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Water Deficit and Excess and the Main Physiological Disorders in Agricultural Crops

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Abstract

The comprehension of the precise water consumption of agricultural crops is a valuable tool for establishing management programs and irrigation schedules. Appropriately, the purpose of this study was to promote a bibliographic review on the main reflexes of the inappropriate use of water and what this process can promote in the establishment and development of agricultural crops. Moreover, theoretical questions were raised regarding physiological responses triggered by soil water deficit and its effect on crop growth, critical periods for water deficit, physiological responses, and their effects on the growth of main agricultural crops. Information on the misuse of water resources and its effects have presented a series of manifestations to plants and, consequently, to agricultural production, such as a production depletion, reduction of carbon fixation, nutritional deficiency, reduction of plant height, reduction of thousand-grain weight, yellowing of leaves, reduction in germination percentage, among other factors. Correspondingly, water stress can cause a drastic reduction in leaf area, productivity decrease, stomatal closure, leaf senescence, reduced roots, reduced flowering, hampering crop emergence and stability, spikelet sterility, etc. Finally, studies aimed at the consequences of poor irrigation and/or inadequate precipitation values are of high importance, mainly due to the investigative improvement on the use of water in an effective and sustainable way.

Keywords: plant morphoagronomic parameters, plant physiological processes, sustainability, water resources rational use

1. Introduction

In agricultural production, the climatic influence normally occurs with the rain establishment to the full crop development in different phenological phases and negatively when the weather comes from droughts, extreme rains, and hail (Duarte & Wollmann, 2021). Furthermore, there is a significant concern about the knowledge of the correct and ration water resources application and how this strategy has not been respected over the years. Accordingly, Figure 1 indicated the main steps according to the water absorption and transpiration in plant and leaf perspectives.

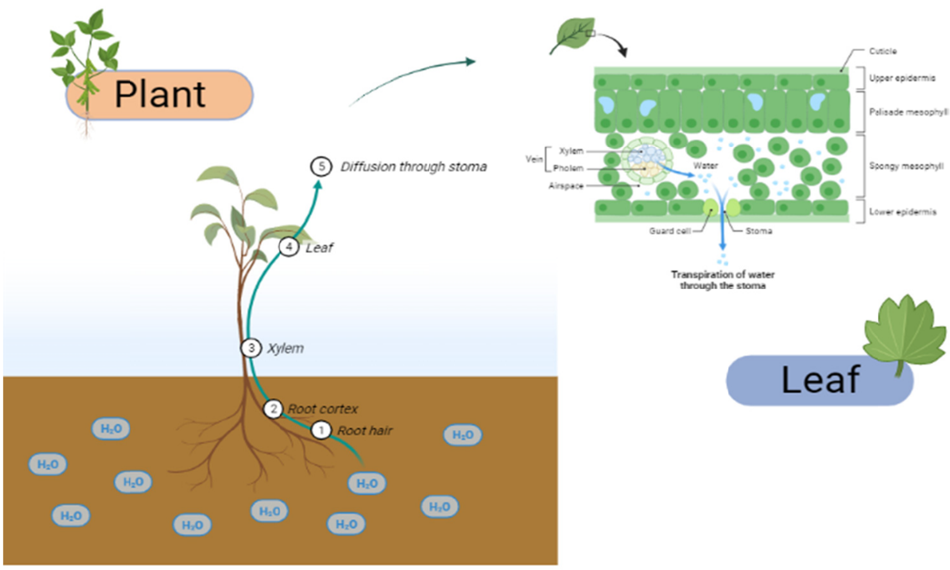

Figure 1. Water performance and main steps in plant and leaf perspectives

Appropriately, a reduced portion of the water, of the amount absorbed by the roots, remains in the plant structures to supply growth (±2%), or to be explored in the biochemical reactions of photosynthesis, or in other metabolic processes (±1%). The main process affected by water deficit is cell growth, which causes reductions in stem growth and leaf expansion, stimulating the elongation of the root system (Taiz & Zeiger, 2017).

Also, the internal moisture of plant tissues influences many physiological processes, a plant under water stress has affected water absorption, stomatal closure, transpiration, photosynthesis, enzymatic activity, and nitrogen metabolism, among others. Furthermore, water stress results in a strong minimization of plant growth, damaged organelle structures, degradation of pigmentation resulting from the action of chlorophyll, and premature physiological maturation (Ying et al., 2015). There is evidence that the effect of water stress influences plant growth through direct and indirect mechanisms, altering hormonal and nutritional relationships and the synthesis of the carbohydrate (Taiz & Zeiger, 2017). Moreover, the reduction in photosynthetic potential caused by water stress is directly caused by the attenuation of the chlorophyll content. As a result, the stomata close to prevent water loss, preventing the entry of CO_2 and drastically affecting the chlorophyll rate (Ashrafi et al., 2022). Under stress conditions, stomatal closure causes contraction of net photosynthesis, as a function of reduced stomatal conductance, chlorophyll fluorescence, and leaf chlorophyll content (Nemeskéri & Helyes, 2019). In order to supply their metabolic requirements, plants require to renew the water that has been transferred to the atmosphere, to maintain the turgidity of their leaves and roots in order to ensure their survival, so the water loss through transpiration must be replaced by absorption (Araújo Júnior, 2019). Contextually, Figure 2 indicated the main phenomena about the water process from the atmosphere to the contact with the plant and the transpiration procedure.

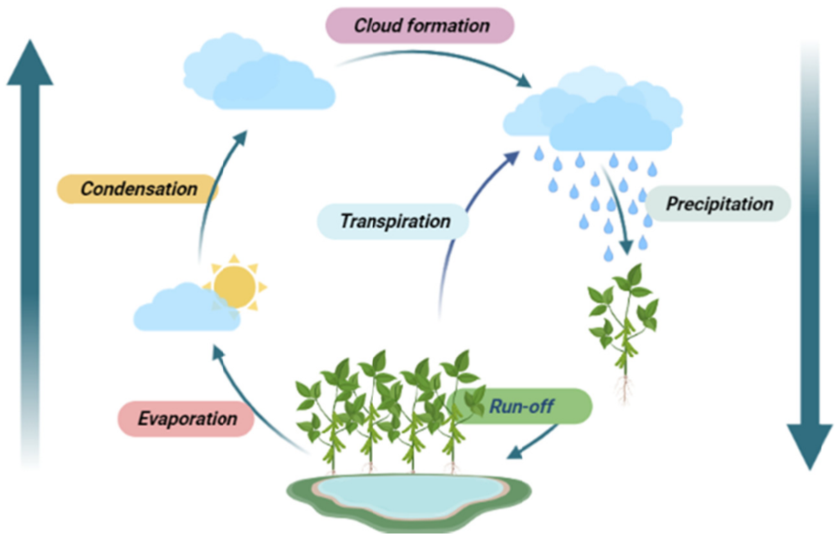

Figure 2. Water cycle and the main phenomena involving plants and its processes

Regarding excess soil water, plants produce metabolic signals of various types in response to decreased oxygen levels (Medeiros, 2021). Accordingly, plants develop anatomical and morphological structures, such as the formation of aerenchyma and the production of adventitious roots (Loose et al., 2017).

As for plant nutrient responses to excess water, they generally differ between species (Li et al., 2018), and the mechanisms still remain undefined (Huang et al., 2019). Studies focused on water excess and deficit become of significant relevance since for each culture there is a necessary amount of water during its development cycle. Correspondingly, the purpose of this study was to promote a bibliographic review on the main reflexes of the water recourses applications and what this process can promote in the establishment and development of agricultural crops.

2. Physiological Responses by Soil Water Deficit and Its Effect on Crops Growth

Water deficit influences aspects related to plant development, reducing leaf area, decreasing photosynthesis, and interfering in several other processes, additionally to altering the crop physical environment (Bergamaschi, 1992). The effects caused are due to changes in the anatomy, morphology, physiology, and biochemistry of plants (Taiz & Zeiger, 2017). A variety of physiological and morphological processes are affected by the lack of water, such as gas exchange between plants and the external environment, cell death, morphophysiological alteration, modification in the rates of translocation and assimilation of nutrients, genetic content, lipid proportions, metabolites, protein, and the antioxidant potential (Santos et al., 2022). Also, excess water available to plants promotes the production of reactive oxygen species (ROS) in high unbalanced proportions. ROS are significantly toxic to organisms and affect the biological processes of plants, since they act in the disorder of stomata and membranes, alterations in photosynthetic systems and metabolic reactions involving proteins, nucleic acids, and lipids (Biareh et al., 2022).

Moreover, under water stress, plant hormones, mainly ethylene and abscisic acid (ABA), are related to morphological and physiological alterations in plants (Dutra et al., 2012). The ABA level increases in plants stressed by a lack of H_2O. This scenario can stimulate stomatal closure and decrease the root/shoot ratio. The lack of O_2 accelerates the production of ACC (1-aminocyclopropane-1-carboxylic acid) which is the precursor of ethylene. ACC is carried from the root to the shoot and in the presence of O_2 is converted to ethylene, which can lead to shooting elongation, epinasty, leaf abscission, senescence, and loss of chlorophyll (Taiz & Zeiger, 2017). Additionally, water stress promotes the closing of stomata, causing an increase in leaf temperature, reducing the rate of transpiration and CO_2 absorption (Maimaitiyiming et al., 2017).

In maize, the occurrence of water stress at critical moments in crop development causes several losses (Guimarães et al., 2019). The water deficiency decreases leaf area, the ability to compete for light, and the photosynthetic rate, which results in an acceleration of the rate of leaf senescence, as well as a delay in plant growth and development, causing a significant reduction in productivity (Araújo et al., 2012; Santos et al., 2018).

Soybean at the morphological level can show changes in the shoot and root zone. These alterations are more frequent when plants are subjected to long periods of drought, which may include a reduction in trifoliate leaves (Mangena, 2018) and a reduction in plant size and root volume (Mesquita, 2018). These morphophysiological changes reduce the percentage of flowering, pod formation, and other yield components (Battisti et al., 2018).

Consequently, they increase the premature fall of flowers and cause the abortion of pods and the "slump" of grains (Monteiro, 2009). Stress during soybean growth can achieve yield reductions of between 46 and 74% (Battisti et al., 2018).

In wheat, it can difficult the crop emergence and establishment. The rubber can harm the final yield, due to the increase in the sterility of flowers and incomplete filling of the grains (Monteiro, 2009).

In rice, water deficiency interferes with many physiological processes with a significant impact on the production of phytomass and grain yield (Monteiro, 2009). Also, it causes several biochemical and morphological alterations in plants, such as a reduction in the stomatal opening, CO_2 absorption, and photosynthetic rate, reflecting negative effects on the vigor, height, and grain yield (Bota et al., 2004). Considering the reproductive phase, panicles are poorly exposed and/or not emitted. Along with the inhibition of anthesis, which leads to high sterility of spikelets. Spikelet fertility is the component that has the highest correlation with grain yield, under water deficit conditions in the reproductive phase (Pinheiro et al., 2000).

In beans, water deficit generates changes in its phenology, whereas Lopes et al. (1986) observed a decrease in the cycle, under conditions of water deficiency, anticipating maturation after the emission of the first plants. Furthermore, its cycle increases, when it occurs during the formation of flower buds and flowering (Monteiro, 2009). Where stomatal resistance and respiratory rate increased and where net photosynthetic rate, plant height, the number of leaflets, and leaf area decreased (Costa et al., 1991). A lack of water reduces turgidity, and subsequently cell expansion, which, in turn, reduces stem and leaf elongation (Monteiro, 2009).

3. Physiological Responses Released by Soil Excess Water and Its Effect on Crop Growth

One of the significant alterations that occur due to excess water related to metabolism is that anoxia causes a drop in the production of ATP (adenosine triphosphate) in plants, which results in low C fixation by photosynthesis. With anoxic stress, ATP production occurs through fermentation and glycolysis pathways (Henrique, 2010). In maize, while the growing point is below ground level, plants will be sensitive to flooding and tend to die from lack of oxygen if waterlogging occurs for a prolonged period (Monteiro, 2009).

Under water excess conditions, the signals originating from the root system are transferred to the soil, causing the stomata to close and, consequently, minimizing the photosynthetic rate and the absorption and assimilation of CO2 (Wu et al., 2022). Moreover, water stress results in a significant accumulation of osmolytes in plants, decreasing the plant osmotic potential to maintain water status and physiological activities required by plants (Mukherjee et al., 2022). Additionally, gas exchange is considerably lower in soils with excess water, driven by the effects of plant and root respiration and low O_2 concentrations (Dash et al., 2022).

In soybean, this variable results in smaller plants, with small, yellowish leaves, short internodes, adventitious roots, and nodules on the soil surface, with the base of the stem showing spongy tissue (aerenchyma). Prolonged periods of soil layer saturation, cloudy days, and low evaporative demand from the atmosphere, reduce plant growth and leaf area. During the growing season, flooding can impair microbiological activity and biological nitrogen fixation, with reflections on grain quality and productivity (Monteiro, 2009).

In wheat, excess soil water has a negative effect on the weight of a thousand grains and on crop productivity (Guarienti et al., 2005). Furthermore, the common bean plant is relatively sensitive to excess water, so it does not support soil excess water, even for short periods (Vieira, 1978). In periods of frequent and/or intense rainfall or excessive irrigation, it impairs its metabolism, restricting its production potential (Silva et al., 2006). Excess water is extremely harmful to the emergence and preservation of grains after physiological maturation (Silva et al., 2006). Finally, considering the rice plant, excess water in the crop in the early stages can cause a reduction in germination percentages, seedling drowning, and tiller abortion (Santos & Rabelo, 2008).

4. Critical Periods for Soil Excess Water

In maize, the critical period to excess water occurs at the beginning of the cycle, while the growth point is below ground level (Monteiro, 2009). In soybean, H_2O is important in germination-emergence, at this stage, the water content in the soil should not exceed 85% of the maximum available total water (Monteiro, 2009).

For wheat, Guarienti et al. (2005) indicated that excess soil water negatively affected hectoliter weight in periods 1-10 and 11-20 days before harvest. The authors expressed that the grain yield was affected by this variable in periods 11-20 and 61-70 days prior to harvest. Accordingly, the 1000-grain weight was negatively influenced by the soil water excess, in the periods of 31-40 and 51-60 days prior to harvest. Furthermore, a reduction in grain yield in the period of 61-70 days prior to harvest was observed. In beans, it is extremely harmful to emergence (Silva et al., 2006). In rice fields, it is harmful in the early stages, causing a reduction in germination percentages, seedling drowning, and tiller abortion (Santos & Rabelo, 2008).

5. Conclusions

Information regarding the incorrect management of water resources entails in the development of agricultural crops indicated that it can cause serious disadvantages for the crop production, reduction of carbon fixation, nutritional deficiency, reduction of plant height, reduction of the 1000-grain weight, yellowing of leaves, and reduction in germination percentage, among other factors. Accordingly, the water stress phenomenon establishes a reduced leaf area, reduced productivity, stomatal closure, leaf senescence, reduced roots, reduced flowering, hampering the emergence and stability of the crop, and sterility of spikelets, etc. Correspondingly, future studies on the consequences of poor irrigation and/or inadequate precipitation values (very dry or very rainy years) are significantly relevant, as they improve the investigative sense of information about the use of water in responsible and efficient perspectives.

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