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Article

PHYSIOLOGICAL RESPONSE OF MAIZE AND WEEDS IN COEXISTENCE

Resposta Fisiológica de Milho e Plantas Daninhas em Convivência

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ABSTRACT - This study aimed at evaluating the physiology of maize and weeds when living under different densities. The randomized block design with 4 replications was used. The factorial scheme 5 x 2 + 1 and 5 x 3 was adopted, for maize and weeds respectively, corresponding to weed species (*Bidens pilosa*, *Commelina benghalensis*, *Urochloa brizantha*, *Sorghum arundinaceum* and *Ipomoea triloba*) and infestation density (control, 15 and 30 plants m^{-2}). Weeds were kept in coexistence with the maize hybrid DKB 390 PRO 2, with an additional treatment for maize plants absent of competition. It was kept in coexistence with maize hybrid DKB 390 PRO 2 besides an additional treatment with maize plants absent of competition. On day 45 and 60 after maize planting (DAP) physiological reviews were performed within the culture, and 38 days after weed transplanting (DAT), an infrared gas analyzer (IRGA) was used. There were physiological changes in maize due to the coexistence with weeds. On day 45 DAP, the competition, regardless of the weed species, caused less photosynthetic rate in maize coexisting with 15 plants m^{-2}; the stomatal conductance was lower in both densities. On day 60 DAP, maize in competition with 15 and 30 plants m^{-2} showed lower transpiration rate. *U. brizantha* and *S. arundinaceum* showed reduction in photosynthesis and transpiration, due to increased density and coexistence with maize.

Keywords: *Zea mays, Urochloa brizantha, Sorghum arundinaceum,* photosynthetic rate, transpiration, competition.

*RESUMO - Objetivou-se neste estudo avaliar a fisiologia de milho e plantas daninhas em convívio sob diferentes densidades. Utilizou-se delineamento em blocos casualizados com quatro repetições. Foi adotado esquema fatorial 5 x 2 + 1 e 5 x 3, para o milho e plantas daninhas, respectivamente, correspondendo aos fatores espécies de planta daninha (**Bidens pilosa**, **Commelina benghalensis**, **Urochloa brizantha**, **Sorghum arundinaceum** e **Ipomoea triloba**) e densidade de infestação (testemunha, 15 e 30 plantas m^{-2}). Mantiveram-se em convívio com o híbrido de milho transgênico DKB 390 PRO 2, além de um tratamento adicional para plantas de milho ausentes de competição. Aos 45 e 60 dias após o plantio (DAP) do milho, foram realizadas avaliações fisiológicas na cultura, e aos 38 dias após o transplantio (DAT), para as plantas daninhas, utilizou-se analisador de gases no infravermelho (IRGA). Houve alterações fisiológicas no milho devido ao convívio com as plantas daninhas. Aos 45 DAP, a competição, independentemente da espécie infestante, causou menor taxa fotossintética no milho em convívio com 15 plantas m^{-2}; a condutância estomática foi inferior nas duas densidades. Aos 60 DAP, o milho em competição com 15 e 30 plantas m^{-2} apresentou menor taxa transpiratória. **U. brizantha** e **S. arundinaceum** apresentaram redução na fotossíntese e transpiração em função do aumento da densidade e do convívio com o milho.*

Palavras-chave: *Zea mays, Urochloa brizantha, Sorghum arundinaceum,* taxa fotossintética, transpiração, competição.

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INTRODUCTION

The productivity of maize (*Zea mays*) varies according to the technological level of the cultivation, the climate, the fertilizing and the management of weeds.

Some weeds produce a high number of propagules with high dissemination capacity and, normally, this happens in maize fields. Under these conditions, resource competition takes place and it can influence the development of the cultivation (Murungu et al., 2011; Marquardt et al., 2012; Cerrudo et al., 2012).

Phyto-sociological relations between weeds and cultivated plants may change both their physiology (Matos et al., 2013) and their morphology (Wandscheer and Rizzardi, 2013). The interference level in cultures is very complex and may be influenced by species, density (Vasilakoglou et al., 2012; Faria et al., 2014) and before of weed emergency in relation to the culture (Silva et al., 2007). When submitted to competition, the physiological mechanism of plants is changed; this produces changes in the use of resources, mainly in water and nutritional catchment (Galal and Shehata, 2015). Also, light catchment may also be changed according to the population arrangement (Liu et al., 2011). Light is an essential resource of the environment for the growth of plants, since it provides the necessary energy for photosynthesis. A lower light interception brings a reduction of the photosynthetic efficiency (Stewart et al., 2003), which may affect the physiology of plants. These changes may interfere with the availability of CO_2 in the foliar mesophile and in the gas flow of the cell, which have an effect on photosynthesis and transpiration (Messinger et al., 2006) and, consequently, on the productive aspects.

Some studies analyze the productive changes of maize by the competition with weeds (Kaefer et al., 2012; Faria et al., 2014; Yeganehpoor et al., 2015); however, the ecophysiological aptitude and adaptation of the species are still not very explored. Plants can look healthy and still present physiological disorders (Barros et al., 2014). These changes can lead to a decrease in the performance of cultures (Da-Yong et al., 2012) and even to less tolerance to biotic and abiotic stress.

In this context, the goal of this work was to assess physiological parameters of maize plants and weeds kept in coexistence in different infestation densities.

MATERIAL AND METHODS

The experiment took place in Montes Claros, Minas Gerais State. According to the Köppen classification, the climate of the region is As type - tropical semiarid, with dry summer (Alvares et al., 2013). The climatic data from the period during which the test was performed are presented in Figure 1.

The test was performed on the field in vases with 12 dm^3 volumetric capacity, 31 cm height, over 31 cm and under 18 cm diameter, filled with substrate composed by soil, manure and sand in a 3:1:1 proportion, respectively. The substrate presented average texture; pH (water) = 6.8; P = 490 mg kg^{-1}; K = 159 mg kg^{-1}; Ca = 9.5 cmol dm^{-3}; Mg = 4.7 cmol dm^{-3}; Al = 0.0 cmol dm^{-3}; H+Al = 0.86 cmol dm^{-3}; effective CTC = 14.61 cmol dm^{-3}; and organic matter rate = 7.61 daq kg^{-1}.

The design used was the randomized block one, with four repetitions. To analyze the maize plants, the 5 x 2 + 1 factor scheme was used; five weed species were allocated in the A factor: *Bidens pilosa*, *Commelina benghalensis*, *Urochloa brizantha, Sorghum arundinaceum* and *Ipomoea triloba*, and in the B factor, their densities (15 or 30 plants m^{-2}); this corresponds to one or two weeds per vase, in coexistence with the transgenic hybrid maize DKB 390 PRO 2. For comparison purposes, an additional treatment was performed on maize plants kept in monoculture. As for weeds, the 5x3 factor scheme design was used, in which the first factor was composed by the five species and the second one by the densities, 15 or 30 plants m^{-2}, in competition with maize and weeds in monoculture. However, only the density factor was compared, since comparing physiologically plants that are from different metabolic classes (C3 and C4) is not pertinent.

The weed seedlings were produced in polyethylene trays and transplanted 15 days after the emergency into vases containing a maize plant, seven days after sowing. The weed seedlings were standardized in size and vigor before planting. The vases were watered three times a day,

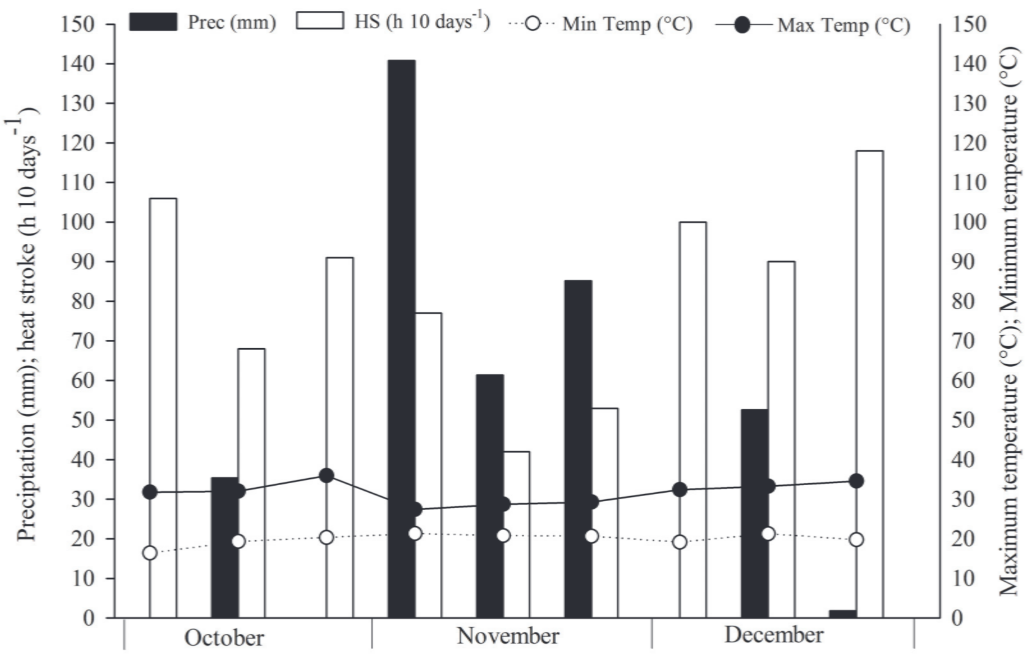

Figure 1 - Averages decennial of precipitation (mm), maximum temperature (°C), minimum temperature (°C) and insolation (h 10 days^{-1}), obtained during the experiment.

keeping the substrate close to field capacity during all the experiment; fertilizing was made according to recommendations for maize culture. The coexistence lasted 78 days, corresponding to reproductive stage 3 – milk stage or sweet corn.

On day 45 and 60 after maize planting (DAP), which represents 38 and 53 days after weed transplanting (DAT), physiological evaluations were performed on the culture; this period represents the final phase of vegetative growth and the beginning of flowering. For weeds, the analysis was exclusively on day 38 DAT, when they were in vegetative growth; on day 53 DAT some species were in foliar senescence. The evaluations were performed by using an infrared gas analyzer (IRGA), ADC make, Lcpro-SD model (Analytical Development Co. Ltd, Hoddesdon, UK), on the field, under natural conditions of air circulation. The evaluations were performed in the plants' upper third, on a completely expanded leaf, using a 1,200 µmol m^{-2} s^{-1} artificial light in the chamber of the equipment. For more homogeneous environmental conditions and correct data reading, the analyses were performed between 8 and 11 hours.

The photosynthetic rate (*A* - µmol m^{-2} s^{-1}), the stomatal conductance of water vapors (g_s - mol m^{-1} s^{-1}), the transpiration rate (*E* - mol H_2O m^{2} s^{-1}), the CO_2 concentration in the substomatal chamber (*Ci* - µmol mol^{-1}), the foliar internal temperature (TF - °C) and the efficiency in water use (WUE - mol CO_2 mol H_2O^{-1}), estimated based on the photosynthesis relation by the quantity of transpired water, were assessed.

The effects of the A factor, B factor and AB interaction levels were tested by F test, with a 5% probability. When significance was identified, the Tukey's test with 5% probability was used to compare the averages. The split of averages was made when there was interaction between the factors.

RESULTS AND DISCUSSION

Regardless of the weed species in competition, maize did not present changes in the analyzed physiological variables. However, the weed density interfered in these variables, on the assessments performed on day 45 and 60 DAP (Table 1). The population arrangement also influenced the assessed physiological parameters of each weed.

On day 45 DAP, maize plants in monoculture presented higher stomatal conductance (g_s) when compared to plants that were under competition in 15 and 30 plants m^{-2} densities; moreover, the exclusive culture was photosynthetically more active when compared to the 15 plants m^{-2} culture. During this period, maize plants in coexistence with 15 plants m^{-2} from the competitor species presented lower transpiration rate (*E)* in relation to the 30 plants m^{-2} density. On day 60 DAP there was no effect of the weed density, except for *E*, which was higher in monoculture maize. The competition did not influence the water use efficiency (WUE) during none of the periods (Table 1).

The obtained physiological variables for monoculture maize were *A* (44.98 and 30.81 µmol m^{-2} s^{-1}), g_s (0.28 and 0.16 mol m^{-1} s^{-1}), and *E* (5.98 and 4.95 mol H_2O m^2 s^{-1}), on day 45 and 60 DAP respectively (Table 1). For maize also, Ye et al. (2016) found values close to 30 µmol CO_2 m^{-2} s^{-1} for *A*, 0.20 mol CO_2 m^{-1} s^{-1} for g_s and *E* of 3 mol H_2O m^2 s^{-1} in assessments performed on the tenth leaf; for sorghum the values were *A* 31.7 µmol m^{-2} s^{-1}, g_s in mature leaves was lower than 0.15 mol m^{-1} s^{-1} and higher when assessed in young leaves (Jiang et al., 2011).

Photosynthesis and transpiration are influenced by the gas flow in the cell (Messinger et al., 2006), which is limited by the stomatal aperture (Taiz and Zeiger, 2004). In a competitive environment, according to the population level, the maize culture tends to get more effective regarding gas exchanges, maximizing the use of water resources. The way in which the photosynthetically active radiation in captured by the plant canopy is fundamental for photosynthesis. Factors such as shape and population density influence the distribution of the foliar area on the plant canopy (Stewart et al., 2003).

Maize cultivated without the presence of weeds presented a better response to the assessed physiological parameters. It was verified that g_s has been changed by the presence of weeds on day 45 DAP. Since this factor regulates the flow of CO_2 inlet and water outlet in the plant, the other parameters also underwent changes according to this physiological relation.

As for weed species, only *U. brizantha* and *S. arundinaceum* had their physiological variables affected by density. *S. arundinaceum* plants in monoculture presented higher *A* than the two tested densities; *U. brizantha* in monoculture presented higher *A* in relation to the 30 plants m^{-2} density. The species *B. pilosa*, *C. benghalensis* and *I. triloba* had a similar behavior, presenting equal *A* in all treatments (Table 2). The *A* values for *S. arundinaceum* varied from 22.23 to 28.5 µmol m^{-2} s^{-1} in the different population levels studied. Martins et al. (2016) found values between 20.33 and 21.87 µmol CO_2 m^{-2} s^{1} in the different phenological phases of this species. For *U. brizantha*, the results varied from 19.85 in coexistence with maize in the 30 plants m^{-2} density to 25.38 µmol m^{-2} s^{-1} in monoculture. These values are close to the ones obtained by Dias Filho (2002), who verified *A* with values between 20 and 30 µmol m^{2} s^{-1} under a 1,000 µmol m^{-2} s^{-1} light intensity.

Table 1 - Photosynthetic rate (*A*), stomatal conductance (g_2), transpiration (*E*) and water use efficiency (WUE) in maize plants cultivated in coexistence with weeds in different densities, after 45 and 60 days from the culture planting

Coexistence density	Variables			
	A (µmol m^{-2} s^{-1})	g_s (mol m^{-1} s^{-1})	*E* (mol H_2O m^2s^{-1})	WUE (mol CO_2 mol H_2O^{-1})
	45 DAP			
15 plants m^{-2}	38.62 B	0.22 B	5.22 B	7.62 A
30 plants m^{-2}	41.29 AB	0.24 B	6.04 A	6.89 A
Control*	44.98 A	0.28 A	5.98 AB	7.75 A
VC%	9.04	14.87	13.87	11.90
	60 DAP			
15 plants m^{-2}	28.19 A	0.15 A	3.96 B	7.14 A
30 plants m^{-2}	26.93 A	0.14 A	3.69 B	7.33 A
Control*	30.81 A	0.16 A	4.55 A	6.79 A
VC (%)	14.15	20.04	10.19	11.36

Averages followed by the same letter on the column, for each test period, do not differ among themselves by the Tukey's test with $p<0,05$; * Control treatment of maize plant without weed coexistence; VC - Variation coefficient.

Table 2 - Photosynthetic rate (*A*), stomatal conductance (g_s) and transpiration rate (*E*) of weeds cultivated within two densities, in coexistence with maize and weed samples kept in monoculture, after 38 days from the transplanting

Coexistence density	*A* (μmol m^{-2} s^{-1})	g_s (mol m^{-1} s^{-1})	*E* (mol H_2O m^2s^{-1})
U. brizantha			
15	22.38 AB	0.16 A	2.59 AB
30	19.85 B	0.14 A	2.43 B
Monoculture	25.38 A	0.21 A	2.99 A
S. arundinaceum			
15	22.23 B	0.15 A	2.68 B
30	23.09 B	0.17 A	2.88 AB
Monoculture	28.50 A	0.22 A	3.27 A
VC	12.82	19.36	9.51
C. benghalensis			
15	14.89 A	0.23 A	3.45 A
30	13.41 A	0.29 A	3.70 A
Monoculture	15.62 A	0.28 A	3.55 A
B. pilosa			
15	16.95 A	0.32 A	3.89 A
30	14.77 A	0.26 A	3.38 A
Monoculture	14.15 A	0.24 A	3.41 A
I. triloba			
15	15.52 A	0.22 A	3.34 A
30	16.07 A	0.28 A	3.47 A
Monoculture	17.69 A	0.30 A	3.62 A
VC (%)	12.82	19.36	9.51

Averages followed by the same letter on the column, for each species, do not differ among themselves by the Tukey's test with $p<0,05$; VC - Variation coefficient.

The sunlight range between the wavelengths from red to blue is vital for the plant physiological mechanism (Messinger al., 2006). When under light competition, metabolic adaptation may occur, since plants may present morphologic changes in response to the captured light intensity (Weller et al., 1997). In this situation, it is likely to have a decrease in the production of photo-assimilated compounds, due to shadowing (Zhao et al., 2012).

C4 plants need more energy to produce photo-assimilated compounds. *U. brizantha* and *S. arundinaceum* are C4 species, which may explain the fact that they are affected by density, since with 30 plants m^{-2} the larger shadowing imposed by intraspecific and interspecific competition made them reduce their *A* (Table 2).

For the studied C4 species, even with reductions in the CO_2 concentration of the foliar mesophile, the photosynthetic process continues, since PEP-carboxylase presents high affinity by CO_2. CO_2 accumulation in the foliar mesophile is the most effective mechanism to reduce photorespiration (Sage, 2013). Although C3 plants develop specific mechanisms to reduce this process, they are still less effective in the atmospheric CO_2 use, which results in a lower ATP production (Busch et al., 2013; Sage, 2013). In a general way, the relation fixed CO_2 molecule/ATP/NADPH is 1:3:2 in C3 plants, and 1:5:2 for C4 plants (Silva et al., 2007). Thus, plants with C3 metabolism need less energy to perform photosynthesis, which may explain the fact that physiological parameters of C3 weeds are not affected by the coexistence density.

Weed species in coexistence with maize did not present changes in the different densities cultivated with maize and also in monoculture for the g_s variable. This physiological parameter is proportional to number, size and diameter of the stomatal aperture – these attributes depend on the species itself and on external factors (Brodribb and Holbrook, 2003).

U. brizantha plants cultivated in 30 plants m^{-2} and in coexistence with maize presented lower *E* when compared to the species monoculture. *S. arundinaceum* cultivated in 15 plants m^{-2} also demonstrated lower *E* values in relation to the single species (Table 2). Only these two species suffered from density interference. The transpiration and CO_2 capture processes occur when the stomata are open, as well as g_s. When there are low levels of active radiation for the photosynthetic process, plants tend to close the stomata. This process is related to the loss of hydraulic conductivity (Martorell et al., 2014); this mechanism is also used to avoid hydric stress (Cochard al., 2002).

The reduction of transpiration may be related to the decrease in water availability. This would explain the fact that *U. brizantha* e *S. arundinaceum* have lower *E* values when submitted to different densities in coexistence with the culture; the higher population level increase the competition for this resource. The other studied species present C3 metabolism and generally need a longer period of stomatal aperture to accumulate CO_2 in the foliar mesophile; thus, they tend to transpire more (Ferreira et al., 2011).

Weeds subjected to higher population level were less effective in the water use, compared to monoculture. As for Ci and internal foliar temperature (TF), there was no difference between the densities (Table 3).

Table 3 - Internal foliar temperature (TF), internal carbon concentration (Ci) and water use efficiency (WUE) of weeds cultivated within two densities, in coexistence with maize and weed samples kept in monoculture, after 38 days from the transplanting

Coexistence density	Variables		
	TF (°C)	Ci ($\mu mol\ mol^{-1}$)	WUE ($mol\ CO_2\ mol\ H_2O^{-1}$)
15 plants m^{-2}	31.45 A	162.95 A	6.12 AB
30 plants m^{-2}	30.45 A	174.15 A	5.77 B
Monoculture	30.56 A	162.80 A	6.17 A
VC (%)	3.79	12.08	7.92

Averages followed by the same letter on the column do not differ among themselves by the Tukey's test with p<0,05; VC - Variation coefficient.

The WUE relates the absorption of CO_2 with the loss of water to the environment (Keenan et al., 2013); this highlights the importance of stomatal regulation and efficiency for plants. Concerning the coexistence situation, we noticed that the physiologic strategy of water use may be affected by competition.

Lower CO_2 values in the internal space of the leaf may come from higher photosynthetic activity, which incorporates CO_2 through carboxylation to create organic compounds. There may be species with great differences in terms of absorption and saturation by atmospheric CO_2 (Da Matta et al., 2001).

The analyzed weed species kept in coexistence with maize did not influence the physiology of this culture. However, their density reduces the photosynthetic rate, the stomatal conductance and the transpiration rate of maize. Only *U. brizantha* and *S. arundinaceum* alter their physiology, with reductions in the photosynthetic and transpiration rate due to the coexistence with maize and the population increase, probably as an adaptive response to the competitive condition. We observed both intraspecific and interspecific influence especially in C4 species, which were affected more by the competition.

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