Beans cultivation and water regime on soil physical attributes

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Abstract: Beans crop is an agricultural staple largely consumed in Brazil because it is part of the basic food of the population. Such a crop is usually grown by small growers and turns out to be one of a great social and economic importance. The aim of the current manuscript was to scrutinize the effect of soil water status on its physical attributes, such as bulk density, total porosity, macroporosity, microporosity, hydraulic conductivity under protected environment conditions on beans crop (*Phaseolus vulgaris* L.). The effect of the soil physical attributes on the biological response of the plants was also investigated. The experiment was installed in March of 2016 in a greenhouse. The experimental design was completely randomized in a factorial scheme with four replications. The soil moisture within the stipulated levels (14%, 21%, 28% and 35% at a volume basis) was monitored by a TDR. Bulk density and microporosity did show an increasing linear trend as a function of the soil moisture levels adopted, whereas total porosity and macroporosity revealed a decreasing linear tendency. The cultivar factor affected bulk density, total porosity and macroporosity. The saturated hydraulic conductivity of the soil did not demonstrate any correlation with crop yield components and was not governed by the beans' genotypes grown under protected environment conditions.

Keywords: *Phaseolus vulgaris* L, hydraulic conductivity, soilmoisture, macroporosity, microporosity, bulk density

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1 Introduction

Beans crop (*Phaseolus vulgaris* L.) has been in the spotlight in Brazil for being one of the main staples for the scenario of food security that is largely consumed by the Brazilians and for being part of the basic food of the population (Cunha et al., 2013). It deals with a crop that possesses a remarkableeconomic importance either nationallyor regionally, and comes to be one of the main sources of protein in the human diet depicting a ratherbroad geographical distribution (Barbano, 2003; Cunha et al., 2013).

With a production of three millions of tons and an average productivity of 1,013 kg ha^{-1}, referring to the growing seasons 2014/2015, Brazil stood out in the world survey as the largest producer and consumer of beans with the main producing states being Paraná, Bahia, Minas Gerais, São Paulo and Goiás (Carvalho et al., 2014; CONAB, 2016).Beans are usually grown by small growers and have been showing an outstanding relevance at the familiar agriculture scale (Lopes et al., 2011).

An adequate crop management might bring about benefits either to the environment orto the yield. Among the management techniques recommended to the crop, irrigation is at the top of the list to maximize yield, reduce costs of production in the field and mitigate effects of climatic risks such as soil water deficiency (Pacheco et al., 2012).

Water plays a crucial role in most of the physical, chemical and biological attributes, as well as processes taking place in the soil, such as water movement, compaction, aeration and root growth and development (Dane and Topp, 2002; Rodrigues et al., 2012). By acting out as a linking agent amidst soil particles, water

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influences stability of its structure and also soil resistance (Dane and Topp, 2002). Thus, cycles of wetting and drying might promote modifications on soil structure, mainly on pores distribution which impinges upon a temporal and spacial distribution of water in such a porous means, and therefore such processes affect water and nutrients retention (Pires et al., 2005).

Soils are strongly characterized by the physical attributes, which determine their potential of use at a given site (Fernández-Ugalde et al., 2009) and play an important role in the development of the plants (Basso et al., 2011). Adequate soil porosities are quite fundamental for soil aeration, water infiltration and root distribution, making it possible a better crop development in production fields (Pires et al., 2005).

Faced with the aforementioned the main aim of the current manuscript was to examine the influence of different cultivars of beans (*Phaseolus vulgaris* L.) and soil water status on the soil physical attributes under protected environment conditions at Ponta Grossa, State of Paraná, Brazil.

2 Materialand methods

The experiment was carried out at a greenhouse belonging to the Agronomic Institute of Paraná – Agricultural Experiment Station of Ponta Grossa, PR, Brazil, throughout the year of 2016 within eight wooden beds. The geographical coordinates of the studied site are 25°5′40″ of South latitude, 50°9′48″ of West longitude, and altitude of 956 m above sea level. The Köppen climatic classification is Cfb. Soil was a dystrophic red latossol, clay textured, plowed, and 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

Note: pH = hydrogenic potential in $CaCl_2$; H+Al = potential soil acidity; Al^{3+}, Ca^{2+}, Mg^{2+} and 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.

The trial was carried out within eight wooden beds with seized soil in an 8mm-mash. The dimensions of the beds were 2.50 m×1.25 m, with each one containing sixsowing rows and 12 plants per row. Row spacing was of 0.40 m and the number of plants per meter was ten. Water management was provided by a drip irrigation system with each sowing row containing one single drip strip at a 0.05 m distance. The drip strip comprised eight drippers spaced 0.15 m apart from one another, and each dripper performed at a maximum rate of 1.4 L h^{-1}.

Beans seeds were manually planted in March of 2016 with two seeds per hole. Shortly after emission of the third trefoil thinning was made in order to leave just one single plant per pit. Soil correction for acidity by means of lime process was not necessary. Soil fertilization was preceded at the sowing date with 19.5 g per row (374.4 kg ha^{-1}) of a 4-14-8 NPK formulation in compliance with technical recommendations of IAPAR (2003). Moreover at 25 days after emergence nitrogen fertilizer was applied in bands under an amount of 7 grams of urea per row, corresponding to 134.4 kg ha^{-1} of N fertilizer (IAPAR, 2003). Harvest was made in May of 2016 after crop physiological maturity came to fruition.

Prior to application of the treatments soil in all of the wooden beds was subjected to eight wetting and drying cycles (W-D). Beds received the same amount of water throughout the initial establishment phenological stage of the crop with a 66.4 mm of water applied at such a phase. As soon as water treatments were adopted in the trial considering four different levels of soil volumetric moisture (θ), each wooden bed received the water amount necessary to maintain θ at stipulated previously levels in the current study.

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 yield components of the crop.

The experimental design was completely randomized with treatments arranged in a 2×4 factorial experiment under four replications. The treatments refer to a combination of two genotypes of beans (Tuiuiú and Campos Gerais) and four levels of soil volumetric moisture (14%, 21%, 28%, 35%). The irrigation treatments were applied at 16 days after emergence of the seedlings. Irrigation was conducted taking into account daily measurements of θ by means of a HydroSense™ Time Domain Reflectometer (TDR) (Campbell Scientific, Inc.) in such a way as to maintain θ within the desired thresholds for each treatment. Before application of the treatments all of the wooden beds received the same amount of water in order to reach field capacity.

At the final crop growth cycle four non-deformed soil samples were taken out from the experimental area for each crop row at an average depth of 7.5 cm. Each sample collection was made with the use of volumetric rings confectioned in iron with an approximate volume of 62.8 cm^3 (roughly 4 cm×5 cm of inner diameter and height, respectively).

After an appropriate preparation procedure, soil samples were saturated by a capillary ascension process (Klute, 1986). After saturation, the following thresholds of soil matric potential (Ψ_m) were applied: –10, –20, –40, –60, –80 and –100 cm H_2O at a tension table (model M-0801, Heijkamp®). Such measurements were taken aiming at scrutinizing an existing relationship between θ, retained under distinct values of Ψ_m, and the different macroscopic physical attributes of the soil.

Soil texture analysis was performed by the classical method of pipette. Soil density (BD) was determined by the volumetric ring method, particles density (PD) was obtained by the conventional picnometry approach (EMBRAPA, 1997), and total porosity (TP) was defined by the relationship between BD and PD (Dane and Topp, 2002). Microporosity (MI) was calculated by the water content retained in the soil at a matric potential of –60 cm H_2O (pore radius equivalent to ~25 μm). Macroporosity (MA) was determined by the difference between TP and MI. Saturated hydraulic conductivity (K_0) was obtained by making use of a constant charge permeation meter (EMBRAPA, 1997).

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 S-N-K (Student-Newman-Keuls -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 (Silva and Azevedo, 2016). Pearson correlation analysis was also considered herein in order to verify the degree of agreement between soil physical attributes and crop yield components.

3 Results and discussion

3.1 Water supply

Figure 1 discriminates different water rates used after the application of the treatments in each one of the wooden beds as a function of the stipulated water supply condition. In the beds related to the Campos Gerais cultivar the following water rates were applied: 216.1; 154.8; 79.6 and25.1 mm, respectively, for 35%, 28%, 21% and 14% of θ. In beds where Tuiuiú cultivar was grown the following amounts were applied: 231.5; 263.4; 113.1 and 106.7 mm for the same soil water levels, respectively.

It is opportune to mention that the number of irrigation episodes within each level of soil moisture is directly proportional to θ. The higher θ determined by the TDR the greater the number of irrigation episodes to be adopted throughout the crop growing season (Figure 1).

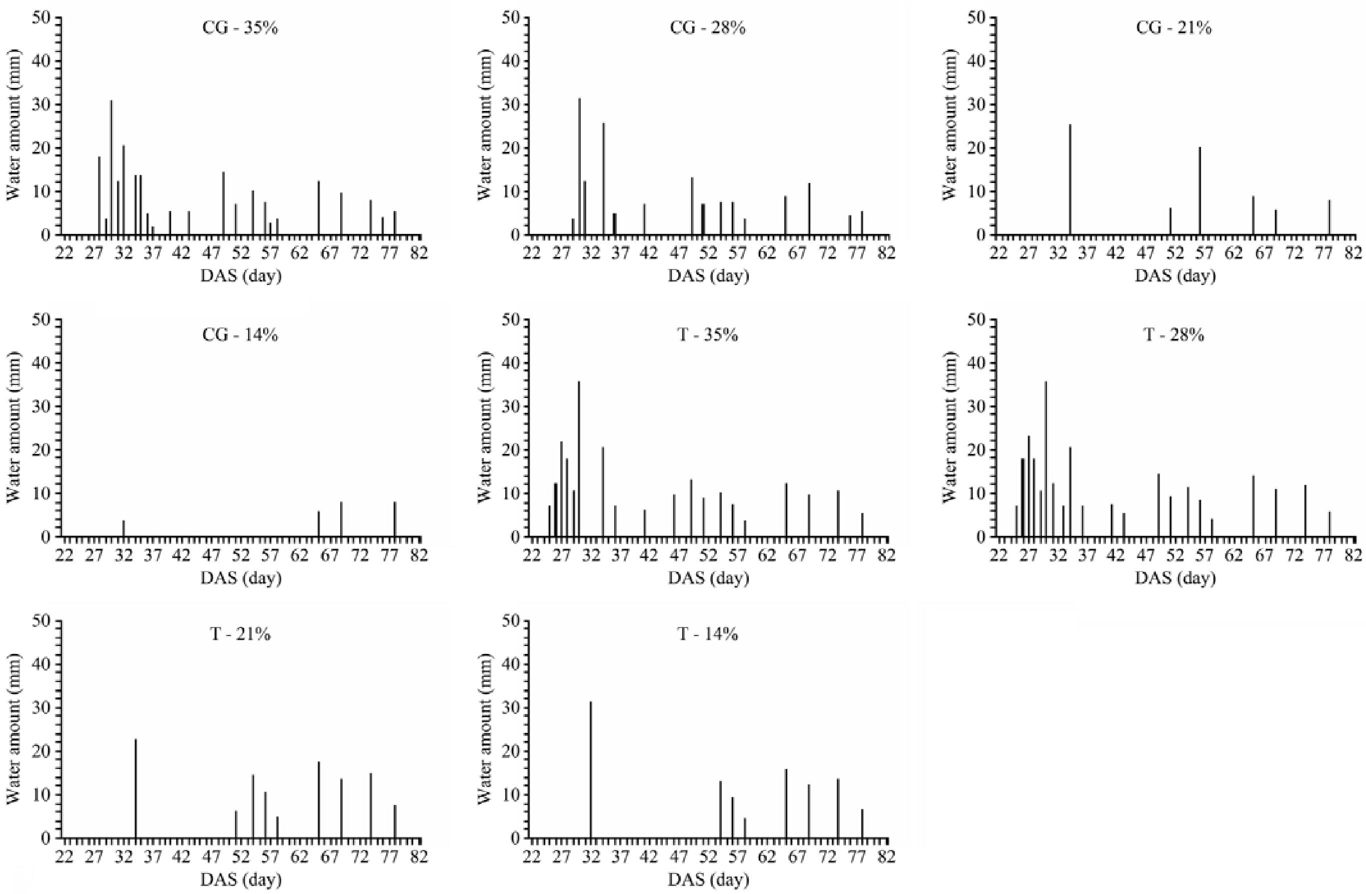

Figure 1 Irrigation water rates applied throughout the whole crop growing season of two cultivars of beans and number of irrigation episodes for each treatment of soil water supply as a function of days after sowing

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

Therefore, for the different levels of θ, the soil was subjected to distinct W-D cycles (Table 2).

Table 2 Number of irrigation episodes applied to the soil for different levels of volumetric soil moisture (θ)

Cultivar	θ (%)			
	35	28	21	14
Campos Gerais	22	15	7	4
Tuiuiú	19	21	10	10

3.2 Soil physical attributes

BD was significantly affected by the cultivar factor (Table 3), having been the Campos Gerais genotype superior to the Tuiuiú one (Figure 2). Soil water status correlated positive and linearly to BD (Figure 3a), with the highest value of BD corresponding to 0.88 g cm^{-3} and the lowest one to 0.82 g cm^{-3} under 35% and 14% of θ, respectively.

Taking into consideration that the soil filled in the wooden bedsdid not possess structure, the action of W-D cycles favored the rearrangement of the microaggregates in the soil in such a manner as to promote an increase in BD under different levels of θ (Sarmah et al., 1996; Li et al., 2004; Pires et al., 2005; Pires et al., 2007; Piresand Cooperet al., 2008; Pires et al., 2014).

Pires and Bacchi (2010), assessing the behavior of soil deformed samples subjected to different W-D cycles, verified an increase in BD faced with an increasing number of W-D cycles. Such increment in BD was due to the settling of soil particles shortly after the action of W-D cycles (Bressonand Moran, 1995). The application of just one single W-D cycle is to be enough to bring about important changes on soil structure.

TP was also conditioned to the cultivar factor (Table 3), reporting that for the Tuiuiú genotype the aforementioned soil physical attribute was superior to the Campos Gerais cultivar (Figure 2). TP correlated negative and linearly to soil water regimes (Figure 3b). The highest value of TP was 0.653 cm^3 cm^{-3} for 14% of θwhilst the lowest one was of 0.63 cm^3 cm^{-3} for 35% of θ. The sequence of W-D cycles was conducive to a rearrangement of soil particles and microaggregates, for throughout such a process particle got in touch with each other making it possible its aggregation and, therefore, modifying the soil porous system as a whole (Sartori et al., 1985; Piresand Cooperet al., 2008).

Table 3 Variance analysis with application of the Test F for BD, TP, MA, MI, and hydraulic conductivity (K_0) (transformed data) under the influence of the factors in study for plants of beans grown under protected environment conditions

Source of Variation	G.L.	Mean Squares				
		BD	TP	MA	MI	K_0^T
Cultivar (C)	1	0.00305*	0.00055*	0.00253*	0.00072^{ns}	0.00737^{ns}
Water (W)	3	0.00833**	0.00149**	0.01040**	0.00404**	0.40831*
C×W	3	0.00142^{ns}	0.00026^{ns}	0.00086^{ns}	0.00018^{ns}	0.05464^{ns}
C.V. (%)		3.11	1.73	7.97	3.86	25.48

Note: ns –non significant; T – Values subjected to the Box-Cox transformation; *,**- significant at 5% and 1% of reliability, respectively; C.V. – Coefficient of Variation; F. D.: Freedom Degrees.

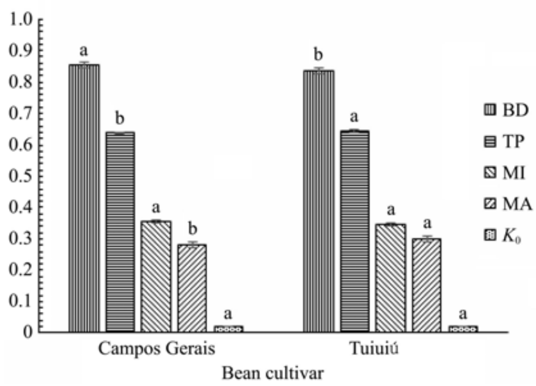

Figure 2 BD, TP, MA, MI and K_0 under the influence of the cultivar factor for plants of beans grown under protected environment conditions

Note: Different letters for the same soil physical attribute differ among themselves by the S-N-K Test (p<0.05).

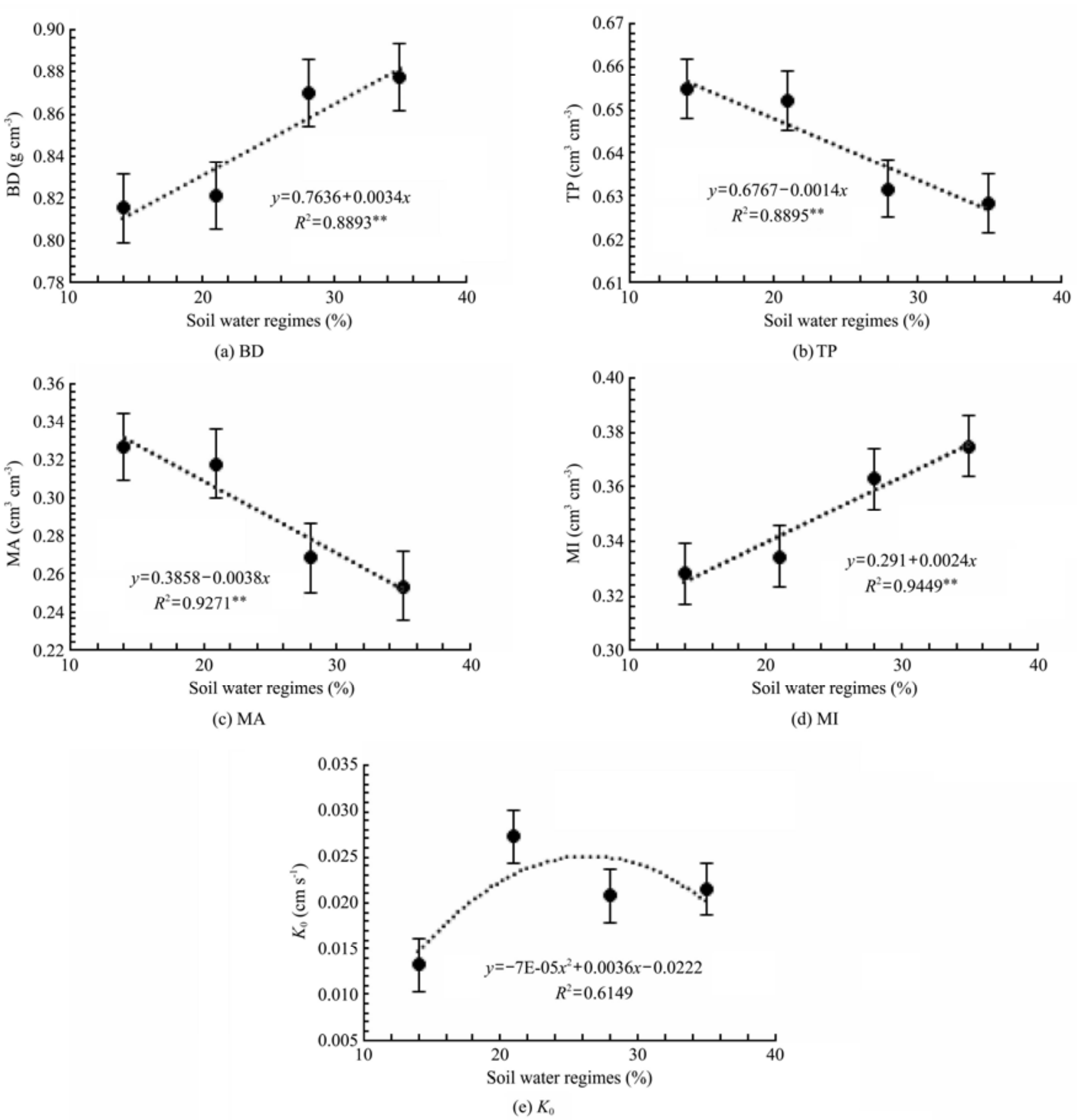

Figure 3 Soil physical attributes BD, TP, MA, MI and K_0 as a function of soil water regimes under the climatic conditions of a protected environment

The distribution of the roots into a given soil volume interferes on TP. This might explain the reason why there was a considerable effect of beans genotype on the behavior of such a soil physical attribute. Pires and

Bacchi (2010), examining the behavior of deformed samples of soil subjected to W-D cycles observed a more pronounced frequency of low TP values as a function of an increasing number of W-D cycles. Sartori et al. (1985) e Pagliai et al. (1987), evaluatingthe influence of W-D cycles on TP noticed that such cycles triggered an increase in the values of the soil physical attribute at stake (Pires et al., 2005).

MA was significantly affected by the cultivar factor (Table 3). The soil cultivated with Tuiuiú beans showed a higher MA in comparison to that one related to the Campos Gerais genotype (Figure 2). Under the soil water regimes in study a negative linear correlation was obtained between MA and the different levels of soil water supply (Figure 3c). The extreme MA values were equal to 0.33 $cm^3\ cm^{-3}$ (14% θ) and 0.25 $cm^3\ cm^{-3}$ (35% θ), respectively.

MI was positive and linearly correlated to θ, with the highest and lowest values corresponding to 0.375 $cm^3\ cm^{-3}$ (35% θ) and 0.33 $cm^3\ cm^{-3}$ (14% θ), respectively (Figure 3d). Treatments with the highest water content in the soil presented the greatest number of W-D cycles and provided, therefore, a more consistent rearrangement of soil particles and depletion in the proportion of macropores as a function of increases in the number of micropores.

Piresand Bacchi (2010) garnered an increase in BD shortly after the deformed soil samples were exposed to W-D cycles. In the current study, such authors considered four treatments (0, 1, 2 and 3 W-D cycles). Piresand Cássaroet al. (2008), analyzing increasing numbers of W-D cycles, found important variations on the distribution of small and big sized pores after the application of these cycles. Phogat and Aylmore (1989) evidenced reductions in MA after the samples were subjected to W-D cycles. The macropores are generally more sensitive as to the deformation as opposed to the micropores (Kutílek et al., 2006).

Under a regression analysis study K_0 demonstrated a better fitting for a quadratic model as a function of soil water regimes (Figure 3e). Such behavior was contrary to further association degrees between soil physical attributes and θ, which were to be linear. The θ rate of 21% revealed the highest non-transformed K_0, assuming avalue of 0.027 $cm\ s^{-1}$. Its lowest non-transformed value obtained under the 14% soil water treatment was of 0.013 $cm\ s^{-1}$.

3.3 Correlations among soil physical attributes

In Table 4, simple linear correlations among all soil physical attributes obtained after the cultivation of beans under protected environment conditions might be visualized. Significant correlations were found for BD×TP (r=–0.999**), BD×MA (r=–0.9904**), BD×MI (0.9738**), TP×MA (r = 0.9904**), TP×MI (r = –0.9738**) and MA×MI (r=–0.9959**).

Table 4 Correlation coefficients among BD, TP, MA, MI and K_0

	TP	MA	MI	K_0
BD	–0.9999**	–0.9904**	0.9738**	0.1384^{ns}
TP		0.9904**	–0.9738**	–0.1384^{ns}
MA			–0.9959**	–0.1509^{ns}
MI				0.1575^{ns}

Note: ns: non-significant; * and **: significant at 5% and 1% of reliabilityby means of the Pearson correlation.

Linear relationships involving BD were direct and inverse in relation to MI and MA, respectively. Both associations in question, BD×MA and BD×MI, demonstrated that with increases in BD a more elevated amount of micropores is to be obtained concerning the proportion of macropores owing to the thickening of the soil, being favored by the action of W-D cycles.

TP showed either an increasing or a decreasing association degree with MA and MI, respectively. Such outcome demonstrates that the increase in the proportion of macropores is related to a higher TP value (Pires et al., 2005). Correlation analysis confronting MA and MI pointed out that both variables were an inverse function between one another, evidencing that the higher the proportion of macropores in a soil the lower the proportion of micropores will be and vice-versa (Hillel, 1998).

The association degree between BD and soil water regime was increasing as a function of the matric potentials applied in the soil (Figure 4). Such association degree was positively strong for all of the matric potentials, with the strongest one obtained at the –100 cm H_2O. The coefficients of determination varied from 0.8719 (at Ψ_m of –10 cm H_2O) to 0.9530 (at Ψ_m of –100 cm H_2O). At the first Ψ_m applied (–10 and –20 cm H_2O), the association between the variables θ and BD revealed a similar precision among soil samples before such samples were placed in the tension table at the laboratory.

TP correlated strong and negatively with θ for all of the Ψ_m applied in the soil (Figure 5). The association degree was to be increasing as a function of the application of Ψ_m. The coefficients of determination varied from 0.8719 (–10 cm H_2O) to 0.9530 (–100 cm H_2O). In the same fashion regarding BD, the relationship between the variables θ and BD revealed a similar accuracy among soil samples shortly before such samples were placed over the table of tension at the laboratory.

MA described a strong and positive correlation between θ and all Ψ_m applied (Figure 6). The coefficient of determination varied from 0.9248 (–10 cm H_2O) to 1.000 (–60 cm H_2O). With reductions in Ψ_m, a stricter relationship between θ and MA was observed.

MI indicated a strong and negative correlation between θ and all of the Ψ_m applied (Figure 7). The coefficients of determination varied from 0.9151 (–10 cm H_2O) to 0.9932 (–100 cm H_2O). With the diminution of Ψ_m a stronger association between θ and MI was noted.

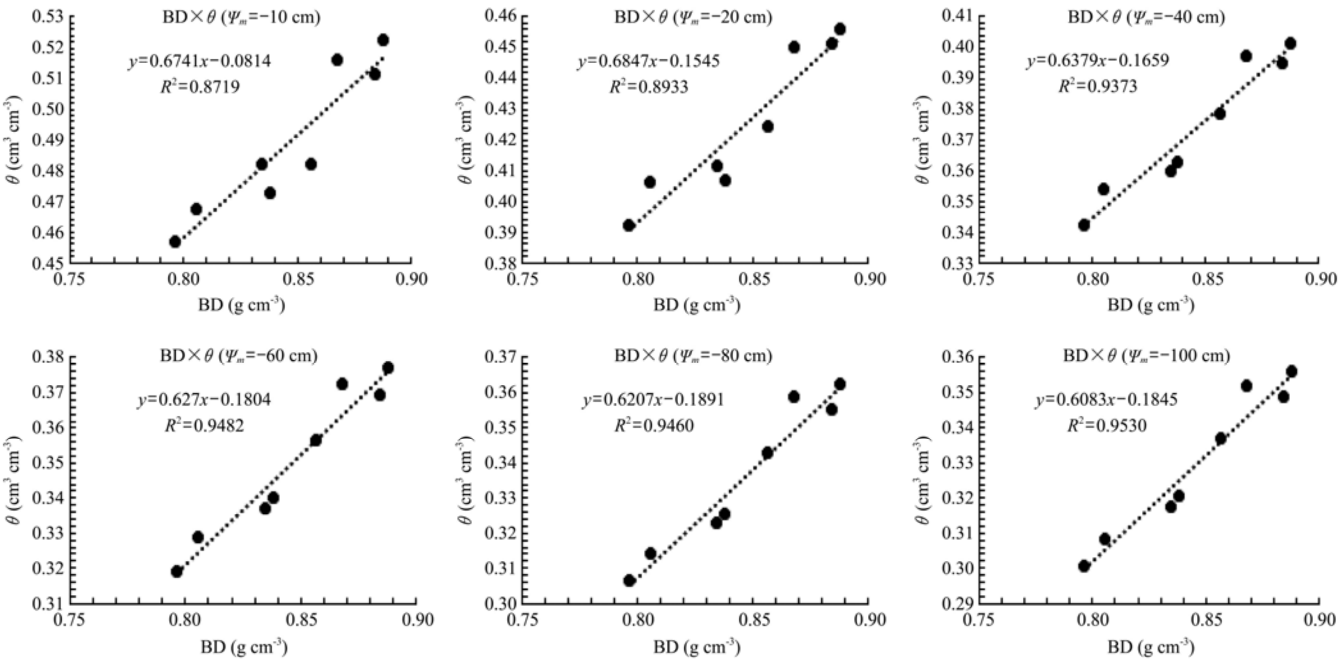

Figure 4 Correlation between BD and soil volumetric moisturelevels (θ) obtained under different soil matric potentials (Ψ_m)

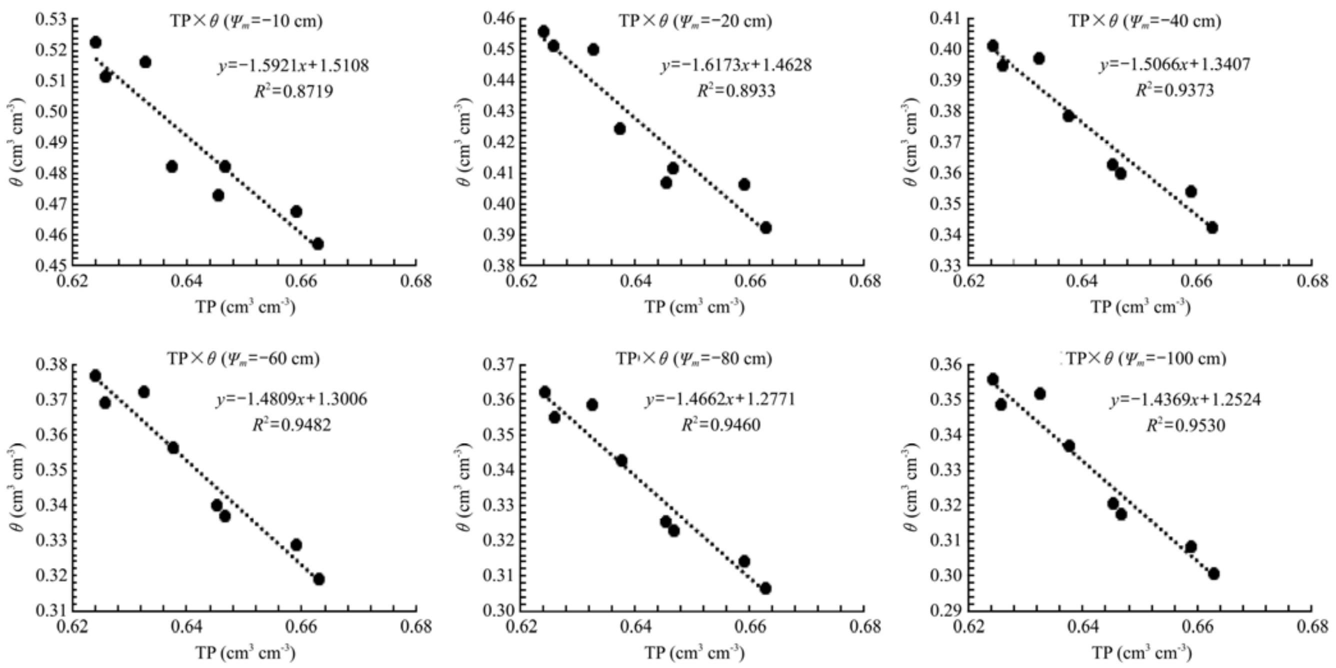

Figure 5 Correlation between TP and θ obtained under different soil matric potentials (Ψ_m)

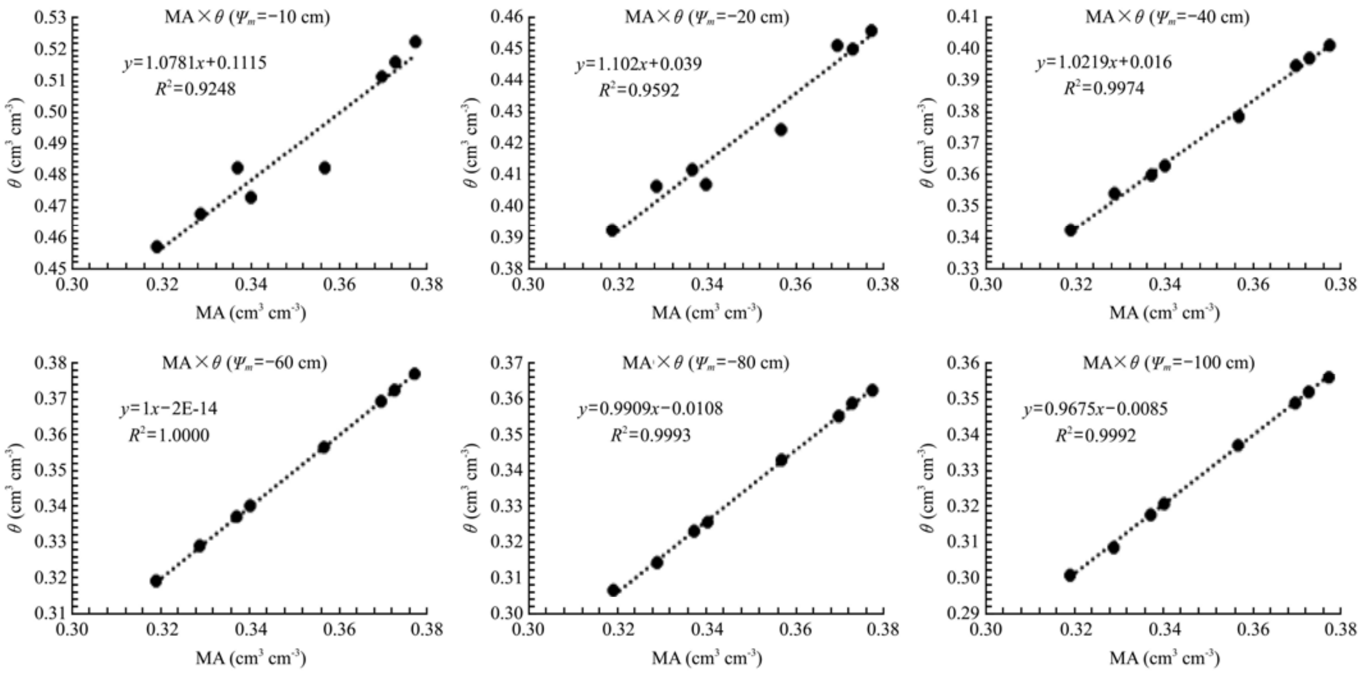

Figure 6 Correlation between soil macroporosity (MA) and soil volumetric moisture levels (θ) obtained under different soil matric potentials (Ψ_m)

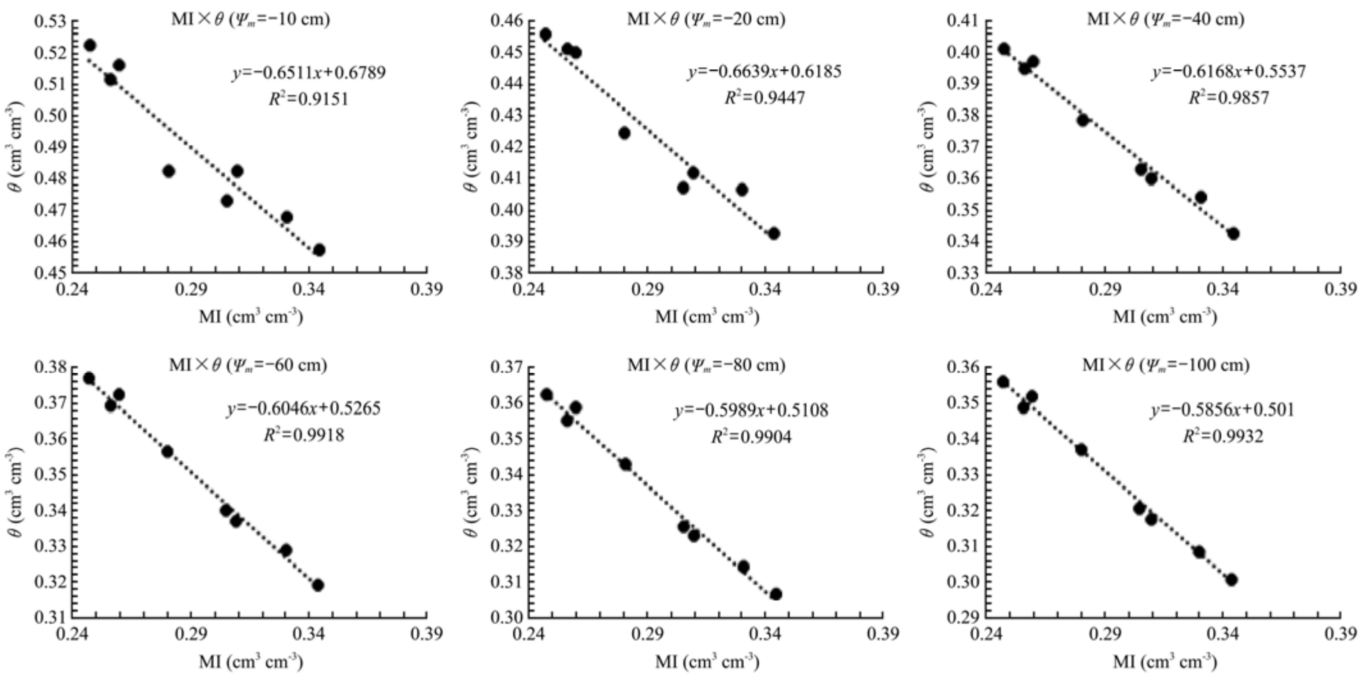

Figure 7 Correlation between soil microporosity (MI) and soil volumetric moisture levels (θ) obtained under different soil matric potentials (Ψ_m)

3.4 Correlations between soil physical attributes and yield components

In Table 5 simple linear correlations between soil physical attributes and beans crop yield components under protected environment conditions are demonstrated. Such correlations between soil physical attributes and yield components were significantly elevated for BD×MGP (r = 0.8178*), TP×MGP (r = –0.8178*), MA×NPP (0.8119*), MA×MGP (r = 0.8759**), MI×NPP (–0.7592*) e MI×MGP (r = –0.8583**).

In Table 5 simple linear correlations between the soil physical attributes and yield components of beans grown under protected environment condition is presented. Such correlations between the aforementioned variables were significantly elevated for BD × MGP (r = 0.8178*), TP × MGP (r = –0.8178*), MA × NPP (0.8119*), MA × MGP (r = 0.8759**), MI × NPP (–0.7592*) and MI×MGP (r = –0.8583**).

Table 5 Correlation coefficients between beans crop yield components and soil physical attributes

	BD	TP	MA	MI	K_0
NPP	0.6671^{ns}	-0.6671^{ns}	0.8119*	–0.7592*	0.1049^{ns}
NGP	0.1970^{ns}	-0.1970^{ns}	0.1080^{ns}	-0.1442^{ns}	-0.4729^{ns}
MGP	0.8178*	–0.8178*	0.8759**	–0.8583**	-0.1483^{ns}
TGM	-0.0801^{ns}	0.0801^{ns}	-0.2032^{ns}	0.1553^{ns}	0.1116^{ns}

Notes: ns: non-significant; * and **: significant at 5% and 1% of reliability by means of the Pearson correlation.

The positive correlation between BD × MGP and negative between TP× MGP is an indication that with an increase in BD and a consequent reduction in TP, MGP increases as a function of such soil physical attributes. Yield components of the beans crop NPP and MGP correlated positively with MA. For MI, the NPP and MGP correlated negatively. Thus, the higher MA and the lower MI the better the physiological performance of the crop will be under the protected environment conditions subjected to several W-D cycles. Soils with a higher BD possess a low MA and a high MI so that the roots of the plants will be in turn facing difficulties to grow and develop well in such small pores (Schenk e Barber, 1979; Silva et al., 2000).

Associations involving the NGP and TGM with all of the soil physical attributes were feeble and inconsistent, demonstrating that there is no relationship between beans crop yield components and soil physical attributes. K_0 did not evidence any correlation with the yield components assessed herein under the environmental conditions in study. Suzuki et al. (2007) stated that a K_0 of 17.38 mm h^{-1} is to be the critical threshold at an Argisoil for the plants to perform their growth within an optimal of physiological efficiency at a given site. Such K_0 value corresponds to an aeration porosity of 0.10 cm^3 cm^{-3}, being, therefore, considered by Vomosil and Flocker (1965) as the critical threshold for a satisfactory crop development.

Montanari et al. (2013) foundweak correlations for the interactions BD × NPP ($r = 0.069^{ns}$) and BD × MGP (r = –0.187*) under field conditions as opposed to what was observed in the current study under protected environment. The aforementioned authors obtained yet more feeble correlations for the interactions TP × NPP (-0.093^{ns}) and TP × MGP (0.200*), corroborating with our outcomes for the interaction TP×NPP and disagreeing from what was found for TP × MGP.

4 Conclusions

Soil moisture influenced soil physical attributes, and beans cultivar factor affected soil density, total porosity and macroporosity.

Soil density and microporosity correlated positive and linearly with soil water status, whilst total porosity and macroporosity diminished linearly with the intensification of water deficit.

Soil density under the cultivation of Campos Gerais genotype was higher than that observed for Tuiuiú cultivar. Total porosity and macroporosity of the soil grown with Tuiuiú were more elevated than those obtained for Campos Gerais.

Soil density, total porosity, macroporosity and microporosity of the soil provided a significant variation in the number of pods per plant, as well as either macroporosity or microporosity brought about impacton the mass of grains per plant for both beans genotypes.

Soil hydraulic conductivity did not show any correlation with yield components of the crop and was not governed by the genotypes of beans grown under protected environment condition at the studied site.

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