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Impacts of Climate Change on the Plant Water Interactions

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Abstract

Climate change has an impact on ecosystem structure and function globally by altering the relationships between plants and soil organisms. Despite the fact that water is the most plentiful molecule on Earth's surface, water scarcity is the element that most severely limits global terrestrial plant production. Little is known about the climatic factors that drive phenological responses to climate change, and less attention has been paid to the fact that phenology is also responsive to other climatic. The aim of this study was to assess the impacts of climate change on plant water interactions. This study was guided by the specific objectives, which included examining the relationship between climate change and plant function; finding out the impacts of climate change on plant water interactions; and assessing how plants handle water scarcity. It was found that there was a linkage between climate change and plant function. The evaporation of water molecules from the outer surfaces of the mesophyll cells initiates the upward transpiration pull in the leaves, and respiring starches and sugars are created during photosynthetic processes using sunlight energy. Climate change enhanced the most enormous movement of species that has occurred without direct human intervention. It was also found that precipitation was a key driver of phenological changes in desert ecosystems. It was also found that drought was one of the most significant biotic challenges faced by plants, with considerable genetic variation in water deficit responses. There is a need for research on climate change to ease biodiversity conservation.

Keywords: Climate change, Plant water interactions, Plant, Water

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1. Introduction

Climate change has an impact on ecosystem structure and function globally by altering the relationships between plants and soil organisms (Council, 2001). Despite the fact that water is the most plentiful molecule on Earth's surface, water scarcity is the element that most severely limits global terrestrial plant production. Many natural ecosystems' production is hampered by a lack of water, especially in arid climates (Jury & Vaux Jr, 2007).

The world's population is expected to grow by one-third between now and 2050 (Conklin, n.d.; He et al., 2021; Simkin et al., 2022). The majority of the additional 2 billion people will live in developing countries, and cities will become increasingly populous. According to the FAO, production will need to increase by 60% by 2050 to meet predicted food and feed demand. As a result, agriculture must adopt climate-smart agriculture practices (Lamnisos et al., 2021). Tropical forests support nearly half of all plant and animal species (Libby et al., 2022), including 96 percent of tree species (de Souza Amorim et al., 2022), with the greatest diversity in areas with the most consistent rainfall.

Hayat et al. (2022) mentioned that the crop yield losses caused by water stress outnumber losses caused by all other biotic and environmental variables combined. The wet tropics, for example, contain luxuriant vegetation because rainfall is plentiful and uniformly dispersed throughout the growth season (Jayaraman et al., 2021). According to Lambers et al. (2008) forests are replaced by grasslands in areas where summer droughts are regular and severe, such as the Asian steppes and North American plains (Jaman et al., 2022).

According to Warne et al. (2019), as rainfall decreases, semideserts, with scattered vegetation, and finally deserts, emerge. According to Lambers et al. (2008a) evaporation and transpiration rates are connected with temperature, the impacts of temperature are partially exerted through water interactions (Solbrig, 2021). Thus, understanding the controls over plant water relations and the consequences of an inadequate water supply for plant development is critical if we want to explain natural patterns of productivity or boost productivity in agriculture or forestry (Shao et al., 2009).

According to the study conducted by Sohel et al. (2019), any ecosystem function, including ecosystem resilience to a changing climate, is dependent on the dynamics of soil water supply and plant water usage. Plant productivity is generally limited by soil moisture according to Umar et al. (2021), hence water supply to plants in dry settings is a concern .

Sohel et al. (2019) added that the response of this plant-water interaction to climate change, such as warming and droughts, has recently been a topic of discussion. Global mean temperatures are expected to climb by 0.3 to 4.8 degrees Celsius by the late twenty-first century, according to observations (Dolan et al., 2021). As a result, there's a good chance that water stress may worsen in several parts of the planet. For plants to be productive and be less vulnerable to climate change, they must be able to handle water stress in hotter, drier climates. Species diversity, ecological structure, and forest type are all significantly influenced by water availability.

Kleine et al. (2021) mentioned that in dry areas with limited water supplies, some plants with deep roots may swallow water from deep soil or groundwater sources. Through hydraulic lift, deep roots may also contribute to the distribution of water in the top soil layer. This water uptake strategy can be advantageous for plants that need water at the top layer of soil. Some plants employ several water sources throughout the year to reduce water competition and increase plant survival rates during dry spells (Honda et al., 2019).

According to Mahmood et al. (2021), the reaction of plants to climate change varies depending on the plant species and developmental stage. Various plants have different species-specific thresholds, and their reactions, such as root elongation, root growth angle disruption, and yield loss, differ between species.

2. Relationship between water and plant functioning

Lambers et al. (2008b) said that water is essential to plant physiology because it plays a critical role in all physiological processes and is required in vast quantities. Nonwoody tissues, such as leaves and roots, contain 70-95 percent water (Berry et al., 2019). Water is the primary channel for moving metabolites through cells at the cellular level. Due to its highly polar nature, water dissolves enormous amounts of ions and polar organic molecules like sugars, amino acids, and proteins, which are essential for metabolism and life.

The lignified cell walls of woody tissues provide additional structural support to large plants. Plants that have lost their turgor (wilt) are unable to perform some physiological processes, such as cell growth and, to a lesser extent, photosynthesis. Long durations of wilting usually result in the plant's death (Kuromori et al., 2018).

The fact that plants need a lot of water is a second argument for the importance of water relations in plant physiological ecology. Less than 1% of absorbed water is retained in biomass, while plants incorporate more than 90% of absorbed N, P, and K into new tissues and between 0 and 70% of photosynthetically fixed C into new tissues (depending on respiratory carbon demands) (Lambers et al., 2008b, p. 190) (Table 1).

The remainder is due to transpiration, or the evaporation of water from plants. Water use by terrestrial plants is inherently inefficient as a function of photosynthesis. Stomates act as a water loss pathway in addition to allowing CO2 to enter the leaf (Lambers et al., 2008). Before CO2 can diffuse to the carboxylation site in the leaf, it first needs to dissolve in water on the moist walls of the mesophyll cells. The moist surface area of mesophyll cells exposed to interior air gaps of the leaf is roughly 7-80 times more than the external leaf area, depending on the species and plant growth conditions.

Table 1: Major constituent concentrations in a hypothetical herbaceous plant, as well as the amount of each constituent that must be taken to generate a gram of dry biomass.

Resource	Concentration (% of fresh mass)	Quantity required (mg g^{-1})
Water	90	500,000
Carbon	4	40
Nitrogen	0.3	3
Potassium	0.2	2
Phosphorus	0.02	0.2

Source: (Lambers et al., 2008b, p. 190).

2.1. Absorption and Conduction of Water

The water potential gradient that occurs in the soil, plant, and air continuum provides the energy to move the water. The flow of water inside the xylem of the root, on the other hand, is almost entirely pressure dependent, with pressure dropping from the root to the stem, leaves, and air (Fig. 1).
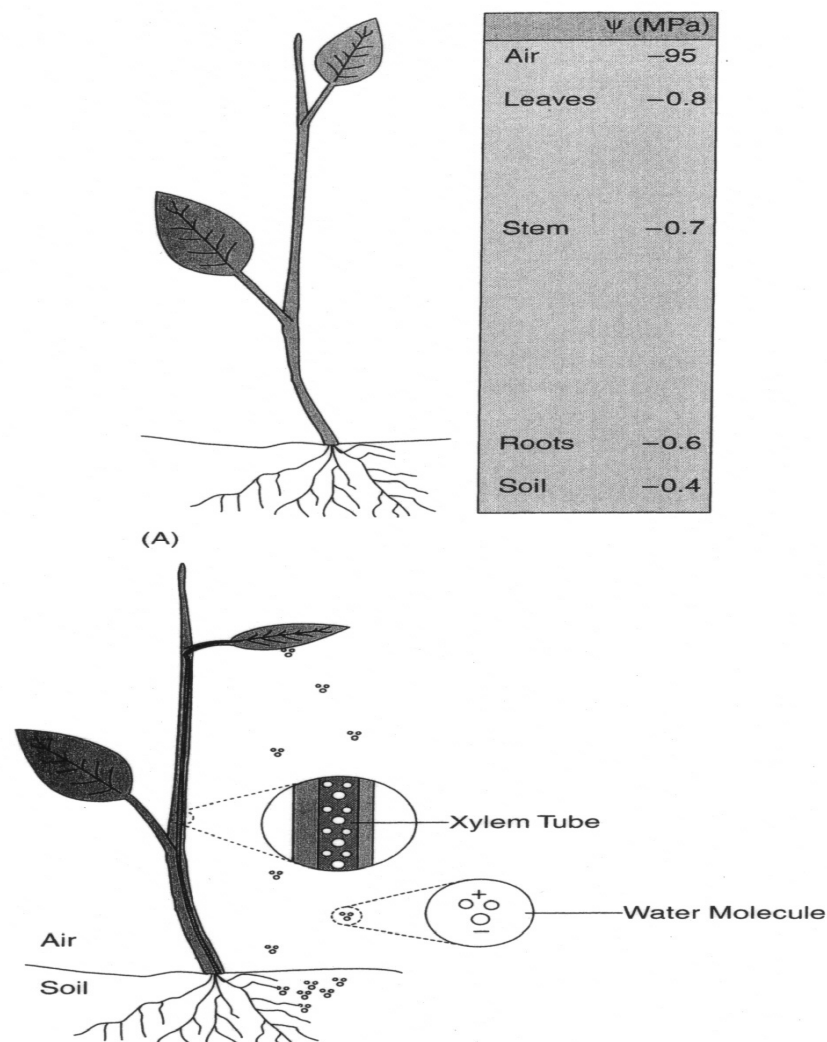
Figure 1: Absorption and conduction of water

The upward transport of water and dissolved minerals occurs mostly in the xylem, as shown in (Fig. 1). Due to transpiration is the principal cause of this upward movement, it is sometimes referred to as the transpiration stream (Ishikawa, 2020). The evaporation of water molecules from the outer surfaces of the mesophyll cells initiates the upward transpiration pull in the leaves (Silva & Lambers, 2021).

The concentration of a given element in root cells is 500 to 10,000 times that of the soil solution. If the main mechanism for taking up soil nutrients was diffusion, mineral nutrients would not get into the roots against such a large concentration gradient (Simler-Williamson et al., 2019). Furthermore, ion transport is generally blocked by cell plasma membranes. Energy is required to drive ions against a concentration gradient and through impenetrable barriers. Respiring starches and sugars created during photosynthetic processes provide this energy (Kuczyk et al., 2021).

2.2. Impact of Climate change on the plant-water interactions

It's problematic to trace environmental changes directly or exclusively to climate change's paraphernalia. When patterns are detected across many species rather than depending on studies of a few specific species, evidence of climate change's ecological implications becomes more convincing (Singh et al., 2018).

Two well-studied and well-documented general ecological implications of climate change that give a glimpse into the larger issue are climate-induced changes in species ranges and seasonal fluctuations in biological activities (known as phenology) or events. These kind of changes have been observed across extensive time periods in a wide range of animals and environments (Sullivan & Koski, 2021).

Other broad effects of climate change that affect many ecosystems include changes in growth rates, the relative abundance of various species, processes like water and nutrient cycle, and the risk of disturbance from fire, insects, and invasive species (Gebeyehu & Hirpo, 2019).

A). Range shift

Since the beginning of the present interglacial (warm) epoch, climate change has driven the most enormous movement of species that has occurred without direct human intervention (Brierley & Kingsford, 2009). Each species can survive and reproduce in a variety of environments. Species can only exist in places with temperatures, rainfall, and precipitation that they can withstand (Gerhard et al., 2001). The well-planned park, preserve, and refuge system of the United States may not function as intended in another hundred years (Chitonge & Mfune, 2015).

A). Seasonal Shifts

According to Change et al. (2002), climate change is also driving changes in phenology. Change et al. (2002) added that many biological events are timed based on seasonal cues, with most of the major ones occurring in the spring and autumn. Many studies looking at changes of the timing of spring events have found that over the last 30 to 40 years, various seasonal behaviors of numerous species now occur 15 to 20 days earlier than several decades ago (Kikvidze et al., 2006).

The types of changes include earlier arrival of migrant birds, earlier appearance of butterflies, and earlier flowering and budding of plants (Bertrand et al., 2019). Many trees, on the other hand, respond to a later arrival of fall by delaying the date their leaves turn color.

One of the main ways that climate change will impact plant performance is through changes in the availability of water. It is generally known that variations in water availability have an immediate impact on plant physiology (Regan et al., 2014). Decrease in fruits, and seeds may result from reduced plant capacity to sustain turgor and transpiration, to absorb nutrients, and through altered plant-microbial interactions in the soil.

Despite the fact that phenological responses to climate change being one of greatest visible and known living indicators of climate change in plants (Biasi *et al.*, 2019), there is need to know climatic factors that drive phenological responses to climate change (Peñuelas et al., 2004), and less attention has been paid to the fact that phenology is also responsive to other climatic (Peng et al., 2021).

Figure 2: Phonology in flowering plants by (Prevéy, 2020).

Findings from the (Figure 2) above show that precipitation is a key driver of phenological changes in desert ecosystems and this is in line with Prevéy (2020), and that future changes in precipitation could negate or even reverse the directionality of phenological responses to temperature in water-limited systems like this one.

2.2.1. Why Does it Matter How Plants Handle Water Scarcity?

Plants suffer from a lack of water or a suboptimal supply of water. Water deprivation responses in plants are complicated and pleiotropic (Zetland, 2011). A decrease in growth rate results in decreased plant vegetative biomass, particularly in the shoot, which lowers a plant's competitiveness relative to other plants and reduces or limits the plant's reserves that can be remobilized into reproductive tissues, which lowers a plant's competitiveness relative to other plants and decreases or limits the plant's reserves that can be remobilized into reproductive tissues (Zetland, 2011).

Drought is one of the most significant abiotic challenges that plants face. According to Ashraf, (2014), water stress impacts a variety of morphological and physiological activities in plants to maturity resulting in a significant reduction in agricultural production and productivity (Chourasia, 2017). Drought is defined as a

shortage of water that results in a loss of yield. Drought in agriculture occurs when the humidity source is insufficient to meet the crop's needs (Wilhite & Glantz, 1985).

Some plants, such as those cereals that make up the majority of the human diet, are more sensitive to water deficits that occur during their reproductive development (Han *et al.*, 2014). The plant's fitness and the yield of grain for animals to eat are both harmed by this reproductive sensitivity. Although we have made significant progress in understanding responses to water shortages, we are still far from being fully informed (Wutich, 2020). The following are some of the most common plant reactions to water shortages.

Severity and Timing of Water Deficit Affect Responses
One of the biggest challenges to understanding water-deficit responses comes from the fact that "water deficit" is difficult to define and to control experimentally. The water status of a plant varies considerably daily and seasonally especially in maize (Sah *et al.*, 2020).

Furthermore, the rate at which a plant experiences dehydration determines how it responds. Gradual water loss allows the plant to adjust metabolically and morphologically, and there may be little actual "stress" perceived (Xu *et al.*, 2016).
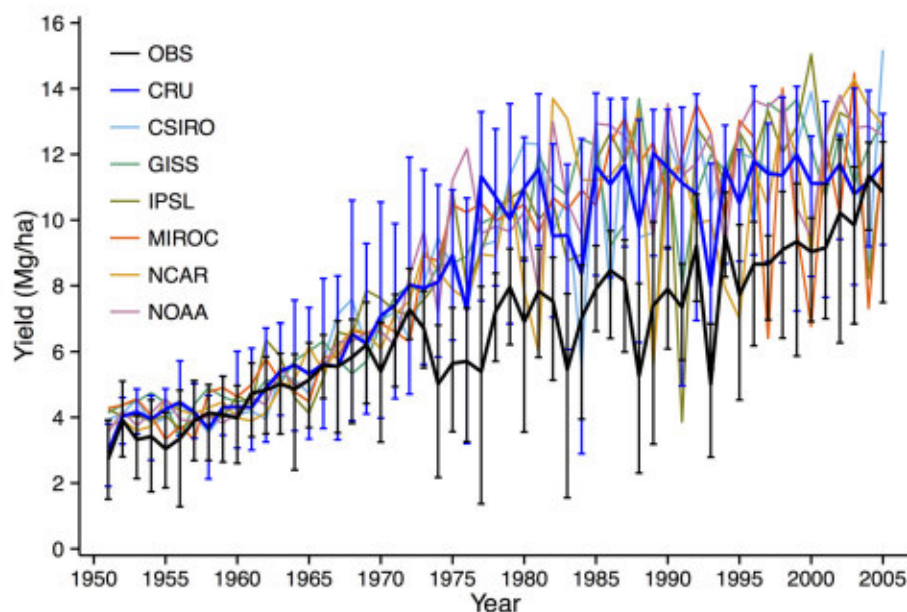

Figure 3: Maize yield and climate change (Xu *et al.*, 2016).

By contrast, a sudden loss of water (such as that sometimes encountered in controlled environment–grown plants when water is withheld) can cause damage before the plant can initiate protective responses. Furthermore, among and within species there is considerable genetic variation in water deficit responses. Nevertheless, we can recognize that there is a combination of responses commonly observed in most plants.

Water Deficit Signaling
Water deficiency is communicated throughout the plant's body. Shoots of well-watered plants, for example, respond to a water shortage provided solely to the roots (Christmann *et al.*, 2007). It's suspected that at least two distinct signals are involved.

When a root system is dehydrated, a shift in the xylem's water potential, known as a hydraulic signal, occurs, which is quickly transduced as a physical change throughout the hydraulic system (Mukarram et al., 2021). A self-contained, high-speed electrical system is also planned. The processes for transducing hydraulic and/or electrical impulses downstream are still unknown.

There's also evidence that roots with a lack of water produce the hormone abscisic acid (Arkhipova et al., 2020), which is transported to the shoot via the xylem. Both hydraulic signals and hormone abscisic acid have been shown to convey water-deficit information. Both contribute to the plant's acclimatization responses, however their respective contributions to various responses are still being debated (Tkemaladze & Makhashvili, 2016).
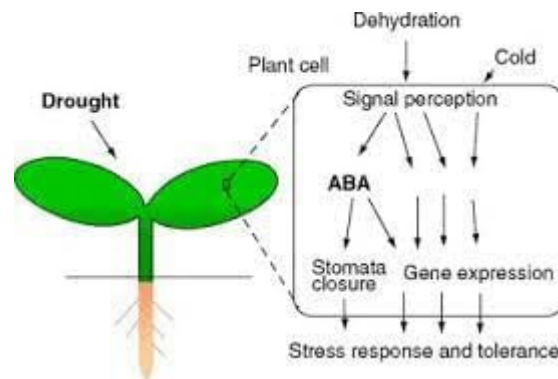
Figure 4: Plant cell physiological drought stress (Du Toit, 2005) as cited in Yamaguchi-Shinozaki (2002).

According to Yamaguchi-Shinozaki (2002), perception of the dehydration signal, signal transduction to the cytoplasm and nucleus, gene expression, and responses and tolerance to drought stress are all examples of molecular and cellular responses to drought stress. ABA (Plant Hormone Abscisic Acid) stands for abscisic acid (Kozlowski & Pallardy, 1997).

The most well-known physiological plant reaction is stomata closing in response to water deprivation. Water loss from leaves is reduced when stomata are closed (Yamaguchi-Shinozaki, 2002). In diverse plants, accumulation of numerous tiny compounds has been reported. Osmotic adjustment is assumed to be the function of these tiny molecules (Agnes et al., 2021).

Wan et al. (2011) noted that there are several genes that have been found to respond transcriptionally to drought stress. Their gene products are thought to contribute in stress tolerance and responsiveness (Figure 4). Stress-inducible genes have been used in gene transfer to increase the stress tolerance of plants. Analysis of stress-inducible gene activity is crucial for both improving crop stress resistance through gene manipulation and for a better understanding of the molecular mechanisms of stress tolerance and response in higher plants (Hsien et al., 2019).

Transcriptional Responses to Water Deficit

There is a plethora of effective tools for analyzing transcriptional responses to water deficiency. A few drought-sensitive cDNAs and genes were painstakingly cloned in the early days of plant molecular biology, revealing a collection of common promoter elements responsive to drought and ABA. ABA-responsive and ABA-independent transcription factors that respond to water deprivation have been found using this as a starting point (Safdarian et al., 2019).

Genomic technologies like as transcriptomics and proteomics, which provide a more global perspective of the plant's transcriptional and translational responses, have overtaken these early methodologies. The emerging picture is that drought or ABA controls thousands of osmotic regulation, hydraulic conductance, and cellular defense. These genes are regulated by a huge number of transcription factors in several families (Wang et al., 2022).

Drought Effects on Stomatal Conductance

In addition, the exchange of carbon and water between plants and the atmosphere is regulated by stomata and this protects plants from drying up. A decrease in stomatal conductance is a common and quick response to ABA or water deprivation in most plants (Gujjar et al., 2020).

Root-borne signals are not necessary to induce stomatal closure, and the stomatal closure response is tightly associated with leaf water status. A detached leaf, for example, has a far faster stomatal closure reaction than a potted plant deprived of water. In most plants, applying ABA directly to leaf petioles or epidermal strips containing guard cells is enough to seal the stomata.

Guard cells are also sensitive to the turgor and water potential of their surrounding cells, a characteristic that may be especially essential in lycophytes and ferns. Although these non-seed plants' genomes include the genes required for ABA signaling, their guard cells are often less responsive to ABA than seed plants'. There appears to be a developmentally mediated influence on ABA sensitivity; stomata of very young leaves appear to be relatively insensitive to ABA, but with exposure to dry air acquire ABA sensitivity, whereas stomata of very old leaves become less sensitive to ABA.

Guard cell responses to ABA accumulation have been studied in several model organisms using techniques ranging from electrophysiology to systems biology (Kruse et al., 2019). ABA activates signaling intermediates, including reactive oxygen species and cytoplasmic calcium, which cause the opening of some membrane localized ion channels.

Potassium and other ions leave the guard cells, and water follows osmotically. This reduces the turgor of

the guard cells and causes them to relax near one another, which closes the stomatal pore. Additionally, ABA prevents the reopening of stomatal pores (Gao et al., 2022).

Drought Effects on Photosynthesis

A reduction in the rate of CO_2 uptake in photosynthesis is another effect of stomatal closure (Cornic & Briantais, 1991). Stomata rarely close entirely, except in extreme circumstances; instead, as water scarcity increases, the stomatal aperture shrinks.

Importantly, the transition from fully open to partially closed stomata influences transpiration more than CO^2 assimilation during stomatal closure. This happens because CO_2 transport has an extra component (mesophyll resistance of the cell wall, plasma membrane, cytoplasm, chloroplast membranes, and stroma, among other things), whereas water does not face this resistance when it exits the intercellular gaps. Hence, as stomata close, the ratio of the two total resistance networks shifts in favor of increased CO_2 uptake per unit of water loss.

Effects of Water Deficit on Development and Change

Effects on Leaf Growth

The suppression of leaf development or expansion, which happens in both monocots and dicots, is one of the most severe and repeatable impacts of drought. Inhibition of leaf expansion can generate secondary dry impacts, such as a reduction in whole-plant photosynthetic rate and seed production, in addition to being an early sign of water deprivation.

There have been various theories proposed to explain why leaf expansion ceases, and this is still a hot topic of research. This is because leaf expansion arrest occurs at a lower water deficit than photosynthesis arrest, it's doubtful that leaf expansive development is limited by a lack of accessible fixed carbon as an energy source, at least during mild drought.

In reality, multiple investigations have shown that the concentration of sugars rises under certain conditions during mild drought stress, possibly as a result of reduced cellular growth or as an osmoregulatory response. Perhaps a reduction in leaf development rate confers a fitness benefit, with the result that water use is reduced when this resource becomes scarce.

It also has the potential to redirect energy away from growth and toward drought adaptation processes. Another theory proposes that the cessation of leaf expansion is due to a hydraulic mechanical constraint, either due to a reduction in water input into developing cells or due to the tendency of cell walls to stiffen under stress.

Finally, there is some indication that hormones like ABA, ethylene, and gibberellins have a role in these reactions, but the exact location and mechanism are unknown (Wullschleger et al., 2002).

Root Responses to Water Deficit

Because most vascular plants get their water from the earth through their roots, it's not surprising that roots are sensitive to water shortages (Bray, 1997). Benešová et al. (2012) found that the nature of the response varies depending on the plant and the severity of the drought stress, but common responses include preferential preservation of the primary root's elongation (as a mechanism to reach water deeper in the soil), a more positive gravitropic curvature of roots (toward deeper water), a hydrotropic growth response (toward more abundant water), and a proliferation of lateral roots in the deeper soil zone (under mild deficits).

The persistence of primary root elongation under water deficit, even at water potentials that fully block shoot growth, is one of the most well-studied of these responses. ABA is known to play a role in mediating this reaction. This acclamatory reaction is aided by an accumulation of proline and other osmolytes in the elongating cells of the root tip, as well as an increase in the cell wall extensibility of these cells. The rate at which water travels through the root and shoot tissues might be affected by a lack of water.

Water Deficit Effects on Reproductive Development

The reproductive phase of many cereals is particularly susceptible to water shortages (Loka, 2012), and short drought episodes during critical developmental phases can have a significant impact on seed yields (Atti et al., 2004). Drought has a significant impact on the formation of the female stigma (the silk) in maize, resulting in a desynchronization of male and female blooming (Carrizo García et al., 2017).

Furthermore, ovule formation is drought-sensitive, and ovules may abort if the plant runs out of water during this time (Li & Zhang, 2022). Ovule abortion, according to some research, is caused by a lack of carbohydrate nourishment for the growing seed; ovule abortion can be avoided by feeding sucrose to the stem linked with the developing ear (Sita et al., 2017).

Pollen formation in rice (*Oryza sativa*) and wheat (*Triticum aestivum*) is very sensitive to water deficit, which may potentially be mediated by carbohydrate constraint (Saini & Westgate, 1999). In rice and wheat, the activity of the enzyme invertase (which hydrolyzes sucrose) and sugar transporters has been linked to reproductive resistance to drought stress (Dolferus et al., 2011).

The discovery of the molecular pathways behind reproductive vulnerability paves the way for genetic interventions to improve reproductive tolerance (Malhi et al., 2021). The graph below illustrates how dryness has a significant impact on seed production (Dolferus et al., 2013).

Abiotic stress has a considerable impact on grain number at young stage. Inflorescences under normal conditions are shown on the left, while those under stress are shown on the right (Dolferus et al., 2013).

Conclusion

Worldwide atmospheric CO_2 concentrations have risen and average global temperatures have risen since the Industrial Revolution, with the most pronounced effects occurring near the poles. As the hydrologic cycle intensifies, precipitation regimes are expected to shift on a regional scale, resulting in greater extremes in dry versus wet conditions, and such changes are already having profound effects on plant physiological functioning, which scale up to influence interactions between plants and other organisms, as well as ecosystems as a whole.

Climate change's effects on plant-water interactions vary across spatial-temporal events, with several negative implications. When the soil water potential near the root diminishes, a plant may not be able to fully meet the transpiration requirement and so enters a phase of water stress, which is accompanied by turgor in the tissue and can impact growth. As the growth slows, so does the respiration associate with it.

Authors' contributions

Benson Turyasingura (MSc. Climate Smart Agriculture at Haramaya University, Ethiopia), mainly did the preliminary article review, writing and some interpretation. **Prof. Natal Ayiga** mainly designed this work and revised the paper totally. The authors read and approved the final manuscript.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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