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RESEARCH ARTICLE

IRRIGATION DEPTHS, SOIL COVER AND PHOSPHATE FERTILIZATION ON GAS EXCHANGES OF OKRA

[1]AntônioMichael Pereira Bertino, [1]Lourival Ferreira Cavalcante, [1]Francisco Thiago Coelho Bezerra, *[2]Francisco Vanies da Silva Sá, [1]Núbia Marisa Fereira, [3]Evandro Franklin de Mesquita, [2]José Thiago Aires Souza and [2]Geovani Soares de Lima

[1]Federal University of Paraíba, Areia, Paraíba, Brasil
[2]Federal University of Campina Grande, Campina Grande, Paraíba, Brazil
[3]State University of Paraíba (UEPB), Catolé do Rocha, Paraíba, Brasil

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ABSTRACT

The okra crop stands out as a viable alternative for family farmers in regions of semi-arid climate, due to its acceptance in the market and for being rich in vitamins, fibers and minerals. Thus, this study aimed to evaluate the gas exchanges of okra under water depths, soil cover and phosphate fertilization, in an experiment carried out in the municipality of Catolé do Rocha-Paraíba, Brazil, in the period from November 2014 to April 2015. The experimental design was randomized blocks with a 2 x 2 x 2 factorial scheme, referring to two irrigation depths (100 and 50% of crop evapotranspiration – ETc), with and without soil cover, with and without phosphate fertilization, with four replicates. Gas exchanges were determined in the flowering stage through the CO_2 assimilation rate, stomatal conductance, transpiration, internal CO_2 concentration, water use efficiency and instantaneous carboxylation efficiency. There is positive influence of phosphate fertilization and soil cover on the gas exchanges of okra plants under different conditions of water availability in the soil. Phosphate fertilization and soil cover mitigate the effects of water stress on okra plants and, when associated, increase the photosynthetic efficiency and water use efficiency of the plants.

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INTRODUCTION

(*Abelmoschus esculentus* (L.) Moench) is a shrub-sized plant with annual cycle that stands out among the main vegetable species cultivated in tropical and subtropical regions worldwide (Filgueira, 2012; Nascimento, 2014). According to NHB (2015), India is the largest okra producer in the world, with production of 6.34 million tons of fruitsin the 2013-2014 season, in an area equivalent to 533 thousand hectares, and estimated at 6.20 million tons of fruitsin the 2014-2015 season, in an area of 524 thousand hectares. The *A. esculentus* crop found in Brazil adequate conditions for its development, especially regarding edaphoclimatic factors, notably the semi-arid regions of Northeast and Southeast Brazil (Oliveira *et al*., 2007; Santos *et al*. 2010; Paes *et al*., 2012; Oliveira *et al*., 2013; Bertino *et al*., 2015). However, the cultivation of okra in regions with semi-arid climate is riskybecause of the low rainfall and theirregularity in long drought periods, causing water deficit in the plants and requiring the use of cultivation practices, such as irrigation management (Ferreira *et al*., 2012; Brito *et al*., 2013; Dutra *et al*., 2015; Ferreira *et al*., 2015; Bertino *et al*., 2015). In spite of that, there are only a few strategies that increase efficiency and minimize the impacts of water deficit on okra plants, such as soil cover, which decreases water evaporation in the soil, which remains wet for a long period (Lima Neto *et al*., 2013; Ferreira *et al*., 2015). Ferreira *et al*. (2015) point out that the use of soil cover and organic fertilization minimize the effects of water stress on castor bean plants in semi-arid climate, allowing the reduction of irrigation depths in relation to the cultivation without soil cover. Besides irrigation management, studies that support the mineral supplementation of the okra crop are also scarce, especially under semi-arid climate conditions (Souza, 2012), and even more scarce regarding phosphate fertilization. Since crops absorb phosphorus (P) since the first development stages (from germination to senescence), it is a key nutrient for obtaining high yield in most situations (Filgueira, 2012). Although some authors report benefits of phosphate

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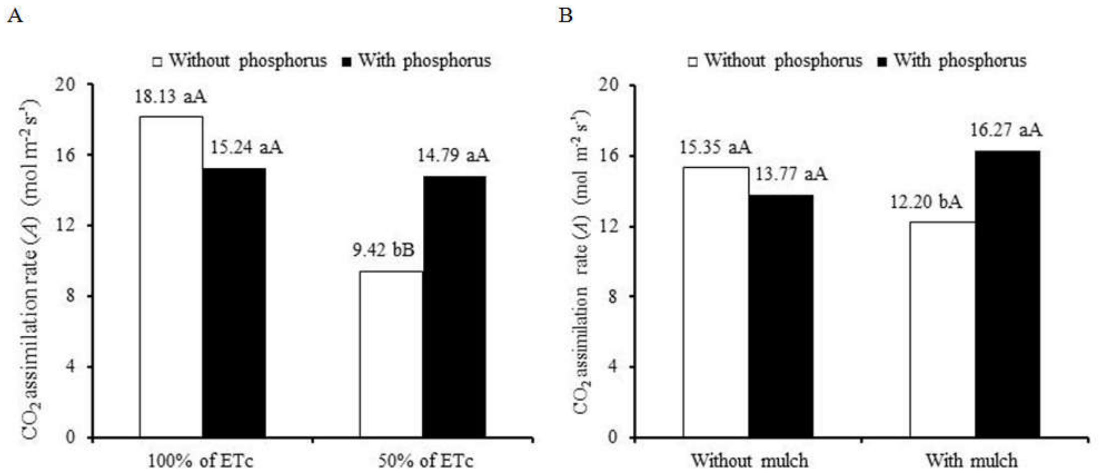
***Corresponding author: Francisco Vanies da Silva Sá,**
FederalUniversityof Campina Grande, Campina Grande,
Paraíba, Brazil.

fertilization on okra yield (Oliveira *et al*., 2007; Galati *et al*., 2013; Muhammad *et al*., 2013), data on the efficiency of phosphate fertilization in the physiological activity of these plants are incipient in the literature. Therefore, this study aimed to evaluate the behavior of the gas exchanges of okra under different water depths, soil cover and phosphate fertilization.

MATERIAL AND METHODS

The study was carried out in the period from November 2014 to April 2015, at the State University of Paraíba (UEPB), Campus IV, in the Agroecology Sector, situated in the municipality of Catolé do Rocha, Paraíba, Brazil. The climate of the region is BSw'h', according to Köppen's classification, characterized as hot semi-arid, with two different seasons, one rainy with irregular rainfall and another without rainfall. The mean annual rainfall is close to 800 mm, mean temperature of 27 ºC, with rainy period from February to April. The soil was classified as eutrophic Fluvic Neosol (Santos *et al*., 2013). The experimental design was in randomized blocks using a 2 x 2 x 2 factorial scheme, referring to two irrigation depths, 100 and 50% of crop evapotranspiration (ETc), in soil with and without cover and with and without phosphate fertilization, 8 and 0 g per plant, respectively, calculated according to the P content existing in the soil and considering the recommendation of Ribeiro *et al*. (1999), with four replicates, totaling 32 plots. Thus, each plot represents one treatment constituted of three rows with length of 3.2 m and width of 2 m, spaced by 1 m, with area of 6.4 m^2 and 8 plants per row, totaling 24 plants per plot. The soil, classified as eutrophic Fluvic Neosol, in the first 20 cm of depth, showed 661, 213 and 126 g kg^{-1} of sand, silt and clay; soil bulk and particle densities of 1.51 and 2.76 g cm^{-3}, respectively, with total porosity of 0.45 m^3 m^{-3}. The values of moisture at field capacity, permanent wilting point and available water were 23.52, 7.35 and 16.17%, respectively. As to its chemical characterization, at the same depth, according to the methodologies of Embrapa (2011), the soil showed pH = 7.02; P and K^+ = 31 and 297 mg dm^{-3}; Na^+ = 0.30 $cmol_c$ dm^{-3}; Ca^{2+}= 4.63 $cmol_c$ dm^{-3}; Mg^{2+}= 2.39 $cmol_c$ dm^{-3}; Al = 0.0 $cmol_c$ dm^{-3}; H+Al = 0.0 $cmol_c$ dm^{-3} and CEC = 8.08 $cmol_c$ dm^{-3}; OM = 1.80%. Basal phosphate fertilization was performed using 8 g of single superphosphate per plant, sowing was performed by planting five seeds per hole of okra, cv. Santa Cruz 47, and thinning was performed when plants showed three definitive leaves, leaving one per hole. At 22 days after sowing (DAS), fertigation was applied using 15 g of potassium chloride and 31 g of urea per plant and again at 42 DAS, using the same doses. The adopted spacing was 1 m between rows and 0.4 m between plants, and the soil was covered at 40 DAS with residues of dehydrated silage of maize (*Zea mays*) and elephant grass (*Pennisetum purpureum Schumach*), covering an area of 40 cm^2. Plant water supply was daily provided based on the Class-A pan evaporation of the previous day, using a localized drip irrigation system with flow rate of 8.5 L h^{-1}, and the experiment was divided into two areas, corresponding to each irrigation depth.The time of irrigation was controlled through valves. Irrigation monitoring (Mantovani *et al*., 2009) was as follows: DNID = ETo x Kc; DNID = daily net irrigation depth; ETo = reference potential evapotranspiration, in mm; Kc = crop coefficient; NDI= ETc x AE(P/100);NDI = L $plant^{-1}$ day^{-1}, AE = spacing between plants, flow rate per plant (L h^{-1} $plant^{-1}$) = q(AP/AE), q = emitter flow rate, AP = area of the plant, AE = spacing between plants, time of irrigation (L/H/Plant) = NIDx(7/J)/Q; J= weekly working hours, Q = flow rate per plant. The values of Kc were 0.68 and 0.79 in the first 40 DASand from 40 to 70 DAS, referring to the first and second stages, respectively (Paes *et al*., 2012).

At 60 DAS, the following variables were determined: gas exchanges, in the fully expanded leaves, from 7 to 10 a.m., on the sixth photosynthetically active leaf, counted from the stem apex;CO_2 assimilation rate (*A*) (µmol m^{-2} s^{-1}); transpiration (*E*) (mmol of H_2O m^{-2} s^{-1}); stomatal conductance (gs) (mol of H_2O m^{-2} s^{-1});and internal CO_2 concentration (Ci), using the portable photosynthesis meter LCPro+ (ADC Bio Scientific Ltda.), operating with temperature control at 25 ºC, irradiation of 1200 µmol photons m^{-2} s^{-1} and air flow of 200 ml min^{-1}, and CO_2 from the environment at a height of 3 m from the soil surface. Based on these data, water use efficiency (WUE) (*A*/*T*) (mmol CO_2 mol^{-1} H_2O) andinstantaneous carboxylation efficiency Φc (*A*/Ci) (mol m^{-2} s^{-1}) were determined (Brito *et al*., 2013; Dutra *et al*., 2015). The data were interpreted through analysis of variance and, in case of significance, the variables were compared by Tukey test ($p < 0.05$) and T test ($p < 0.01$), using the computational program System for Analysis of Variance - SAS 9.3 (SAS Institute Inc., 2012).



Means followed by lowercase (for phosphorus levels within irrigation depths and soil covers) and uppercase (for irrigation depths and soil covers within phosphorus levels) letters do not differ by Tukey test ($p < 0.05$).

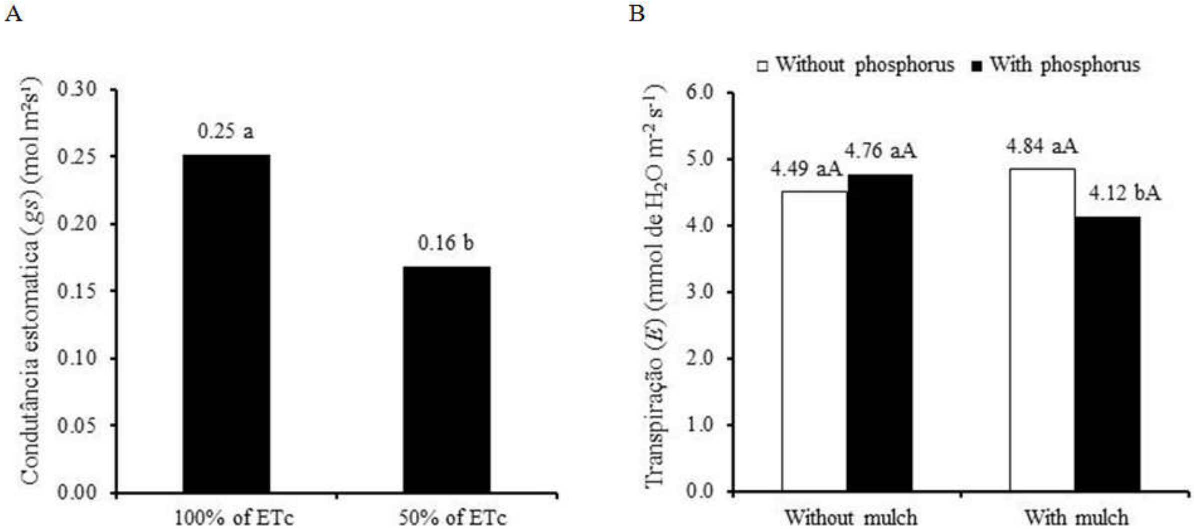
Figure 1.CO_2 assimilation rate of okra plants under irrigation depths (A), in soil with and without mulch, with and without phosphorus (P) (B), at 60 days after sowing

RESULT AND DISCUSSION

The CO_2assimilation rate of okra plants fertilized with P was not significantly ($p > 0.05$) influenced by the reduction in irrigation depth (Figure 1A). This fact is related to the better nutritional conditions of plants that received phosphate fertilization, since P is a basic constituent of biomolecules that are crucial to the photosynthetic activity, such as ATP and NADP, which serve as energetic source and electron acceptors, used in the biochemical phase of photosynthesis, more precisely in the Calvin cycle (Taiz & Zeiger, 2013), besides acting as regulator of the enzymatic activity, release of energy from ATP and adenine nucleotide phosphate – respiration, CO_2 fixation, biosynthesis and ionic absorption (Malavolta, 2008). In the comparison of plants that were not fertilized with P, there were reductions of 48% in the CO_2 assimilation rate between plants irrigated with water depth of 100% and 50% ETc. In addition, the CO_2 assimilation rate of the plants that did not receive phosphate fertilization was also lower than that of plants under water deficit (50% ETc) that received P supplementation (Figure 1A). The predominant mechanism of P for the transport in the soil is the diffusive flow, which is limited under water deficit conditions and, consequently, decreases the supply of P to the plants in soils with water deficiency. However, such limitation can be compensated by the increment in the surface of the root system (Kawahara *et al*., 2016). However, the presence of P is necessary for the synthesis of phosphorylated compounds and the absence of this nutrient causes immediate disorders in plant metabolism and development, directly reducing plant growth (Kawahara & Souza, 2009). Hence, the high photosynthetic rates observed in plants that did not receive P can be related to the need for a higher investment in root growth; however, under the deficit condition, this investment is limited by the water and nutritional conditions of the plant.

As to soil cover, okra plants that received phosphate fertilization in the soil with cover obtained higher CO_2 assimilation rates in relation to those cultivated without phosphate fertilization (Figure 1B). The response of phosphate fertilization in the soil with cover is clear, due to the greater water availability in the soil of these treatments, because soil cover reduces losses through evaporation (Paul *et al*., 2013; Ferreira *et al*., 2015; Bertino *et al*., 2015), conditioning plants to a higher P absorption, for helping to increase its availability, due to fertilization, and guaranteeing its mobility, because the soil remains wet for a longer time. Stomatal conductance was higher in plants under water depth of 100% in relation to those cultivated with 50% ETc (Figure 2A). This phenomenon can be related to the greater water availability in the soil, favoring the stomatal opening in plants grown under higher water depth, whereas plants under the lowest water depth are conditioned to stomatal closure to avoid excessive water loss through the stomata and decrease the effect of water deficit (Brito *et al*., 2013; Ferraz *et al*., 2014; Bertino *et al*., 2015). For transpiration, there was significant influence of the interaction between P and soil cover, so that plants cultivated in soil with cover and phosphate fertilization obtained lower transpiration rates in comparison to those under the same condition of cover without phosphate fertilization (Figure 2B).

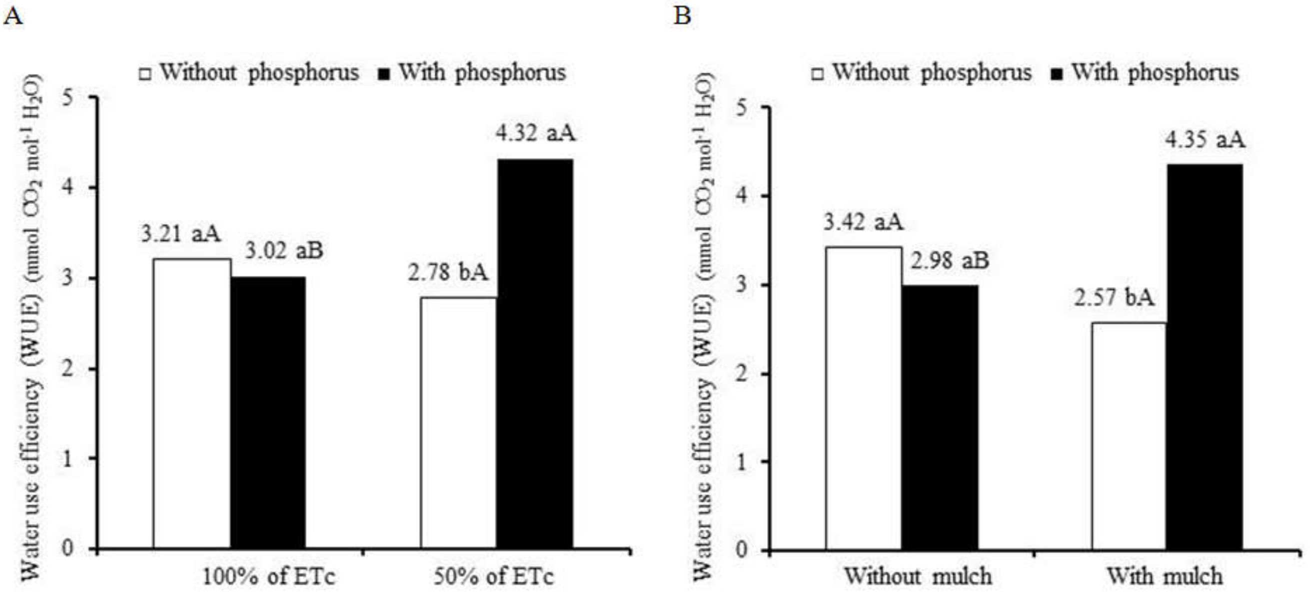
Considering that P is one of the nutrients that most limit the growth of okra plants (Galati *et al*. 2013), in plants under the lowest availability of P in the soil and with favorable moisture conditions, as in the soil with cover, the need for nutrient absorption is stimulated to highest water losses through transpiration, thus promoting greater absorption of water and nutrients of the soil, to maintain the vital activities. However, in the soil without cover, where there is lower water availability, there was no significant influence of phosphate fertilization on the transpiration of okra plants. Nonetheless, plants that received phosphate fertilization in the soil without cover transpired more than those grown in soil with cover (Figure 2B). P supply can increase the levels of free proline in the plant tissues, which is an important cellular osmotic regulator, mitigating the water stress on the plants (Guimarães *et al*., 2008), allowing them to maintain their activity of gas exchanges in adequate conditions to their development.



Means followed by lowercase (for phosphorus levels within irrigation depths and soil covers) and uppercase (for irrigation depths and soil covers within phosphorus levels) letters do not differ by Tukey test ($p < 0.05$).

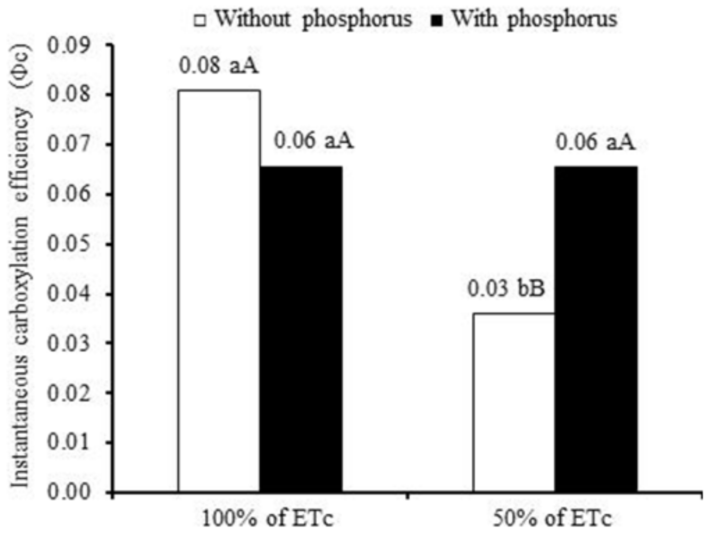
Figure 2. Stomatal conductance (gs) and transpiration (E) of okra plants under irrigation depths, in soil with and without mulch, with and without phosphorus, at 60 days after sowing

Water use efficiency in okra plants fertilized with P under the water depth of 50% ETc was 30% higher than that observed in plants irrigated with 100% ETc and 36% higher than that of plants that did not receive P under water depth of 50% ETc (Figure 3A). Considering that water use efficiency expresses the relationship between the amount of carbon fixed and the amount of water lost through transpiration during the photosynthetic process (Brito *et al*., 2013; Brito *et al*., 2014), phosphate fertilization mitigated the effects of water stress on okra plants, increasing the photosynthetic activity of the plants even under water deficit conditions (Figure 1A). Soil cover associated with phosphate fertilization also had positive influence on water use efficiency in okra plants, surpassing in 41% the water use efficiency in plants that were not fertilized with P under the same cover condition and in 31% in plants grown in soil with phosphate fertilization and without cover, respectively (Figure 3B).



Means followed by lowercase (for phosphorus levels within irrigation depths and soil covers) and uppercase (for irrigation depths and soil covers within phosphorus levels) letters do not differ by Tukey test ($p < 0.05$)

Figure 3. Water use efficiency (WUE) (A/T) (mmol CO_2 mol^{-1} H_2O) of okra plants under irrigation depth (A), in soil with and without mulch, with and without phosphorus (B), at 60 days after sowing



Means followed by lowercase (for phosphorus levels within irrigation depths and soil covers) and uppercase (for irrigation depths and soil covers within phosphorus levels) letters do not differ by Tukey test ($p < 0.05$).

Figure 4. Instantaneous carboxylation efficiency (Φc) (A/Ci) of okra plants under irrigation depths, in soil with and without phosphorus, at 60 days after sowing

Thus, the positive effects of phosphate fertilization on okra plants, reported by authors such as Oliveira *et al*. (2007), Galati *et al*. (2013) and Muhammad *et al*. (2013), are possibly related to the beneficial effects of P on the photosynthetic activity, increasing the water use efficiency of the plants. Plants that did not receive phosphate fertilization showed similar values of instantaneous carboxylation efficiency, regardless of the water availability condition, denoting the capacity of P to mitigate the effects of water stress on okra plants (Figure 4). However, the lowest values of instantaneous carboxylation efficiency were obtained in plants grown under water depth of 50% ETc without phosphate fertilization, in relation to the other treatments (Figure 4). The reduction of (Φc) is an indication of the existence of non-stomatal factors acting on the activity of gas exchanges, especially under onditions in which there is no influence of the treatments on internal CO_2 concentration (Brito *et al*., 2013).

The water stress associated with the nutritional imbalance may have compromised the activity of chlorophyll *a*, affecting the availability of the electron acceptors ATP and NADP, reducing the activity of RuBisCO in the carboxylation of CO_2, consequently causing negative impacts on its assimilation (Taiz and Zaiger, 2013).

Conclusions

The reduction in irrigation depth increases the stomatal conductance of the plants. The low availability of phosphorus inhibits the CO_2 assimilation rate and water use efficiency in okra plants. The increment in phosphorus availability promotes increase in theCO_2 assimilation rate and water use efficiency of okra plants irrigated with 50% ETc. Soil cover reduces transpiration and increases water use efficiency in okra plants.

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