4th International Crop Science Congress, Brisbane, Australia.

[90] Zhong, Y.-P., Li, Z., Bai, D.-F., Qi, X.-J., Chen, J.-Y., Wei, C.-G., Lin, M.-M., & Fang, J.-B. (2018). In vitro variation of drought tolerance in five Actinidia species. Journal of the American Society for Horticultural Science, 143(3), 226–234. https://doi.org/10.21273/JASHS04399-18

[91] Zhou, S., Duursma, R. A., Medlyn, B. E., Kelly, J. W. G., & Prentice, I. C. (2013). How should we model plant responses to drought? An analysis of stomatal and non-stomatal responses to water stress. Agricultural and Forest Meteorology, 182–183, 204–214. https://doi.org/10.1016/j.agrformet.2013.05.009.

Author Profile

Astha Singh received the B.Sc. degree in Biology and M.Sc. degree in Environmental Sciences from Kamla Nehru Institute of Social & Physical Sciences, Sultanpur, Uttar Pradesh affiliated to Ram Manohar Lohia Awadh University, Faizabad, Uttar Pradesh in year 2016 and 2018 respectively. Since May 2019, she is pursuing Ph.D. from Guru Ghasidas Vishwavidyalaya, Bilaspur, Chhattisgarh, India.