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Establishment of corn plants under different water regiments

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Abstract: The objective of this study was to identify the effect of water availability on corn plant growth. The study was carried out in greenhouse located at the State University of Goiás, Brazil, South-East Campus Ipameri. Four corn seeds 2A401P hybrid were planted in each polyethylene pot containing 8 kg substrate consisting of soil, sand and manure at the proportion of 3:1:1, respectively. A completely randomized design was used with six treatments and six replications. After emergence and initial development, the plants were irrigated with volumes of water corresponding to 0% (0ml), 25% (80 ml), 50% (160 ml), 100% (320 ml), 200% (640 ml) and 400% (1280 ml) of the daily crop evapotranspiration at 23 days after emergence. At 31 days after emergence the following variables were analyzed: number of leaves, plant height, stem diameter, total biomass, root mass ratio, stem mass ratio, leaf mass ratio, photosynthetic pigments, relative water content, transpiration rate and chlorophyll *a* fluorescence. Water shortage and flooding inhibited corn plant growth of 2A401P hybrid and thus damaged the establishment of the crop, but at different intensities, because water shortage was shown to be much more restrictive to plant growth than flooding. Furthermore, it is pointed out that corn plants are isohydric, because they anticipate water shortage by an efficient stomata sensitivity that controls water loss by transpiration. Considering the results of corn plants growth, is recommended that it be irrigated with a volume of water corresponding to 200% of the daily evapotranspiration.

Keywords: *Zea mays,* Flooding, Drought.

Estabelecimento de plantas de milho sob diferentes regimes hídricos

Resumo: O objetivo deste estudo foi identificar o efeito da disponibilidade de água no crescimento da planta de milho. O estudo foi realizado em casa de vegetação localizada na Universidade Estadual de Goiás, Brasil, Campus Sudeste de Ipameri. Quatro sementes de milho do híbrido 2A401P foram plantadas em cada vaso de polietileno contendo 8 kg de substrato constituído de solo, areia e esterco na proporção de 3: 1: 1, respectivamente. O delineamento inteiramente casualizado foi utilizado com seis tratamentos e seis repetições. Após a emergência e desenvolvimento inicial, as plantas foram irrigadas com volumes de água correspondentes a 0% (0ml), 25% (80 ml), 50% (160 ml), 100% (320 ml), 200% (640 ml) and 400% (1280 ml) da evapotranspiração diária da cultura aos 23 dias após a emergência. Aos 31 dias após a emergência, as seguintes variáveis foram analisadas: número de folhas, altura da planta, diâmetro do caule, biomassa total, proporção da massa da raiz, proporção da massa do caule, proporção da massa da folha, pigmentos fotossintéticos, teor de água relativo, taxa de transpiração e fluorescência da clorofila a. A escassez de água e as inundações inibiram o crescimento das plantas de milho do híbrido 2A401P e, portanto, prejudicaram o estabelecimento da cultura, mas em intensidades diferentes, pois a escassez de água se mostrou muito mais restritiva ao crescimento das plantas do que as inundações. Além disso, destaca-se que as plantas de milho são isoídricas, pois antecipam a escassez hídrica por meio de uma sensibilidade estomática eficiente que controla a perda de água pela transpiração. Considerando os resultados do crescimento das plantas de milho, recomenda-se que seja irrigado com um volume de água correspondente a 200% da evapotranspiração diária.

Palavras chave: *Zea mays,* Inundação, Seca.

Introduction

Corn (*Zea mays)* one of the most important cereals in the world socially and economically because it helps to create employment, income and foodstuff. The corn grain is important in human and animal nutrition. It is used in typical Brazilian dishes and animal feed because it is rich in nutrients and proteins (Mutlu et al., 2018). The main world producers of this cereal are the United States and China, followed by Brazil in third place, Food and Agriculture Organization Corporate Statistical Database [Faostat] (2019).

The National Supply Company [CONAB] carried surveyed yield in the 2018/2019 harvest in Brazil and estimated 99.984 million tons of corn. The two main producing regions of Brazil are the central west and the south, especially the states of Mato Grosso, Paraná, Mato Grosso do Sul and Goiás. The area cropped with corn corresponds to 4.9 million ha in the first harvest in the period of abundant rainfall and 12.3 million ha are cropped in the second harvest or the growing season with little rainfall. Increases of 7.8% in the cultivated area are projected for 2027 (CONAB, 2020 & Brasil**,** 2017).

In Brazil corn is cropped in the first harvest period with a high water volume and in the second harvest period when water availability is limited and thus the species is subject to intermittent periods of flooding and water shortage (Fornasiere, 2007). Water is the most abundant and limiting resource for agricultural production, because it is essential in fundamental processes including seed germination, nutrient dilution and absorption, cellular lengthening, metabolic reactions and others (Johnová et al., 2016 & Matos et al., 2019). Excess water and restriction of this resource can limit the corn plant establishment and growth (Andrea et al., 2018). Furthermore, variation in water availability, considered a primary restriction, reduces yield and quality of the cereals produced, such as corn (Dejonge et al., 2015 & Santana et al., 2017).

The biggest production losses in corn are observed when water shortage occurs at the reproductive stage because it affects fertilization, grain number and grain swelling (Yin et al., 2016). However, it can be observed that in the establishment stages, between germination and initial growth, the development of the species may be damaged by water shortage caused by droughts or by excess rainfall, at the start of the second harvest. Corn is a plant with a C4 photosynthetic metabolism with a certain tolerance to water shortage and therefore is one of the species preferred for the second harvest period which is characterized by low water availability, but the grain yield depends on the soil water storage capacity, evapotranspiration, tolerance of the plant material used and other factors (Paterniani et al., 2019).

Water supply for the crop may totally affect yield, so that it is necessary to understand the plant response to the water regime. Thus, research is fundamental to detect the morphological responses of the plant for greater agricultural development and generation of new technologies. The objective of the present study was to identify the effect of water availability on corn plant growth.

Material and methods

The study was carried out in a greenhouse covered with transparent plastic and with side panels that intercepted 50% of the solar radiation at the State University of Goiás, *Campus* Sudeste, UnU-Ipameri (Lat. 17º 43 '19 ”S, Long. 48º 09 '35 ”W, altitude 773 m, Ipameri, Goiás, Brazil). This region has a tropical climate with dry winter and humid summer (Aw) according to the Köppen classification (Alvares et al., 2013). Four hybrid corn seeds 2A401PW for grain production were planted per polyethylene pot containing 8 kg substrate composed of soil, sand and manure in the proportion of 3: 1: 1, respectively. The chemical analysis of the mixture revealed the following values: pH (CaCl2) 5.4; 16 g dm^{-3} organic matter; 68 mg dm^{-3} P; 6.81 mmolc dm^{-3} K (Mehlich-1); 22 mmolc dm^{-3} (Buffer SMP) H + Al; 31 mmolc dm^{-3} Ca; 15 mmolc dm^{-3} Mg; 53 mmolc dm^{-3} SB; 75 mmolc dm^{-3} CTC; and 71% base saturation.

The seedlings were initially irrigated daily with a volume of water corresponding to 100% of the daily evapotranspiration until 23 days after emergence (DAE). At 23 DAE, the plants were thinned leaving only the most vigorous plant in the pot and at this same age, treatments were applied for eight days. The plants were irrigated with water volumes referring to 0%, 25%, 50%, 100%, 200% and 400% daily crop evapotranspiration, corresponding to 0 ml, 80 ml, 160 ml, 320 ml, 640 ml and 1280 ml respectively. A completely randomized design with six treatments and six replications was used.

As the crop coefficient (kc) for corn has not yet been determined for the region of Ipameri, GO., we used the kc equal to 1.00 following the Food and Agriculture Organization [FAO] 56 estimate (Allen et al., 1998) for a group of crops at the initial growth stage. The volume of water supplied was estimated by determining the reference evapotranspiration and the crop coefficient. The evapotranspiration of the crop was determined by the following equation

ETc = ETo x kc

Where:

ETc = culture evapotranspiration

kc = crop coefficient

ETo = Reference evapotranspiration

The daily ETo was calculated by the Penman-Monteith method recommended by FAO (Smith et al., 1991) using the daily data on maximum and minimum air temperature, relative humidity, insolation and wind speed obtained at the National Institute of Meteorology [INMET] Meteorological Station located in the municipality of Ipameri, GO.

At 31 DAE, the following variables were analyzed: plant height, stem diameter, number of leaves, total biomass, leaf mass ratio (RMF), stem mass ratio (RMC), root mass ratio (RMR), photosynthetic pigments, relative water content (TRA), transpiration rate and chlorophyll a fluorescence.

Growth Variables

Plant height was measured from the root-stem transition region at soil level (crown) to the tip of the stem using a graded ruler. The stem diameter was measured at the crown with a digital pachymeter. The number of leaves was obtained by counting. The roots, stems and leaves were separated and dried in an oven at 72 ºC until constant dry weight and then weighed. The dry matter data were used to calculate the biomass, root mass ratio, stem mass ratio and leaf mass ratio.

Photosynthetic Pigments

To determine the total chlorophylls and carotenoid concentrations, 0.6 mm diameter leaf discs were removed from completely opened leaves and placed in test tubes containing dimethyl sulfoxide (DMSO). Then extraction was carried out in a water bath at 65 °C for one hour. Aliquots were removed for spectrophotometric reading at 480, 649 and 665 nm. Then the contents of chlorophyll a (Cl *a*), chlorophyll b (Cl *b*) and total carotenoids (Car) were determined according to the equation proposed by Wellburn (1994).

Relative Water Content

To obtain the relative water content, five 1.2 cm diameter leaf discs were removed from fully expanded leaves, weighed to record the fresh mass (FM) and placed to saturate for 24 hours in petri dishes with distilled water when they were again weighed and the turgid mass (TM) determined, then placed to dry at a temperature of 70 ºC for 72 hours, after which the dry mass (DM) was obtained and then the relative water content was calculated following the equation: [(FM - DM) / (TM - DM) x 100].

Transpiration

The total daily transpiration of the plant was measured by the difference in pot weight. Initially each pot was inserted into a plastic bag fixed to the plant stem with a rubber band, leaving only the aerial part (leaves and stem) outside the bag, then the set of plant and plastic bag were weighed (mass 01), and 24 hours later weighed again (mass 02). Total sweating was estimated by the difference between mass 01 and mass 02.

Fluorescence

Chlorophyll *a* fluorescence was analyzed with six readings using a portable fluorometer (JUNIOR-PAM (Walz, Germany)) at 4 am with 0.3 second light saturation pulse emission under 0.6 KHz frequency, at 30 days after implementing the water regimes. The fluorescence data were computed using the software, WinControl-3.

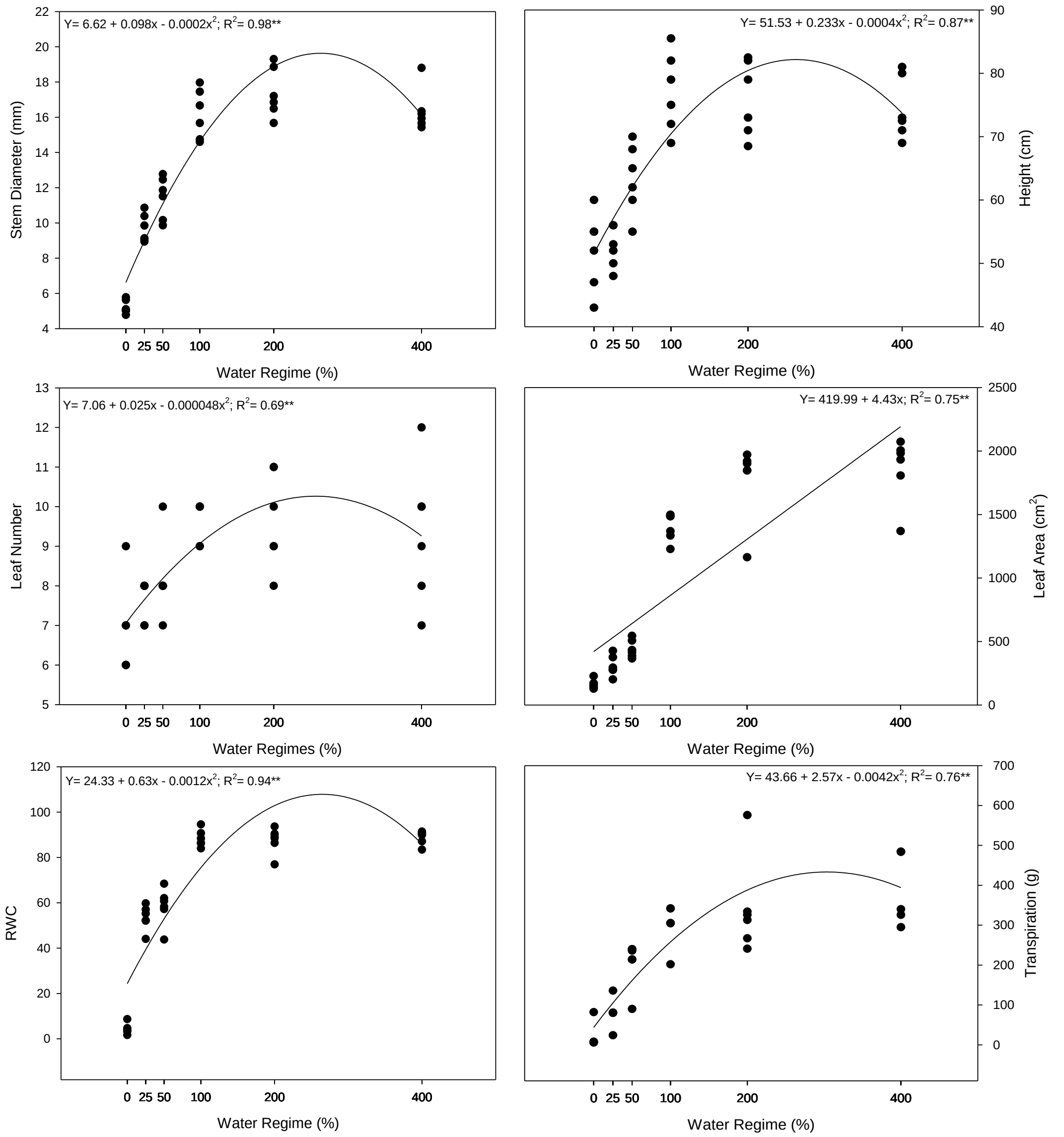
Statistical Procedures

The variables were submitted regression analysis using the software SigmaPlot10 (Sysstat, 2006). Multivariate analysis was carried out by multiple regression using the *forward stepwise* model (Sokal & Rolf, 1995) in the Statistical software (Statsoft, 2007).

Results

The data for stem diameter, plant height, leaf number, relative water content and transpiration were fitted to following the quadratic regression model while the leaf area was fitted to the linear model (Figure 1).

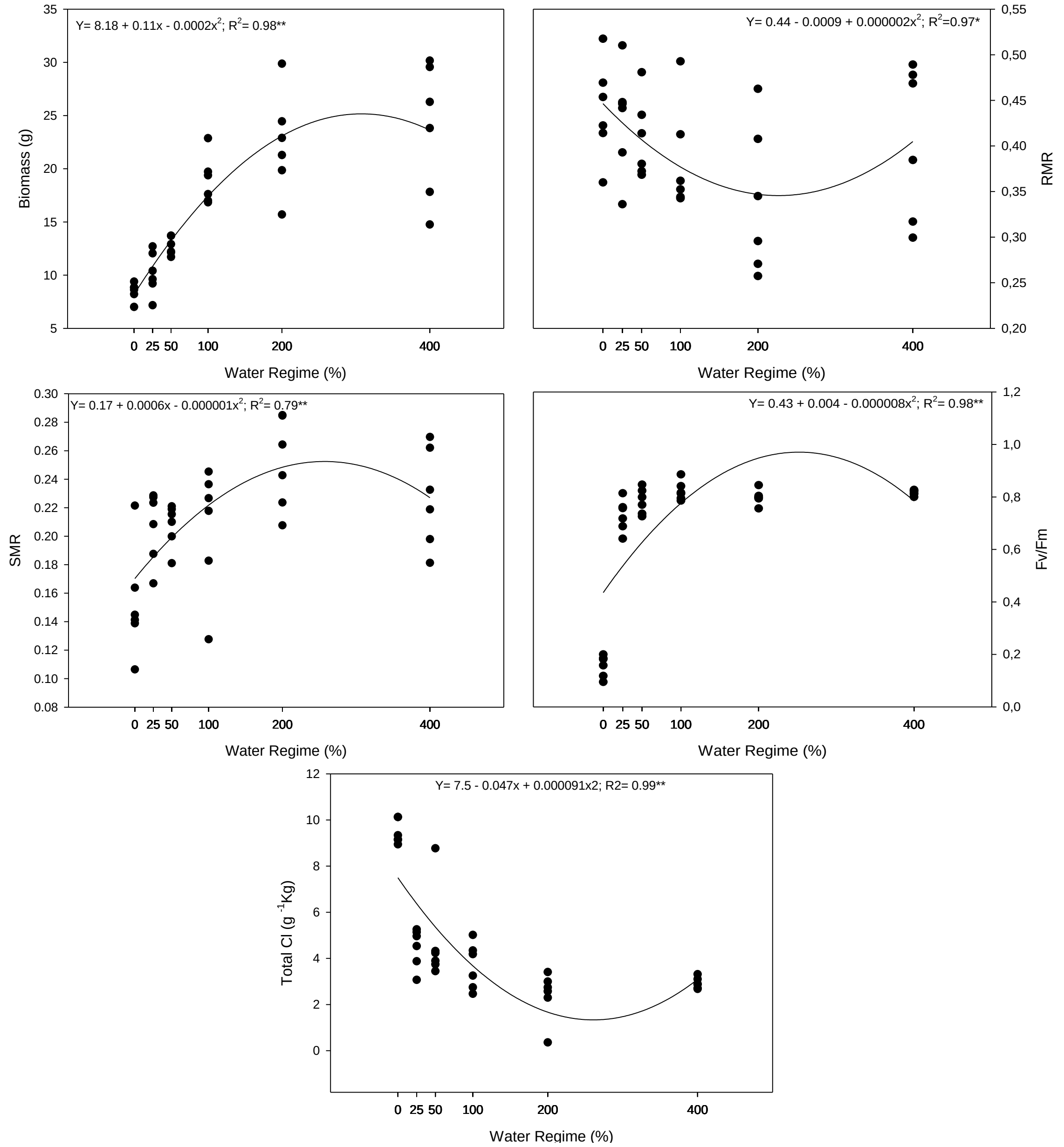
Figure 1 - Regression for the variables stem diameter, plant height, number of leaves, leaf area, relative water content (RWC) and transpiration in corn plants submitted to different water regimes.



The results indicated significant increases in the stem diameter, plant height and number of leaves with increase in available water and the maximum values were obtained at the water supply volumes of 245%, 291% and 260%, respectively. The biggest values of relative water value and transpiration were achieved with water regimes of 262% and 306%, respectively. In the treatment with 400% water supply there were reductions in stem diameter, plant height, number of leaves, relative water content and transpiration.

The biomass, stem mass ratio and maximum FSII (Fv/Fm) quantic efficiency reached maximum values under the 275%, 300% and 250% water regimes, respectively, while the root mass ratio and leaf concentration of total chlorophylls were largest under water shortage without water supply (Figure 2).

Figure 2 - Regression to biomass, root mass ratio (RMR), stem mass ratio (RMC), maximum FSII quantum efficiency (Fv/Fm) and total chlorophyll (total Cl) in corn plants submitted to different water regimes.



The principal components analysis shown in Figure 3 represented 78.7% of the variation in the data analyzed and showed that the growth was shown to be dependent on the volume of water, as demonstrated on axis I. Analysis of axis 2 indicated that the positive points on this axis represented greater biomass participation in the root system of these plants while below this axis represented plants with bigger leaf area. The multiple regression analysis in Table 1 showed that 91% of the variation in the biomass was due to alterations in leaf area, root mass ratio and plant height.

Figure 3 - Principal component analysis for ordering the variables analyzed in corn plants submitted to different water regimes.

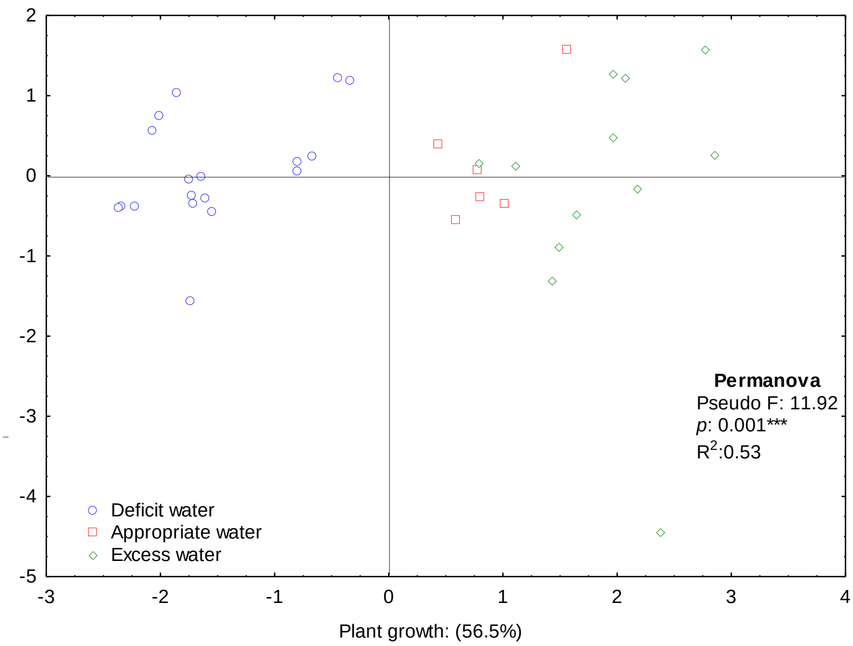


Table 1 - Multiple regression model to evaluate the importance of the variables analyzed on total biomass in irrigated corn plants with different water volumes.

Biomass	R²= 0,91		F (05,30) =75,1		p<0,0000	
	Beta	Std.Err. of Beta	B	Std.Err. of B	t (30)	p-level
Intercept			-4.56	8.50	-0.54	0.596
Leaf area	0.80	0.10	0.01	0.00	8.12	0.000
Root mass ratio	0.20	0.10	20.19	9.38	2.15	0.040
Plant height	0.19	0.09	0.11	0.05	2.06	0.049
Root Length	0.09	0.05	0.07	0.04	1.82	0.079
Leaf mass ratio	-0.11	0.09	-14.60	11.33	-1.29	0.207

Source: The Authors

Discussion

The results obtained in the present study showed concisely and significantly that both water excess and water deficit in corn plant development as discussed next. Reduced growth was the first symptom of water shortage observed in the plants (Imorou et al., 2018) and in the present study, the succinct multiple analysis regression and principle components analyses showed that the root system and shoot growth is the main process affected by flooding or water shortage. Thus the eight days of treatment were sufficient identify significantly reduced shoot growth and increase in root system growth. Reduction in water availability may limit cell lengthening because it decreases turgor pressure and also damages cell division (Schulze et al., 2019).

Adjustment in the number of leaves and leaf area is one of the adaptation strategies of plants to water shortage, because the leaf is the main transpiration organ and under the condition of water shortage the plant needs to reduce the loss of this limited resource, Thus the small leaf area and number of leaves under water shortage observed in the present study was one of the first responses of the plants to water shortage (Cruz et al., 2019). In addition, the significant reductions in plant height, stem diameter, stem mass ratio and biomass were strong indications that corn plant growth was severely limited by the 8-day water shortage. Although the plant has C4 metabolism and is indicated for planting in the period of little rainfall in Brazil – the second second harvest, the plant is considered moderately tolerant to water shortage compared to other species with greater tolerance such as *Sorghum bicolor* L. (Choudhary, et al., 2020).

The reduced transpiration rates and low relative water content in plants under water shortage indicated dehydration of the corn plants and cell flaccidity and under these conditions there is no turgor pressure needed for cell lengthening. The low values of these two variables indicated that the corn plant is isohydric. Matos et al. (2019) reported that isohydric plants have a hydraulic system of drought tolerance so that even before the water shortage is established at severe levels the plant starts to reduce transpiration by an efficient stomata control measure mechanism using guard cells sensitive to variation in moisture variation.

The FSII maximum quantic efficiency was damaged under water shortage, indicating probable damage to the photosynthesis FSII. This alteration in photochemical activity may have been due to photo inhibition in the plants submitted to severe water shortage, that led to the formation of reactive oxygen in the chloroplasts and consequently to physical damage in the FSII (Maia et al., 2019). As a protection mechanism, the plant intensified the root system growth in the imminence of exploiting a larger volume of soil and obtaining moisture. According to Matos et al. (2019) under water shortage there is less assimilate investment in the shoot and they are directed to the root system to maximize soil solution absorption. The high total chlorophyll concentration under water deficit referred to the demolition effect, and the cell sap was concentrated in the irrigated plants under low water volume.

Starting with water supply between 260% and 300% of the volume evapotranspired by the corn crop, reductions were observed in the stem diameter, height, number of leaves, transpiration, relative water content, biomass, stem mass ratio and maximum FSII quantic efficiency. These results indicated that flooding is restrictive to corn plant growth. According to Sousa et al. (2018), excessive water application can generate hypoxia in the plants, restricting plant matter accumulation.

Under flooding in the soil there are fewer spaces destined for gases and if this situation remains inhibited cell respiration,reduced cytosol pH and decreased aquaporin activity are common. Reduction in aquaporin activity culminates in low soil solution absorption so that under flooding the main symptom is similar to the symptom of water shortage, namely reduced growth. The biggest root mass ratio values under water shortage and flooding demonstrated similarity in the response of the plant when submitted to both these stresses. Faria et al. (2020) reported that both water shortage and flooding showed reductions in plant growth that resulted in delayed establishment of *Passiflora edulis* plants. In summer corn season, according to Bi et al. (2020), the effects of abrupt changes between drought and flooding interfered on corn plants growth, precisely, in seeding-jointing stage and tasseling-grain filling stage and, consequently, reducing yield.

Thus, both water shortage and flooding damage corn plant growth and development, but at different magnitudes, because the absence of irrigation resulted in more severe damage than supplying a water volume corresponding to 400% of the crop evapotranspiration.

Conclusion

Water shortage and flooding inhibited corn plant growth of the 2A401P hybrid and thus damaged the establishment of the crop, but at different intensities, because water shortage was shown to be much more restrictive to plant growth than flooding. Furthermore, it is pointed out that corn plants are isohydric, because they anticipate water shortage by an efficient stomata sensitivity that controls water loss by transpiration. Based on the results obtained, it is recommended that the volume of water applied to corn plant irrigation does not exceed 200% of the daily evapotranspiration.

References

Allen, R. G., et al. (1998). *Crop evapotranspiration: guidelines for computing crop water requirements .FAO. Irrigation and Dranaige Paper, 56.* (300p.). Rome: FAO.

Alvares, C. A., et al. (2013). Koppen's climate classification map for Brazil. *Meteorologische Zeitschrift*, 22 (6), 711-728. DOI: https://doi.org/10.1127/0941-2948/2013/0507

Andrea, M. C. D. S., et al. (2018). Variability and limitations of maize production in Brazil: Potential yield, water-limited yield and yield gaps. *Agricultural systems*, 165, 264-273. DOI: https://doi.org/10.1016/j.agsy.2018.07.004

Bi, W., et al. (2020). Effects of Drought-Flood Abrupt Alternation on the Growth of Summer Maize. *Atmosphere*, 11 (1), 01-18. DOI: https://doi.org/10.3390/atmos11010021

Brasil. Ministério da agricultura, pecuária e abastecimento. (2017). *Brasil projeções do agronegócio 2016/2017 a 2026/2027* (8 ed.). Brasília, DF: MAPA. Recuperado de https://www.gov.br/agricultura/pt-br/

Choudhary, S., et al. (2020). Maize, sorghum, and pearl millet have highly contrasting species strategies to adapt to water stress and climate change-like conditions. *Plant Science*, *295*, 110297. DOI: https://doi.org/10.1016/j.plantsci.2019.110297

Companhia Nacional de Abastecimento. (2020). *Observatório Agrícola. Acompanhamento da Safra Brasileira de Grãos* (v. 7 - Safra 2019/20 - Quarto levantamento). Brasília: CONAB.

Cruz, Y. C. C., et al. (2019). Growth of *Typha domingensis* as related to leaf physiological and anatomical modifications under drought conditions. *Acta Physiologiae Plantarum*, 41 (64), 01- 09. DOI: https://doi.org/10.1007/s11738-019-2858-1

Dejonge, K. C., et al. (2015). Comparison of canopy temperature-based water stress indices for maize. *Agricultural Water Management*, 156, 51-62. DOI: https://doi.org/10.1016/j.agwat.2015.03.023

Faria, L. O., et al. (2020). *Passiflora edulis* Growth Under Different Water Regimes. *Journal of Agricultural Science*, 12 (4), 231-238. DOI: https://doi.org/10.5539/jas.v12n4p231

Food and Agriculture Organization of the United Nations. (2019). Recuperado em 01 agosto, 2020, de http//:www.faostat.fao.org.

Fornasiere Filho, D. (2007). Manual da cultura do milho (273p). São Paulo: FUNEP.

Imorou, L., et al. (2018). Water stress effect on agro-morphological and physiological parameters of three local cultivars of maize (*Zea mays* L.) of South Benin. *International Journal of Biological and Chemical Sciences*, 12 (5), 2294-2308. DOI: https://doi.org 10.4314/ijbcs.v12i5.29

Johnová, P., et al. (2016). Plant responses to ambient temperature fluctuations and water-limiting conditions: a proteome-wide perspective. *Biochimica et Biophysica Acta (BBA)-Proteins and Proteomics*, 1864 (8), 916-931. DOI: https://doi.org/10.1016/j.bbapap.2016.02.007

Maia Jr., S. O., et al. (2019). An efficient antioxidant system is associated with lower photosynthesis photoinhibition and greater tolerance to drought in sugarcane cultivars. *Bioscience Journal*, 35 (3), 691-704. DOI: https://doi.org/10.14393/BJ-v35n3a2019-39571

Matos, F.S., et al. (2019). *Folha Seca: Introdução à Fisiologia Vegeta*. (189p). Curitiba, PR: APPRIS.

Mutlu, C., et al. (2018). Physicochemical, Thermal, and Sensory Properties of Blue Corn (*Zea Mays* L.). *Journal of Food Science*, 83 (1), 53-59. DOI: https://doi.org/10.1111/1750-3841.14014

Paterniani, M. E. A. G. Z., et al. (2019). Estratégias de melhoramento para tolerância à seca em germoplasma de milho tropical. *Singular Meio Ambiente e Agrárias*, 1 (1), 19-24. DOI: https://doi.org/10.33911/singular-maa.v1i1.48

Santana, M. C. B., et al. (2017). Produtividade de grãos e parâmetros fisiológicos de sorgo granífero sob deficiência hídrica e irrigação plena. *Revista Brasileira de Milho e Sorgo*, 16 (3), 361-372. DOI: https://doi.org/10.18512/1980-6477/rbms.v16n3p361-372

Schulze, E. D., et al. (2019). Water Deficiency (Drought). In: *Plant Ecology*. (pp. 165-202). Berlin, Heidelberg: Springer.

Sokal, R. R., & Rolf, F. J. (1995). *Biometry* (3rd Edition, 15p). New York: Freeman.

Smith, M., et al. (1991). *Report on the expert consultation on revision of FAO methodologies for crop water requiremebts*. (45p). Rome FAO.

Sousa, R. S., et al. (2018). Identification of Drought-Tolerant Corn Genotypes by Multivariate Analysis. *Pesquisa Agropecuária Tropical*, 48 (3), 204-211.

StatSoft Inc. (2007). *Statistica: data analysis software system* (Version 7) [Programa de computador]. Recuperado em 01 agosto, 2020, de http://www.statsoft.com/Products/STATISTICA-Features

Sysstat Software. (2006). *SigmaPlot for Windows* (Version 10) [Programa de computador]. Recuperado em 01 agosto, 2020, de https://systatsoftware.com/products/sigmaplot/.

Wellburn, A. R. (1994). The spectral determination of chlorophylls a and b, as well as total carotenoids, using various solvents with spectrophotometers of different resolution. *Journal of Plant Physiology*, 144 (3), 307-313. DOI: https://doi.org/10.1016/S0176-1617(11)81192-2

Yin, X., et al. (2016). Adapting maize production to drought in the Northeast Farming Region of China. *European Journal of Agronomy*, 77, 47-58. DOI: https://doi.org/10.1016/j.eja.2016.03.004

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