Biological responsiveness of beans under different soil water regimes in a protected environment in Brazil

Rafael Domingues[1*], André Belmont Pereira[1], Luiz Fernando Pires[2], Luis Miguel Schiebelbein[1], Eduardo Augusto Agnellos Barbosa[1], Jadir Aparecido Rosa[3]

(1. *Department of Soil Science and Agricultural Engineering, State University of Ponta Grossa, UEPG, C.E.P. 84.030-900 Ponta Grossa, PR, Brazil*;
2. *Department of Physics, State University of Ponta Grossa, UEPG, C.E.P. 84.030-900 Ponta Grossa, PR, Brazil*;
3. *Laboratory of Soil Physics, Agricultural Research Institute of Paraná, 84001-970 Ponta Grossa, PR, Brazil*)

Abstract: Climatic conditions and soil water requirement notably impinge upon agriculture in such a way as to galvanize scientists to come up with advanced research in order to assure a more sustainable production at a given site. The aim of the current work was to scrutinize the effect of soil water status on the ecophysiological parameters and yield components of two cultivars of beans (*Phaseolus vulgaris* L.) under tropical climatic conditions. The experiment was carried out in March of 2016 at a greenhouse belonging to the Agronomic Institute of Paraná (Ponta Grossa, PR, Brazil) with beans. The experimental design taken into account herein was a completely randomized design at a factorial scheme with six replications for yield components and four replications for crop ecophysiological parameters. For such a crop, yield components of two genotypes under the influence of four levels of soil humidity were assessed for agronomical purposes. Soil humidity within the stipulated levels at this trial was monitored by means of a Time Domain Reflectometer (TDR). The ecophysiological parameters were analyzed at four distinct times through a LICOR Infrared Gas Analyzer (IRGA), model 6400-XT. By means of such an equipment net photosynthesis, stomachic conductance, transpiration, and photosynthetic water use efficiency were evaluated. Number of pods per plant, grain mass per plant and yield were to be affected linearly as a function of soil water status. A thousand grain mass and transpiration rates for the cultivar Tuiuiú were higher than those related to the cultivar Campos Gerais, regardless of soil water conditions. Apart from transpiration rates, all other ecophysiological parameters did not detect effect of the studied treatments on the biological responsiveness of the crop.

Keywords: *Phaseolus vulgaris* L., soil water, climate, yield components, ecophysiological parameters

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1 Introduction

Agriculture is by far an economic activity extremely impinged upon climate patterns and turns out to be highly susceptible to either temporal or spacial variability at a given site. Local meteorological elements regime governs not only metabolic processes of the plants directly linked to crop yield, but also several human activities in production fields. Roughly 80% of the overall variability on world agricultural production is a result of the effect of climate and weather conditions on the crop physiological responses, particularly under non-irrigated systems, since it is not possible to adopt measures of control over natural phenomena (Sentelhas and Monteiro, 2009).

Relative water content in the plants is the most important physiological variable to be taken into account

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*** Corresponding author: Anthony Nolan,** PhD candidate. Tel.: +35317167484; fax: +35317167415; Email: anthony.nolan@ucd.ie.

both in ecophysiological and agrometeorological studies when it comes to assure maximization of crop yield along with grade of agricultural products. Plants water status is strongly conditioned by soil water regimes and also by the atmosphere evaporative demand, with these factors affecting accumulation of dry matter in the plant and vegetative growth of most of the crops (Aminifar et al., 2012).

Beans (*Phaseolus vulgaris* L.) is a crop that occupies a remarkable economic relevance in Brazil, being therefore considered to be a staple extremely appreciated by the Brazilian population and for coming to being a basic subsistence product under a world scenario of food security. Thus, it deals with a crop of great economical and social impacts either at a regional, national or international scale owing to its richness in protein and a large geographical distribution (Barbano, 2003; Cunha et al., 2013).

The occurrence of soil water deficiency might impair growth and development of beans, mainly throughout the yield formation phenological stages of the crop (Barbano, 2003). The duration, frequency and time of occurrence of water and environmental stresses play an important role in most of the morphological and physiological processes of the plants bringing about negative impacts on yield components of the crop in study (Nóbrega et al., 2004). Such a crop, however only meets its water requirements when precipitation throughout the stages from sowing to physiological maturation ranges from 300 to 400 mm, demanding a uniform distribution at a given region (Maluf and Caiaffo, 2000).

Crop productivity and good quality of food constitute the main features to be pursued by the growers at their farms. Such features are highly important in agricultural systems, but are to be envisioned of a great deal of complexity with impacts that reside in the expression and association of different components (Carvalho et al., 2002; Amorim et al., 2008). According to Fehr (1987), grains yield potential is dependent on physiological processes that might directly and/or indirectly influence final production and grade.

Solar radiation, air and soil temperature, carbon dioxide concentration in the atmosphere, nitrogen content in the leaf, and soil water status are environmental factors influencing photosynthetic activity of the plants (Marenco and Lopes, 2005). The opening and closing of the stomata are related mainly to light intensity and water content of the leaf. Nevertheless, both the functioning of the stomata and leaf area index determine the level of crop productivity; the former for controlling the uptake of atmospheric carbon dioxide assimilation, the latter for promoting light interception by the canopy (Costa and Marenco, 2007).

Faced with the aforementioned, the aim of the current study was to assess yield components of beans and ecophysiological parameters of two different genotypes of this crop subjected to four distinct levels of soil water supply under protected environment conditions at Ponta Grossa, Paraná State, Brazil.

2 Materials and Methods

The experiment was carried out at a greenhouse belonging to the Agronomic Institute of Paraná – Agricultural Experiment Station of Ponta Grossa, throughout the year of 2016 within eight wooden beds. Soil was a dystrophic red latossol, clay textured, collected from a layer of 0 to 20 cm deep with the chemical and granulometric compositions described in Table 1.

Table 1 Chemical and granulometric attributes of the soil before the installation of the trial.

Composition content of the original soil													
pH	H+Al	Al^{3+}	Ca^{2+}	Mg^{2+}	K^+	CTC $_{(pH\ 7.0)}$	P	CO	Sand	Silt	Clay	V	m
	---------------------cmol$_c$ dm^{-3}---------------------						mg dm^{-3}	---------------g kg^{-1}---------------				-----%-----	
4.9	6.69	0.1	5.1	1.8	0.48	14.07	7.8	30	158	302	540	52.5	1.3

Notes: pH = hydrogenic potential in $CaCl_2$; H+Al = potential soil acidity; Al^{3+}, Ca^{2+}, Mg^{2+} e K^+ = aluminum, calcium, magnesium and changeable magnesium and potassium, respectively; CTC$_{(pH\ 7.0)}$ = potential cations exchange; P = available phosphorus (Melich^{-1}); CO = organic carbon (Walkley-Black); V and m = basis and aluminum saturation, respectively.

Soil correction for acidity by means of lime process was not necessary. Fertilization was performed at sowing date with 19.5 g per row of the 4-14-8 NPK formulation. At 25 days after emergency (DAE) nitrogen fertilizer in bands was applied at a rate of 7 g of urea row in compliance with the recommendation of IAPAR (2013). Sowing was made on March 10th, 2016 with two treated seeds per digging hole. After the first tree leaf emission roughing was performed by leaving only one plant per digging hole in the wooden beds.

The experimental design taken into account herein was a completely randomized design at a 2 × 4 factorial scheme (cultivars and soil water regimes) with six replications for yield components and four replications for crop ecophysiological parameters. For such a crop, yield components of two genotypes (Campos Gerais and Tuiuiú) under the influence of four regimes of soil humidity were assessed for agronomical purposes (35%, 28%, 21% and 14% on volumetric basis). Soil humidity within the stipulated levels at this trial was monitored by means of a Time Domain Reflectometer – TDR – portable manual device from Hydrosense. The ecophysiological parameters were analyzed at four distinct times through a LICOR Infrared Gas Analyzer (IRGA), model 6400-XT, Lincon, USA. By means of such portable equipment net photosynthesis (NP), stomachic conductance (SC), transpiration (Tr), and photosynthetic water use efficiency (WUE) were evaluated at 23, 30, 36 and 44 DAE.

Soil water supply was equal for all treatments up until 16 days after the emergency of the seedlings. Irrigation was applied based on the measurements provided by a TDR. The wooden beds possessed dimensions of 2.50 × 1.25 m each with six spaced rows at 40 cm a part, counting with 12 plants each one. Each row had one single drip strip comprised by eight emitters with a maximum outflow of 1.4 L h^{-1}. Rows related to the extremities of the beds along with plants at the position 1, 2, 11 and 12 along the row were selected to be border strips. Two central rows were utilized for assessment of yield components and two remaining rows were, therefore, ascribed to evaluate ecophysiological parameters responsiveness. Each bed was constituted of one cultivar and one soil water regime (Domingues, 2016).

At harvest of the crop the following response variables were measured: number of pods per plant (NPP), number of grains per pod (NGP), mass of grains per plant (MGP), a thousand grains mass (TGM), and yield (Y). For assessment of NPP, a viable pod was taken into account as that one which showed at least one formed grain. For the scrutiny of MGP and TGM pods were pinched and grains were weighed with a precision scale of 0.01 g and an error of 0.1 g. Afterwards grain moisture and its masses were corrected for 13% moisture in weight. One single plant as a replication was taken into consideration for the statistical analyzes to be applied to the experimental data, for both yield components of the crop and ecophysiological parameters.

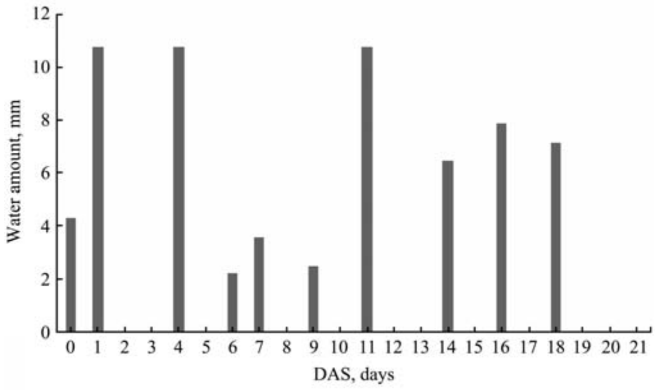
Experimental data were subjected to the analysis of variance with Test F application. The presuppositions of data normality were verified by means of the Shapiro-Wilk Test (p<0.05). Whenever data normality was not evidenced a Box Cox transformation factor was applied to the data. In order to denote the effect of treatments a Comparison Test of Averages Student-Newman-Keuls (S-N-K, p<0.05) was adopted to examine the performance of both beans genotypes, as well as a regression analysis study was performed to quantify the effect of all different soil water regimes on the measured response variables. Faced with interactions of the factors in study, such interactions were, however, partitioned for further investigations. Statistical analyses were made with the use of Assistat 7.7 software.

3 Results and Discussion

3.1 Water Supply

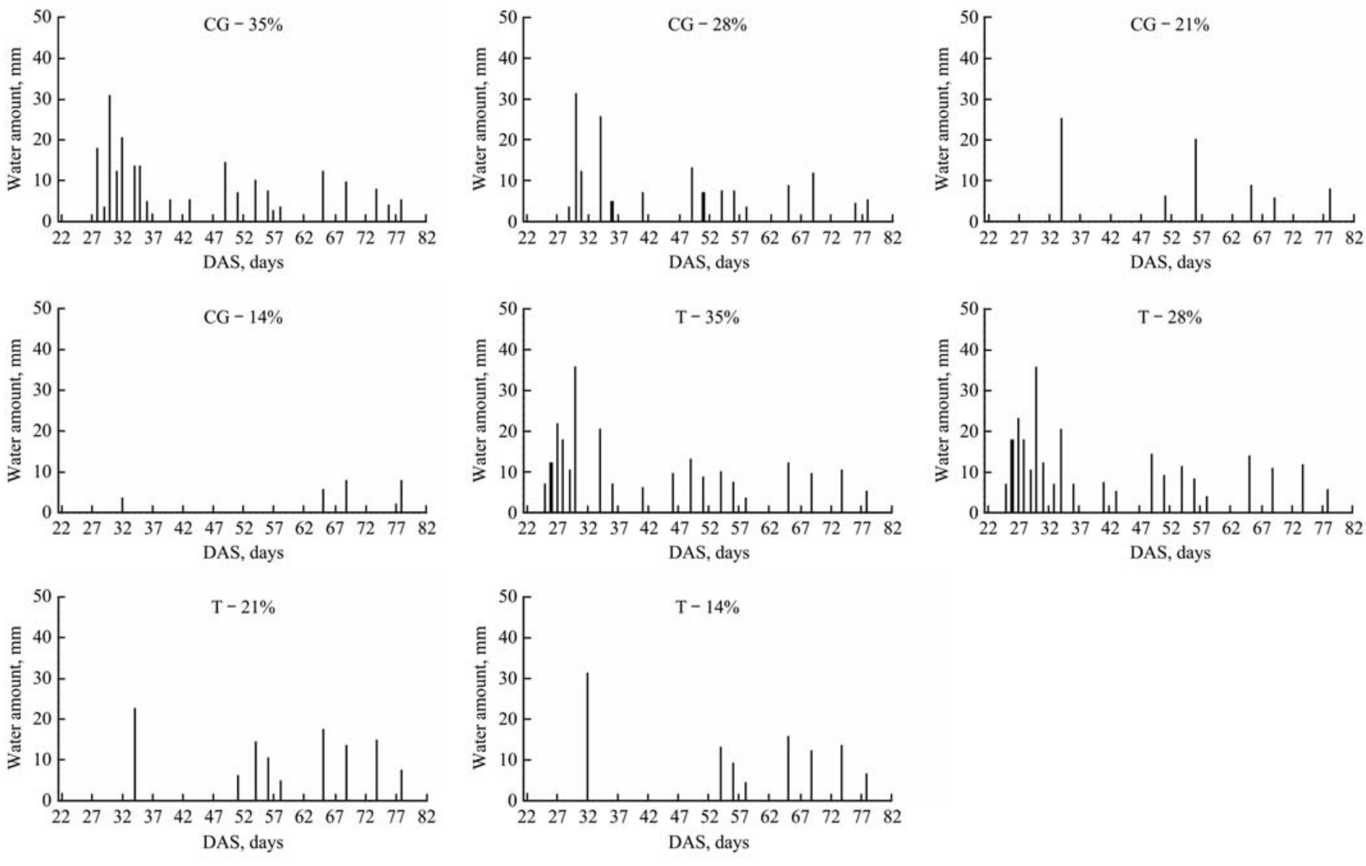
Data referring to the water amounts applied to the wooden beds are demonstrated in Figures 1 and 2. Figure 1 stipulates water application rates that were adopted in each wooden bed throughout the establishment phenological stage of the crop. All beds received the same amount of water during the initial development stage of the crop, with an overall water application rate corresponding to 66.4 mm at such a stage. After this crop period, each bed received the irrigation water regime previously proposed in the current research.

Figure 2 discriminates the different water application rates utilized shortly after the application of the treatments for each wooden bed as a function of the water supply regime established. Beds with more available water in the soil, such as 35% and 28%, received more water ranging from 154.83 to 263.44 mm for both treatments. Beds with less water in the soil, such as 21% and 14%, received water rates ranging from 25.09 to 113.12 mm. Water rates were applied in such a manner as to maintain soil humidity within the thresholds desired for each treatment. The number of irrigation episodes within each level of soil humidity was directly proportional to soil water content.



Note: DAS; days after sowing

Figure 1 Daily values of irrigation water application rates adopted at the initial development stage of beans plants grown under protected environment conditions as a function of days after sowing



Notes: DAS, days after sowing; CG, Campos Gerais; T, Tuiuiú.

CG – 35%: cultivar Campos Gerais with level of 35% soil moisture level; CG – 28%: cultivar Campos Gerais with level of 28% soil moisture level; CG – 21%: cultivar Campos Gerais with level of 21% soil moisture level; CG – 14%: cultivar Campos Gerais with level of 14% soil moisture level; T – 35%: cultivar Campos Gerais with level of 35% soil moisture level; T – 28%: cultivar Campos Gerais with level of 28% soil moisture level; T – 21%: cultivar Campos Gerais with level of 21% soil moisture level; T – 14%: cultivar Campos Gerais with level of 14% soil moisture level.

Figure 2 Irrigation water rates applied throughout the whole crop growing season of two cultivars of beans and number of irrigation episodes for each treatment of soil water supply as a function of days after sowing

3.2 Ecophysiological parameters

3.2.1 Net Photosynthesis (NP)

In Table 2, ecophysiological parameters determined for beans, cultivars Campos Gerais and Tuiuiú, are shown under protected environment conditions. The Tuiuiú cultivar presented a higher NP as opposed to Campos Gerais genotype during the evaluation made at 30 days after emergency (DAE) of the crop (Figure 3). Plants of beans described a linear behavior at 23 DAE, considering that NP values varied from 16.2 µmol to 20.3 µmol of

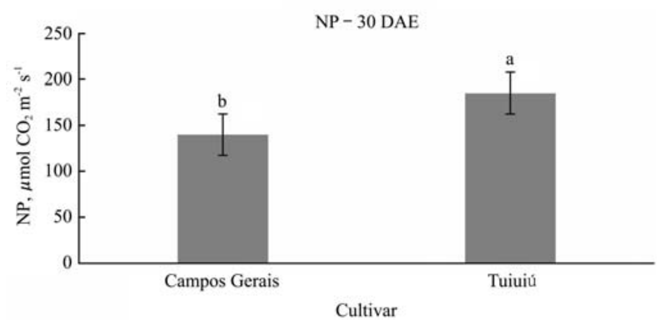
CO_2 m^{-2} s^{-1} (non-transformed values) (Figure 4).

Table 2 Summary of the analysis of variance for ecophysiological parameter net photosynthesis (NP) determined by means of an IRGA portable gadget

Source of Variation	F. D.	Mean Squares			
		23 DAE^T	30 DAE^T	36 DAE	44 DAE
Cultivar (C)	1	589.15^{ns}	16,531.2*	10.1106^{ns}	17.0784^{ns}
Water (W)	3	7977.54**	3,562.77^{ns}	15.2661^{ns}	0.2540^{ns}
C×W	3	3053.57^{ns}	134.53^{ns}	3.9073^{ns}	29.3322^{ns}
CV (%)		19.66	31.13	13.51	24.36

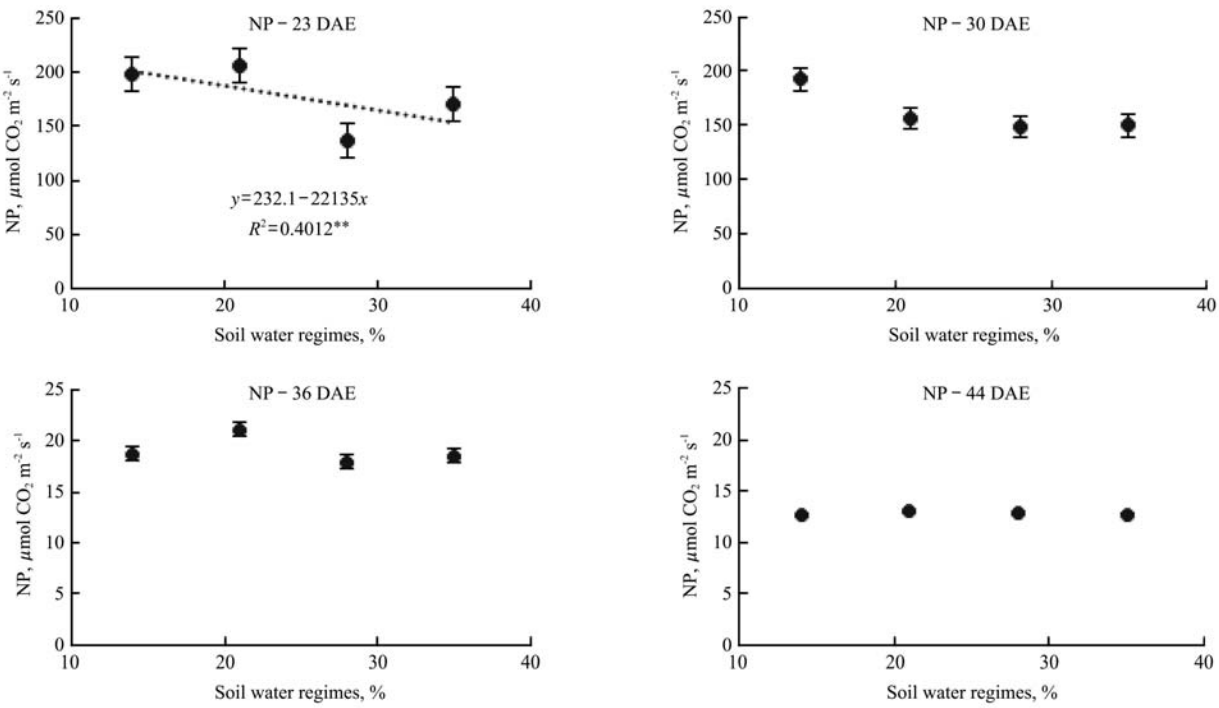
Notes: ns: non-significant at 5% and 1% of significance levels; T: values subjected to Box-Cox transformation; *, **: significant at 5% and 1% of significance levels, respectively; C. V.: Coefficient of Variation; F. D.: Freedom Degrees.

For other physiological times of the crop NP did not show significant statistical differences among treatments and, therefore, varied from 16.5 µmol to 19.5 µmol of CO_2 m^{-2} s^{-1} at 30 DAE (non-transformed values), of 17.9 µmol to 21.1 µmol of CO_2 m^{-2} s^{-1} at 36 DAE, and of 12.7 µmol to 13.1 µmol of CO_2 m^{-2} s^{-1} at 44 DAE. The lowest NP values obtained at 44 DAE might be associated to the lowest mean air temperature reached on that day (21.4°C).



Notes: Different letters for cultivar statistically differ between themselves by the S-N-K Test (p<0.05).

Figure 3 Net photosynthesis (NP) of two cultivars of beans grown under protected environment conditions



Notes: The 23 and 30 DAE data were transformed by Box-Cox factor. Different letters within the same soil water level statistically differ from themselves by the S-N-K Test (p<0.05).

NP – 23 DAE: net photosynthesis determined at 23 days after emergency; NP – 30 DAE: net photosynthesis determined at 30 days after emergency; NP – 36 DAE: net photosynthesis determined at 36 days after emergency; NP – 44 DAE: net photosynthesis determined at 44 days after emergency.

Figure 4 Net photosynthesis (NP) as a function of soil water regimes for each time of evaluation under the climatic conditions of protected environment

Biochemical reactions of the photosynthesis are affected by temperature resulting in complex responses (Taiz and Zeiger, 2004), under which C3 plants reach the highest possible photosynthesis rates at air temperature ranges of 20-30°C, with physiological peaks at 25°C (Kerbauy, 2004). Under low temperatures, photosynthesis turns out to become more limited owing to availability of phosphate on the chloroplast membrane (Taiz and Zeiger, 2004), and decreases rapidly if temperatures exceed thermal limits considered to be physiologically ideals (Kerbauy, 2004; Taiz and Zeiger, 2004). Chavarria et al. (2015), examining physiological responses in soybean plants under different soil water regimes, obtained the highest rates of NP under matric potentials in the soil of –40 and –60 cm of H_2O resulting in NP values of 19.30 and 18.39 μmol of CO_2 m^{-2} s^{-1}, respectively, corroborating the outcomes reported herein. Under matric potentials of –260 cm of H_2O a reduction of 53.22% in NP was found in comparison to the soil water regimes yoked to more negative potentials. Under matric potentials of –420 and –1640 cm of H_2O NP rates were to be null. Plants exposed to high atmosphere evaporative demands in conjunction with precarious soil water regimes tend to reduce stomata conductance in such a way as to diminish water loss and maintain hydric equilibrium. Thus, the more pronounced soil water deficiency the lower stomachic conductance will be and, consequently, the lower atmospheric carbon dioxide assimilation rate will also be (Kerbauy, 2004). Nevertheless, the availability of photo assimilates under water restricted conditions will then be scarce for pods filling of beans in production fields (Oliveira et al., 2005).

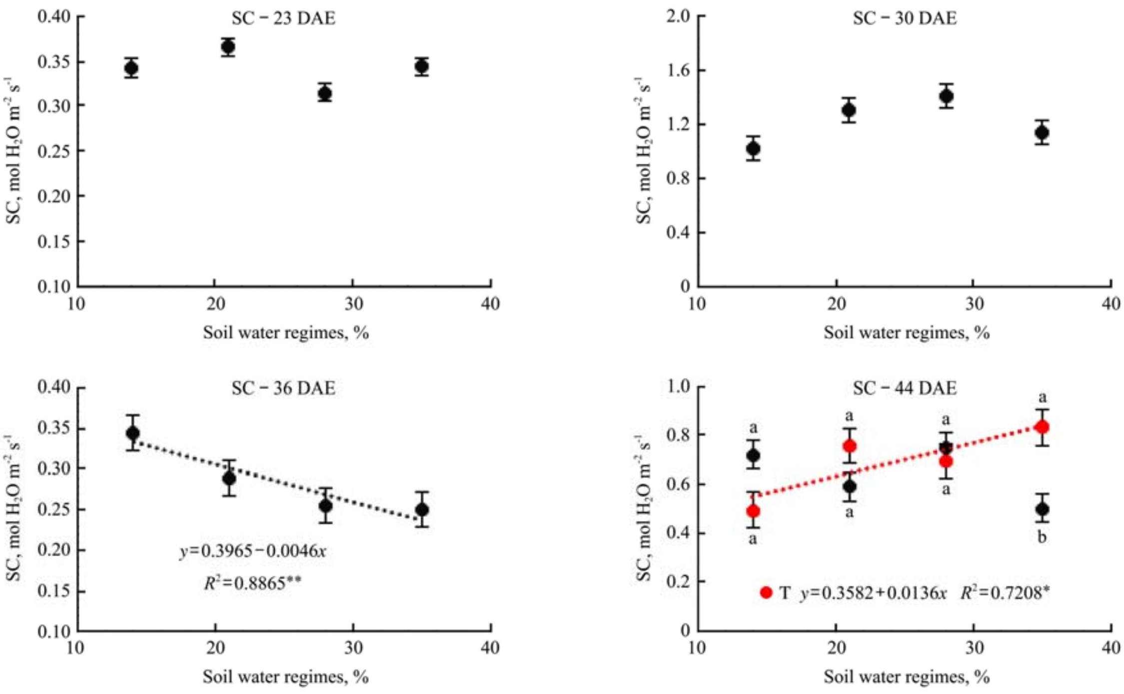
3.2.2 Stomachic conductance (SC)

SC did not differ among treatments at the 95% reliability level for all times of evaluation and both cultivars (Table 3). The physiological response of the plants under the soil water regimes in study was described by a linear model at 36 and 44 DAE (Figure 5). At other times SC values did not differ among themselves. Plants of beans evidenced SC ranging from 0.32 mol to 0.36 mol of H_2O m^{-2} s^{-1} at 23 DAE, of 0.38 mol to 0.63 mol of H_2O m^{-2} s^{-1} at 30 DAE, of 0.25 mol to 0.34 mol of H_2O m^{-2} s^{-1} (non-transformed values) at 36 DAE, and of 0.13 mol to 0.16 mol of H_2O m^{-2} s^{-1} at 44 DAE (non-transformed values). SC revealed significant effects for the interaction between cultivar and soil water regimes at 44 DAE, with the cultivar Tuiuiú selected as the one with a better performance compared to Campos Gerais' at 35% of soil moisture on volumetric basis (Figure 5).

Table 3 Summary of the analysis of variance for ecophysiological parameter stomachic conductance (SC) determined by means of an IRGA portable gadget

Source of Variation	F. D.	Mean Squares			
		23 DAE	30 DAE^T	36 DAE	44 DAE^T
Cultivar (C)	1	0.0255^{ns}	0.3845^{ns}	0.00002^{ns}	0.0238^{ns}
Water (W)	3	0.0035^{ns}	0.2373^{ns}	0.01540**	0.0184^{ns}
C×W	3	0.0090^{ns}	0.0563^{ns}	0.00247^{ns}	0.1201*
CV (%)		24.42	37.80	22.24	27.99

Notes: ns: non-significant at 5% and 1% of significance levels; T: values subjected to Box-Cox transformation; *, **: significant at 5% and 1% of significance levels, respectively; C. V.: Coefficient of Variation; F. D.: Freedom Degrees.



Notes: Measurements taken at 30 and 44 DAE were transformed by Box-Cox factor and summed to the factor 2. CG: Campos Gerais. T: Tuiuiú. Different letters within the same soil water regime statistically differ among themselves by the S-N-K Test (p<0.05).

SC – 23 DAE: stomachic conductance determined at 23 days after emergency; SC – 30 DAE: stomachic conductance determined at 30 days after emergency; SC – 36 DAE: stomachic conductance determined at 36 days after emergency; SC – 44 DAE: stomachic conductance determined at 44 days after emergency.

Figure 5 Stomachic conductance (SC) as a function of soil water regimes under the protected environment conditions

Oliveira et al. (2005) obtained SC values varying from 0.1216 mol to 0.1470 mol of H_2O m^{-2} s^{-1} for vegetative growth and from 0.0698 mol to 0.1220 mol of H_2O m^{-2} s^{-1} during the flowering stage of the crop, being such values quite lower than those found herein. Soil humidity treatments were defined by the aforementioned authors as a function of the water deficit level adopted over the course of irrigation. Therefore, irrigation was applied whenever accumulated ETc was equivalent to 22 (T1), 33 (T2) and 44 (T3) mm plus a water treatment considered only for the establishment of the crop (T4). SC values reported by such authors were higher under treatments of adequate soil water supply. Treatments T2, T3 and T4 were conducive to a reduction in SC throughout the flowering. Paiva et al. (2005) assessed SC in irrigated beans as a function of the depletion fraction of soil water capacity (SWC): T1, irrigated when 40% of SWC was depleted; T2, when 60% of SWC was depleted; T3, when there was a reduction of 80% of SWC; T4, non-irrigated treatment. Such researchers found a remarkable difference between T1 and T4 treatments over the course of the crop growing season. SC were of 0.4560 mol of H_2O m^{-2} s^{-1} at the phenological stage V4 and of 0.7266 mol of H_2O m^{-2} s^{-1} at the phenological stage R6 for T1, as well as of 0.3220 mol of H_2O m^{-2} s^{-1} at V4 stage and of 0.4408 mol of H_2O m^{-2} s^{-1} at the phenological stage R6 for T4.

According to Silva et al. (1998), under conditions of a low soil humidity the stomata get closed shortly early in the morning and at such environmental condition the physiological response of the plants is much more significantly governed by the water status in the plant than it is by the availability of radiant energy for photosynthesis. Reductions in SC as a result of a low availability of soil water triggers a fall in water potential of the leaves, causing the stomata to close and also leading the cells to lose its turgescence (Nascimento et al., 2011).

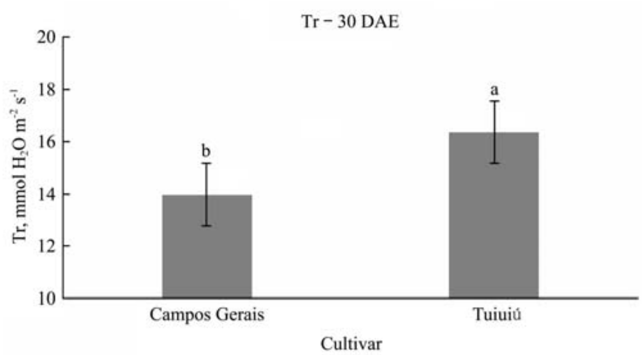
3.2.3 Transpiration (Tr)

For Tr a significant effect of the cultivar factor at 30 DAE, as well as of the interaction between both cultivar and soil water regime at 44 DAE was observed (Table 4). The Tuiuiú cultivar presented a higher Tr rate in relation to Campos Gerais' (Figure 6). In Figure 7 transpiration rates under the four soil water regimes showed a proclivity that might be described by a quadratic model at 23 DAE, and a linear increasing pattern at the other times of evaluation. In general, no expected effects of soil water regimes on Tr have been noticed under protected environment conditions. This is because probably the energetic availability within the canopy which received less water irrigation rates masked the responsiveness of the beans plants to soil water regimes considered in the current study.

Table 4 Summary of the analysis of variance for ecophysiological parameter transpiration rate (Tr) determined by means of an IRGA portable gadget

Source of Variation	F. D.	Mean Squares			
		23 DAE	30 DAE^T	36 DAE	44 DAE
Cultivar (C)	1	0.2888^{ns}	45.2459*	2.7596^{ns}	1.0041^{ns}
Water (W)	3	1.8575^{ns}	91.7898**	17.3384**	0.4325^{ns}
C×W	3	0.4305^{ns}	24.3355^{ns}	2.2026^{ns}	1.5682*
CV (%)		6.78	20.60	18.17	31.81

Notes: ns: non-significant at 5% and 1% of significance levels; T: values subjected to Box-Cox transformation; *, **: significant at 5% and 1% of significance levels, respectively; C. V.: Coefficient of Variation; F. D.: Freedom Degrees.

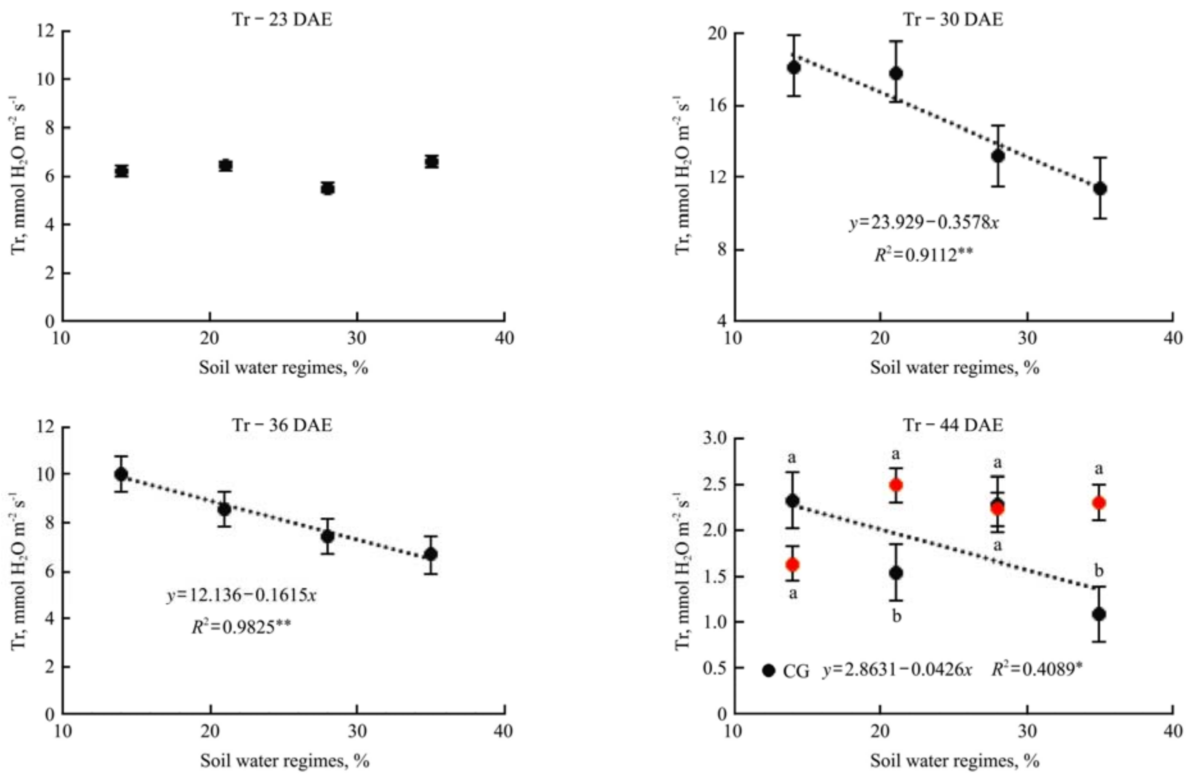


Notes: Different letters for cultivar differ statistically between themselves by the S-N-K Test (p<0.05).

Figure 6 Transpiration rates (Tr) of beans grown under protected environment conditions

3.2.4 Water Use Efficiency (WUE)

Concerning WUE there was no effect of the cultivars as a function of all different soil water regimes (Table 5). The trend of WUE might be described by a linear model with limits ranging from 2.775 to 3.234 [(μmol of CO_2 m^{-2} s^{-1}) (mmol of H_2O m^{-2} s^{-1})$^{-1}$] at 23 DAE, and of 1.888 to 2.806 [(μmol of CO_2 m^{-2} s^{-1}) (mmol of H_2O $m^{-2}s^{-1}$)$^{-1}$] at 36 DAE (Figure 8). At the other times of assessment WUE did not differ among themselves due to soil water status.



Notes: Measurements taken at 30 DAE were transformed by the Box-Cox factor. CG: Campos Gerais. T: Tuiuiú. Different letters within the same soil water regime differ statistically among themselves by the S-N-K Test (p<0.05).

Tr – 23 DAE: transpiration rates determined at 23 days after emergency; Tr – 30 DAE: transpiration rates determined at 30 days after emergency; Tr – 36 DAE: transpiration rates determined at 36 days after emergency; Tr – 44 DAE: transpiration rates determined at 44 days after emergency.

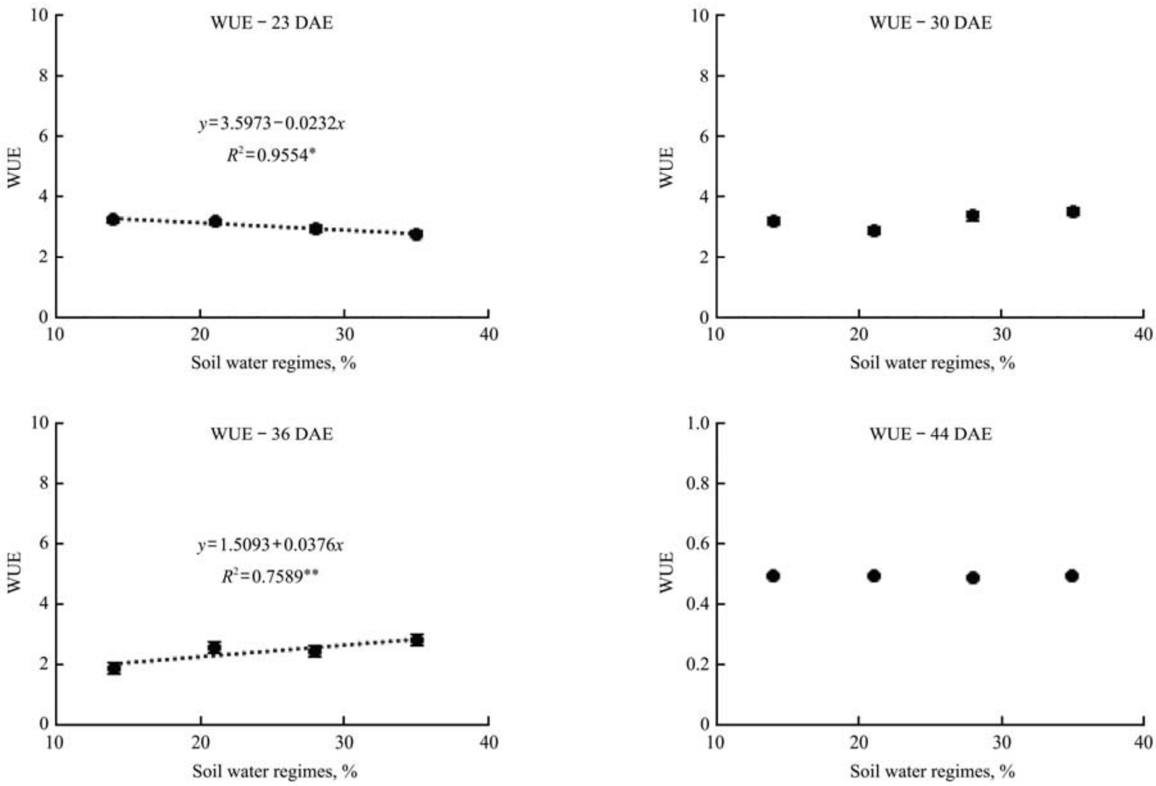
Figure 7 Transpiration rates (Tr) as a function of soil water regimes under protected environment conditions

Likewise in the current study, Xiao et al. (2016) obtained a rise in WUE throughout the flowering stage of beans grown at arid regions of China. Values of WUE were found to be of 3 [(μmol of CO_2 m^{-2} s^{-1}) (mmol of H_2O m^{-2} s^{-1})$^{-1}$] at the vegetative development, increased to up to over 6 [(μmol of CO_2 m^{-2} s^{-1}) (mmol of H_2O m^{-2} s^{-1})$^{-1}$] at the flowering stage. Fernández et al. (2002), scrutinizing physiological responses on cassava subjected to two concentration levels of atmospheric carbon dioxide (CO_2), observed a lower SC from plants exposed to a higher CO_2 concentration. Therefore, the partial closing of the stomata brought about a rise in WUE given a high photosynthetic rate, resulting in a greater accumulation of phytomass per unit of transpired water (Gabriel et al., 2013). In the same fashion, in the current study due to the time of evaluation where WUE was higher, SC was conducive to low rates. Tenhunen et al. (2002) reached the conclusion that global warming accelerated crop transpiration rates and soil evaporation process, and triggered fluctuations in WUE at arid and semiarid regions. WUE from crops under the influence of prevailing ecological systems decreased with soil water depletion and this demonstrates that photosynthesis is strongly influenced by other variables a part from the stomachic factor. Zhao et al. (2007) discovered that NP and SC in wheat throughout the grain filling phenological stage at semiarid regions diminished severely, and transpiration rates increased with the elevation of air temperature. Thus, photosynthesis and accumulation of dry substances were inhibited and as a result WUE dropped drastically.

Table 5 Summary of the analysis of variance for ecophysiological parameter water use efficiency (WUE) determined by means of an IRGA portable gadget

Source of Variation	F. D.	Mean Squares			
		23 DAE	30 DAE	36 DAE	44 DAE^{T}
Cultivar (C)	1	0.4924^{ns}	0.2623^{ns}	0.4770^{ns}	0.00003^{ns}
Water (W)	3	0.3679*	0.5803^{ns}	1.2168**	0.00006^{ns}
C×W	3	0,.2347^{ns}	0.2796^{ns}	0.4576^{ns}	0.00005^{ns}
CV (%)		12.13	14.93	16.19	1.06

Notes: ns: non-significant at 5% and 1% of significance levels; T: values subjected to Box-Cox transformation; *, **: significant at 5% and 1% of significance levels, respectively; C. V.: Coefficient of Variation; F. D.: Freedom Degrees.



Notes: Measurements taken at 44 DAE were transformed by Box-Cox factor. Different letters within the same soil water regime statistically differ from themselves by the S-N-K Test (p<0.05).

WUE – 23 DAE: water use efficiency determined at 23 days after emergency; WUE – 30 DAE: water use efficiency determined at 30 days after emergency; WUE – 36 DAE: water use efficiency determined at 36 days after emergency; WUE – 44 DAE: water use efficiency determined at 44 days after emergency.

Figure 8 Water use efficiency (WUE) as a function of soil water regimes under protected environment conditions.

3.3 Yield components and yield

In Table 6, the outcomes concerning yield components of plants of beans subjected to different soil water regimes under protected environment conditions are presented. The NPP depicted a linear tendency under the different regimes of soil water, i.e., in so far as soil water supply increases a linear increment was observed on the response variable in study (Figure 9). The highest NPP obtained herein was of 10.25 and the lowest one was of 7.08 under the soil water levels of 35% and 14%, respectively. Tatagiba et al. (2013) assessed beans yield at protected environment conditions with plants subjected to soil humidity regimes of 100% and 50% of field capacity. Plants submitted to soil humidity levels corresponding to 100% of field capacity showed mean values of NPP higher than those obtained from plants under 50% of field capacity under the climatic conditions of Viçosa, MG, Brazil. However, NPP measured in the current study were higher than those found by Tatagiba et al. (2013). None interaction effect between cultivar and soil water status has been noticed herein.

Table 6 Summary of the analysis of variance for number of pods per plant (NPP), number of grains per pod (NGP), grain mass per plant (GMP), a thousand grains mass (TGM) and production per hectare or yield (Y) from a population of beans grown under protected environment conditions. Ponta Grossa, PR, Brazil

Source of Variation	F. D.	Mean Squares				
		NPP	NGP	GMP	TGM	Y
Cultivar (C)	1	2.5208^{ns}	0.2552^{ns}	4.6563^{ns}	62.9979**	291019^{ns}
Water (W)	3	27.5764**	0.3835^{ns}	17.8835**	12.2238^{ns}	1117717**
C×W	3	2.0208^{ns}	3.5806**	3.3572^{ns}	10.2040^{ns}	20982^{ns}
C.V. (%)		18.94	12.22	25.57	12.47	25.57

Notes: ns: non-significant; *, **: significant at 5% and 1% of reliability, respectively; D. F.: Degree of Freedom; C. V.: Coefficient of Variation.

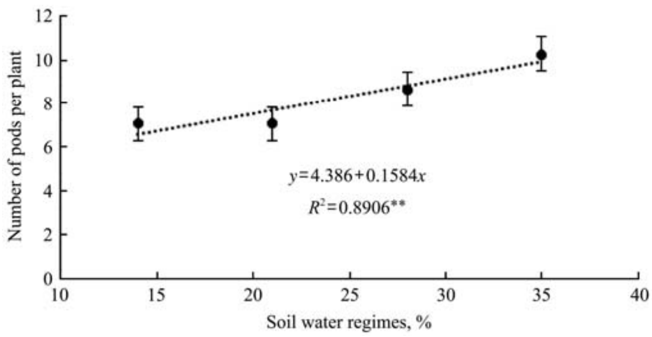
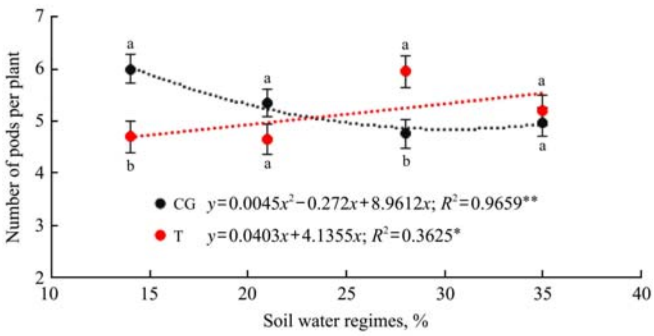


Figure 9 Number of pods per plant (NPP) from beans as a function of soil water regimes under protected environment conditions

NGP was conditioned by neither cultivar nor soil water status. However, the interaction effect between cultivar and soil water supply was observed in the current study (Table 2). For the Campos Gerais cultivar soil water regime of 14% provided the highest NGP in plants of beans as opposed to the soil water regimes of 35% and 28% at 95% of reliability. Whereas the Tuiuiú cultivar under the soil water level of 28% generated the highest NGP in relation to other soil water treatments. Campos Gerais cultivar performed better than Tuiuiú cultivar under a soil water regime of 14%. Under the soil water level of 28% Tuiuiú had a superior performance when compared to Campos Gerais genotype. On the other hand, under both 35% and 21% soil water treatments none significant differences of NGP were obtained between cultivars (Figure 10).



Notes: CG, Campos Gerais. T, Tuiuiú. Different letters within the same soil water regime statistically differ from themselves by the S-N-K Test ($p<0.05$).

Figure 10 Number of grains per pod (NGP) as a function of soil water regimes for both beans cultivars, Campos Gerais and Tuiuiú, under protected environment conditions

By evaluating two groups of beans genotypes "black" and "carioca", Aguiar et al. (2008) came across distinct physiological behaviors for such a characteristic within both groups subjected or not to soil water restriction for over 20 days from the beginning of the flowering stage.

Likewise NPP, GMP did not suffer any influence of the cultivar factor (Table 2) and demonstrated a linear positive correlation for the soil water regimes (Figure 11). The GMP peak was of 9.84 g and its minimum value was of 7.07 g under the 35% and 21% soil water regimes, respectively. Aguiar et al. (2008) obtained a significant reduction in GMP ranging from 52.5% to 69.1% for the genotypes belonging to the group "black", as well as from 36.8% to 62.8% for those within the category of "carioca" both submitted to water restriction imposed over 20 days after the beginning of the flowering stage.

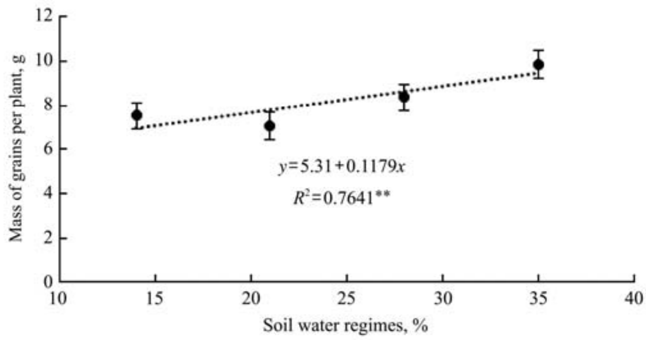
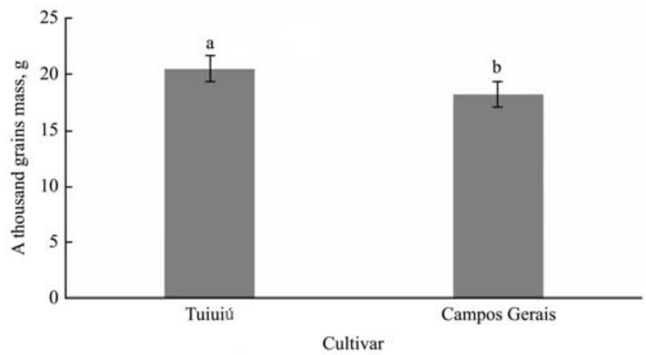


Figure 11 Mass of grains per plant (MGP) from beans as a function of soil water regimes under protected environment conditions

For TGM Tuiuiú cultivar revealed a superior performance in relation to Campos Gerais cultivar (Figure 12). Such a difference in response might be explained by the visual and physiological aspects of the seeds.



Notes: Different letters for cultivar statistically differ between themselves by the S-N-K Test ($p<0.05$).

Figure 12 A thousand grains mass (TGM) of beans crop as a function of cultivars under protected environment conditions

By assessing the genotype groups of beans "black" and "carioca", Aguiar et al. (2008) garnered distinct responsiveness between the studied groups for such a crop yield component. Isolated effects of soil water regimes were not observed, as well as interaction effects between cultivar and soil humidity factors on the TGM of beans could not be found.

Water deficiency throughout flowering stage of the crop promoted flowers abscission with a consequent reduction in the number of pods. During the grains filling stage lack of water in the soil result in significant reductions in both number of grains and weight of pods (Oliveira et al., 2005).

Actual yield was expressed by a linear positive correlation for the factor soil water regime (Figure 13).

The peak of actual yield was of 2,460 kg ha^{-1} and its minimum value was corresponding to 1,767 kg ha^{-1} under the soil water regimes of 35% and 21%, respectively.

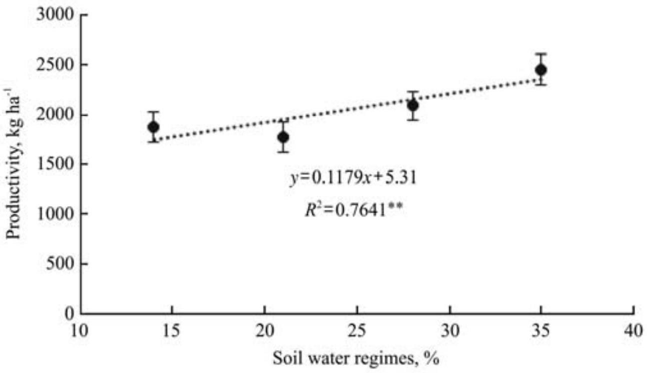


Figure 13 Actual yield of beans as a function of soil water regimes under protected environment conditions

4 Conclusions

Soil humidity within the levels stipulated in the current work did not integrally affect physiological responsiveness of both genotypes of beans grown under protected environment conditions. However, yield components and final productivity throughout crop production formation stages were highly conditioned by soil water status.

Stomachic transpiration and a thousand grains mass of the Tuiuiú cultivar were higher than those obtained for Campos Gerais cultivar, evidencing influence of the genotypes on the physiological responsiveness of beans.

The number of pods per plant and the mass of grains per plant were not consistently conditioned by the genotypes of beans submitted to different soil water regimes. Nevertheless, crop yield components were strongly affected by soil water status.

Both cultivars of beans were significantly more productive under adequate soil water supply along with microclimate under a protected environment, having been attained a yield gap of roughly 30% between 35% and 14% volumetric soil water treatments.

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