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Biomass production and macronutrient content in *Pennisetum glaucum* (L.) R. Brown as affected by organic fertilization and irrigation

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ABSTRACT: Given the growing and needing for more effective organic fertilization and irrigation on pearl millet cultivated in Brazilian semi-arid, a field experiment was conducted in 2012 and 2013 simulating the smallholder farming system adopted in the Brazilian semi-arid to explore the effect of five organic sources (bovine manure, goat manure, compost, green manure, and control) under irrigation and no irrigation conditions. The experiment was a fully factorial design with four replications. The highest values of shoot dry biomass (16.55 Mg ha^{-1}), and plant contents of Ca, Mg and S (6.77; 4.39; and 1.47 g kg^{-1} of Ca, Mg and S, respectively) were found on plots where compost was applied combined with the irrigation. Whereas for crude protein crude protein (15.41%), the highest values were found where the green manure was applied combined with the irrigation. Finally, for plant N, P and K content (24.60; 2.00; 45.75 g kg^{-1} of N, P and K, respectively) the highest values where found where the goat manure was applied combined with the irrigation. Our findings suggest that organic amendments can affect plant dry biomass production and crude protein content (increased by 723.38 and 223.73% compared to control, respectively). The results of our study highlight the importance of considering organic fertilization and irrigation as key-factors to improve both food and forage production.

Key words: irrigated agriculture; organic sources of fertilization; plant nutrition

Produção de biomassa e conteúdo de macronutrientes em *Pennisetum glaucum* (L.) R. Brown em função da adubação orgânica e irrigação

RESUMO: Dado o crescimento e necessidade por sistemas de adubação orgânica e irrigação mais efetivos em plantas de milheto (*Pennisetum glaucum* (L.) R. Brown) cultivado no semiárido brasileiro, um experimento de campo foi conduzido nos anos de 2012 e 2013 simulando os sistemas de agricultura familiar adotados no semiárido brasileiro para explorar os efeitos de cinco fontes de adubos orgânicos (esterco bovino, esterco caprino, compostagem, adubação verde e controle) sobre condições irrigadas e não irrigadas. O delineamento experimental foi um esquema fatorial com quatro repetições. Os maiores valores de biomassa seca da parte aérea (16,55 Mg ha^{-1}), e conteúdo de Ca, Mg e S na planta (6,77; 4,39; e 1,47 g kg^{-1} de Ca, Mg e S, respectivamente) foram observados nas parcelas onde a compostagem e a irrigação foram aplicadas. Enquanto para a proteína bruta (15,41%), os maiores valores foram observados onde a adubação verde e a irrigação foram aplicadas. Finalmente, para os conteúdos de N, P e K na planta (24,60; 2,00; 45,75 g kg^{-1} de N, P e K, respectivamente), os maiores valores foram observados onde o esterco caprino e a irrigação foram aplicados. Os resultados observados neste estudo sugerem que fontes orgânicas podem afetar a produção de biomassa seca da planta e o conteúdo de proteína bruta (aumentando em 723,38 e 223,73% comparado com o controle, respectivamente). Os resultados deste estudo ressaltam a importância de considerar a adubação orgânica e a irrigação como fatores-chave para melhorar ambas a produção de alimento e forragem.

Palavras-chave: agricultura irrigada; adubação com fontes orgânicas; nutrição de plantas

Introduction

Understanding the effects of both organic fertilization and irrigation that may regulate the plant biomass production and macronutrient content in pearl millet plants cultivated in the Mesoregion of occidental "Cariri" (e.g., The driest ecoregion of the Brazilian semi-arid) are essential to test if the smallholder faming system adopted in the Brazilian semi-arid using this annual plant could be considered sustainable. Some works have reported organic fertilization and irrigation as sustainable farming approaches that improve plant performance (Souza et al., 2015). Accordingly, Souza & Santos (2018), the introduction of annual plant species adapted to the new-range of soil and climatic conditions such as pearl millet is essential to avoid the soil degradation process and to mitigate the water stress conditions by plants which is very common into this ecoregion (Souza et al., 2015; Souza & Santos, 2018).

Organic fertilization is recognized as one of the most important activities that influence soil fertility, plant performance and contents of macronutrients in semi-arid regions (Souza et al., 2015). However, there is limited information about pearl millet contents of macronutrients after short-term cultivation under an irrigated organic fertilization system on a Luvissolo Crômico Órtico típico from the Brazilian semi-arid ecoregion. In fact, this annual plant species is rarely irrigated in semi-arid due its drought tolerant traits. Several works have recently been shown the irrigation contributing to enhance plant yield and plant contents of macronutrients in arid and semi-arid ecoregions around the world (Heidari et al., 2019; Onoja et al., 2019; Ullah et al., 2019; Zhang et al., 2019). In semi-arid conditions, irrigation plays an important role for biomass production, plant nutrition and quality of fodder plants (Zhang et al., 2019). This implies for a better regional food supply, livestock maintenance and social sustainability when compared to no irrigated areas (Ahmad et al., 2018). To our knowledge, this work is the first field study into the Brazilian semiarid examining the effects of organic fertilization and irrigation on pearl millet plants during two cropping seasons following the smallholder faming system adopted there.

In this context, our hypotheses were based in two questions proposed by the regional farmers: (i) Could the different organic matter sources be affected by irrigation and the interaction between these two factors affect the quality of fodder and nutrient content of pearl millet? Based on the results of Borges et al. (2019), and Choudhary et al. (2019), we expected to find high crude protein and contents of macronutrients in plots where compost and goat manure was applied as organic fertilizers combined with irrigation. According these studies, both compost and goat manure in irrigated plots present faster decomposition rate and better chemical composition (i.e., N, P, K and Mg contents) when compared with bovine manure or even green manure. This hypothesis will enable us to recommend the most efficient organic fertilizer with or without irrigation, once regional farmers in most of the cases need to buy organic fertilizers for a high price based on a high demand for these resources in our studied region; and (ii) Even pearl millet plants being considered tolerant to water stress, in our context could irrigation promotes pearl millet performance? Since the irrigation promotes in ordinary plants their nutrient absorption and growth through both mass flow and root absorption processes. Based on the results obtained by Heidari et al. (2019) and Ullah et al. (2019), we expected to find high contents of macronutrients in plots where the irrigation was applied. This second hypothesis will help us to test the performance of pearl millet plants using a water irrigation with pH, electrical conductivity, and sodium adsorption ratio values of 7.8, 0.9 dS m^{-1} and 0.61, respectively.

The purpose of this study was to investigate the effects of organic fertilization and irrigation on shoot dry biomass production, crude protein and the contents of macronutrients (i.e., N, P, K, Ca, Mg and S) of pearl millet [*Pennisetum glaucum* (L.)R. Brown] plants during two cropping seasons on a Luvissolo in Brazilian semi-arid.

Materials and Methods

Site and soil description

The study was conducted during two cropping seasons in 2012 and 2013 at the experimental station from the Semi-arid Sustainable Development Centre, Federal University of Campina Grande, Sumé, Paraiba, Brazil (7° 40' 18" S; 36° 52' 54" W, 518 m above sea level), to determine the influences of different organic sources and irrigation on shoot dry biomass, crude protein and macronutrients contents of pearl millet plants cultivated in a ten-years-old natural camp. The experimental area is Bsh climate type according to the Köppen-Geiger classification (e.g., hot semi-arid). The experiment is located into the driest region of the semi-arid portion of the Paraiba river basin, with annual total precipitation and average air temperature of 600 mm and +26 °C, respectively. Data on climatic condition of the investigated area from November 2012 to May 2013 were obtained from the website: http://www.inmet.gov.br. For downtown Sumé, Paraiba, Brazil, monthly rainfall, and main temperature were considered and reported (Figure 1).

The soil of the experimental area was classified as Luvissolo Crômico Órtico típico (e.g., Aridisols accordingly to Soil Taxonomy classification). Forty soil samples were taken from a depth of 20 cm before to start the experiment (at the beginning of November 2012, during the dry season) to determine its soil physical-chemical properties. All soil samples were analysed according to the methods given by IITA (1979), Black (1965), Olsen et al. (1954), and Okalebo et al. (1993). The following physical-chemical properties were analysed: soil texture, soil bulk density, soil reaction (pH), available phosphorus, soil exchangeable cations (K^+, Na^+, Ca^{2+}, Mg^{2+}, Al^{3+}), active hydrogen (H^+), cation exchange capacity, and total organic carbon. Soil texture was determined by a particle size analysis of the dispersed soil (IITA, 1979). Soil bulk density was measured considering the weight of soil per unit

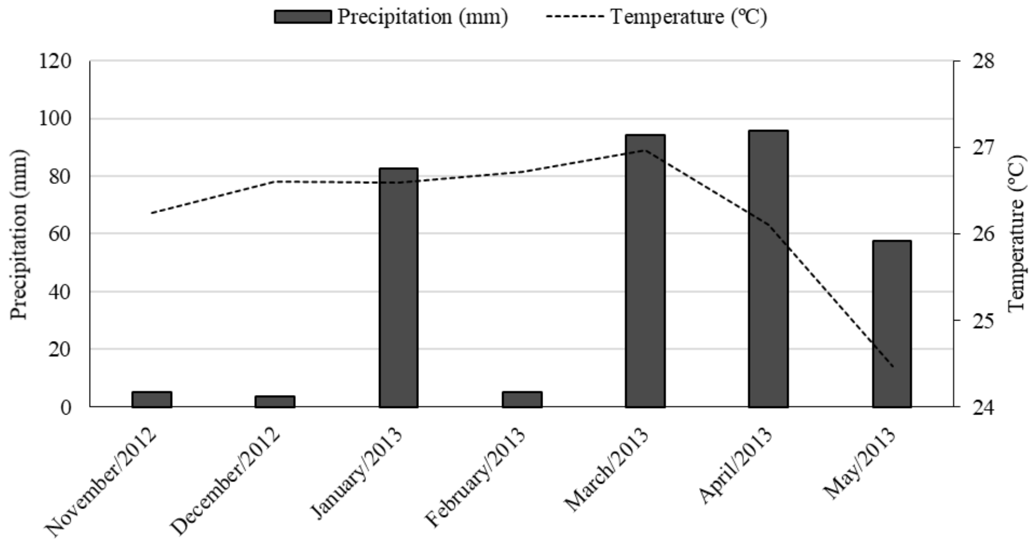

Figure 1. Monthly total precipitation (mm, black bar) and mean air temperature (ºC, dotted black line) in the studied area near to downtown Sumé, Paraiba, Brazil during two cropping periods (November 2012 to May 2013). Data were obtained from the website: http://www.inmet.gov.br.

volume of a metallic cylinder (Black, 1965). Soil reaction (pH) was measured in a suspension of soil and $CaCl_2$ 0.01 M (Black, 1965). Available phosphorus (Olsen's P) was determined colourimetrically using a spectrophotometer at 882 nm by extraction with sodium bicarbonate for 30 min (Olsen et al., 1954). All soil exchangeable cations (K^+, Na^+, Ca^{2+}, Mg^{2+}) were determined by extraction methods. For Ca^{2+} and Mg^{2+}, we used atomic absorption spectrophotometer. For K^+ and Na^+, we prepared a sodium standard stock solution (by dissolving 0.2542 g of sodium chloride in 0.1 M hydrochloric acid and making up to a volume of 100 mL) and a potassium standard stock solution (by dissolving 0.1907 g of potassium chloride in 0.1 M of hydrochloric acid and adjusting to the final volume of 100 mL), and both ions determined by flame photometry (IITA, 1979). Primarily, the exchangeable acidity ($H^+ + Al^{3+}$) was determined by tritation of 25 mL of potassium chloride (KCl) extract with 0.025 mol L^{-1} NaOH using 1 g L^{-1} phenolphthalein. Next, the concentration of Al^{3+} was obtained by back-tritation of the same KCl extract added with a 0.025 mol L^{-1} and 40 g L^{-1} NaF. Finally, active hydrogen was estimated using the following equation: $H^+ = (Al^{3+} + H^+) - Al^{3+}$. Cation exchange capacity was measured using the following equation: C.E.C. ($cmol_c$ kg^{-1}) = $K^+ + Na^+ + Ca^{2+} + Mg^{2+} + H^+ + Al^{3+}$ (Black, 1965). Total organic carbon was estimated according to the methodologies described by Okalebo et al. (1993). Soil physical-chemical characteristics are given in Table 1.

Table 1. Soil physical-chemical characteristics (0-20 cm) from the experimental area during the dry season.

Soil texture	Silt loam
Soil bulk density (g cm^{-3})	1.34 ± 0.12
Soil pH ($CaCl_2$)	7.00 ± 0.52
Available P (mg kg^{-1})	68.90 ± 8.64
Exchangeable K ($cmol_c$ kg^{-1})	0.40 ± 0.02
Exchangeable Na ($cmol_c$ kg^{-1})	0.80 ± 0.10
Exchangeable Ca ($cmol_c$ kg^{-1})	15.30 ± 1.03
Exchangeable Mg ($cmol_c$ kg^{-1})	2.70 ± 0.65
(H + Al) ($cmol_c$ kg^{-1})	0.70 ± 0.10
C.E.C. ($cmol_c$ kg^{-1})	19.90 ± 0.53
Soil organic carbon (g kg^{-1})	14.50 ± 4.23

Experimental design

To better simulate the smallholder farming system commonly used in Sumé, Paraiba, Brazil, we used animal traction to soil preparation. Pearl millet (the variety IPA-BULK-1BF) was sown on November 2 and February 6 on a seeding rate of 50 seeds m^{-2} and 2.5 cm soil depth. We used an area of 288 m^2 which was under natural vegetation for about 10 years. The experiment was a fully factorial design with four replications. Each experimental plot was arranged 6 m long and 4 m wide with a total area of 24 m^2 (Figure 2). Ten different treatments [five organic fertilization systems (bovine manure, goat manure, compost, green manure, and non-fertilization) and two irrigation systems (Water-stressed treatment - no irrigation; and irrigation)] were tested during two cropping seasons. The first season started at November 2012, and the second season started at February 2013. We used 40 plants located into the central portion (5 × 3 m) of each plot. To avoid bias, we selected plants with similar height, diameter, number of leaves and without show any symptoms of nutritional deficiency, pests, and diseases.

For the organic fertilization treatments, bovine and goat manures were obtained from regional farmers. The compost was constituted of a mixture of bovine manure and plant remain biomass (i.e., *Beta vulgaris* L., *Capsicum annum* L., *Cynodon dactylon* (L.) Pers., *Ficus benjamina* L., *Gliricidia sepium* (Jacq.) Kunth ex Walp., *Lactuca sativa* L., *Leucaena leucocephala* (Lam.) de Wit, *Sesbania cannabina* L., and Spinacia oleracea L.). First organic residues were air-dried for two days to remove excessive moisture. A moisture level of 50% (v/w) of the compost was maintained during the composting process. Temperature varied from 34.5 to 72.2 ºC in the composting unit during 3rd and 4th day of composting

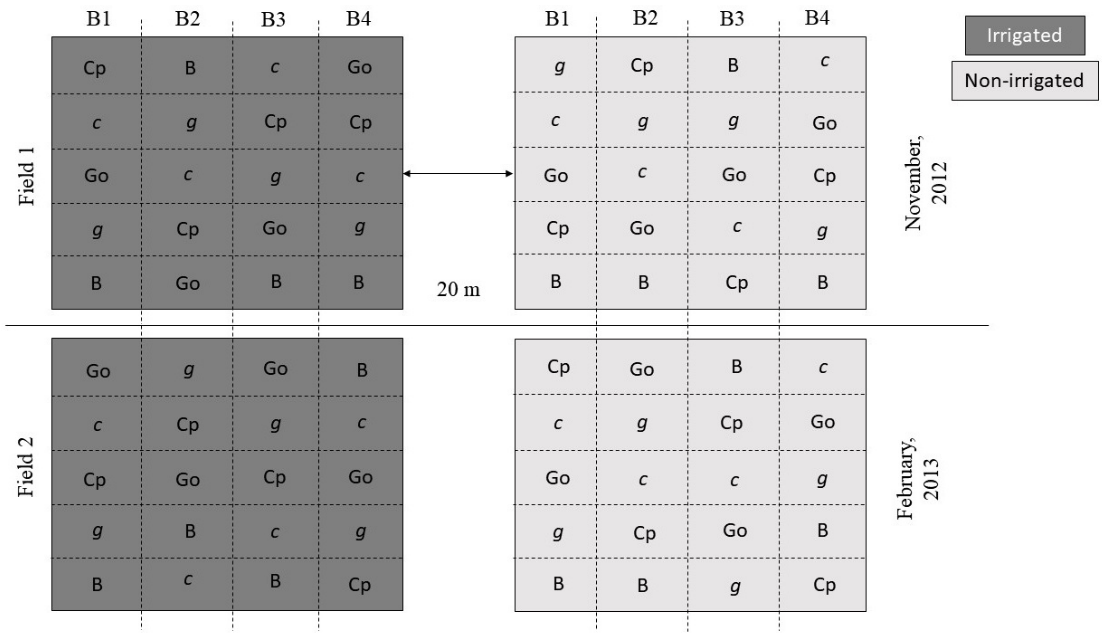

Figure 2. Schematic view of the field experiments.

Table 2. Chemical composition of the organic fertilizers used in the field experiment. Values are given as mean ± standard deviation.

Variable	Bovine manure	Compost	Goat manure	Green manure
Carbon (g kg^{-1})	257.60 ± 50.19	492.70 ± 25.64	192.52 ± 19.43	350.18 ± 23.33
Total nitrogen (g kg^{-1})	14.82 ± 1.19	40.91 ± 5.44	11.90 ± 2.91	35.09 ± 1.91
Total phosphorous (g kg^{-1})	3.73 ± 0.79	2.49 ± 0.81	2.51 ± 0.33	3.34 ± 0.39
Total potassium (g kg^{-1})	6.91 ± 1.44	8.30 ± 5.44	15.66 ± 3.12	25.48 ± 5.44
C/N ratio	17.38 ± 42.17	12.04 ± 4.71	16.17 ± 6.67	9.97 ± 12.21

and then reduced gradually to 28.9 °C after 5th day process. Composting was done for 6 months. In the plots where the green manure was incorporated, we previously cultivated *Vigna unguiculata* (L.) Walp., which was harvested 40 days after sowing. Because organic fertilizers are slow-release and to better simulate smallholder system adopted in the semi-arid portion of the Paraiba river basin, all organic fertilizers (20 Mg ha^{-1}) were incorporated 2 months before sowing pearl millet. The mean chemical composition of the organic fertilization treatments is shown in Table 2.

Irrigation schedule

The irrigated experiment took place during dry season (November 2012), whereas the non-irrigated experiment took place during rainy season (March 2013). The irrigation water was supplied to irrigated experiment to each plot continuously through the inlet gate system from November 2 to the end of February (end of the first cropping season). However, in January 2013, we stopped irrigation for approximately 2 weeks because rainy days that correspond a total rainfall of 84 mm. The irrigated experiment was separated from non-irrigated experiment by approximately 20 m to prevent lateral movement of water on it.

The pH, electrical conductivity and sodium adsorption ratio values of the irrigation water were 7.8, 0.9 dS m^{-1} and 0.61, respectively. According to Richard (1954), the irrigation water was classified as C1-S1 type. In drip irrigation systems, four driplines with a length of 6 m were placed on each plot with 1.0 m spacing. The average flow rate of the emitters (in-line type emitters) was 4.8 L h^{-1} under 0.12 MPa. Irrigation quality required for each irrigation was calculated following the equation proposed by Ertek (2011). Pearl millet plants were irrigated by drip irrigation on a 1-day schedule to replace water lost to evapotranspiration. Irrigated treatments received 136.71 mm water application for 60 days after pearl millet sowing.

Plant analyses

We selected 40 plants into the central portion of each plot to quantify shoot dry biomass production, crude protein, and plant macronutrient content. For all selected plants, shoot dry weight was determined, and plant dry biomass calculated to ton dry weight per hectare by the Equation 1 (Souza et al., 2015).

$$\text{SDB}\left(\text{Mg ha}^{-1}\right) = \frac{\text{sdb}\left(\text{g m}^{-2}\right)}{1.5} \quad (1)$$

where SDB is the Shoot dry biomass estimated in ton dry weight per hectare, sdb (g m^{-2}) is the shoot dry biomass collected into the central portion of each plot, and 1.5 is the conversion factor considering the area of the central portion of the plot.

Shoot biomass samples were analysed for crude protein by near-infrared reflectance spectroscopy (NIRS) protocol (Dixon & Coates 2009). Plant dry biomass was calculated by drying in a forced draft oven for 24 h at 70 ± 2 °C and then ground in a stainless-steel blender. A known mass of the dry leaves was first digested in a 10:1:4 mixture of HNO_3: H_2SO_4: HCl (60%), and then analysed using the protocol described in Kjeldahl to estimate plant N content (Black, 1965), the vanadate molybdate colorimetric method to estimate plant P content, and plant K, Ca, Mg and S contents were determined by atomic absorption spectrophotometer (Black, 1965).

Statistical analyses

The Shapiro-Wilk test was applied to assess the normality of the data distribution. Two-way ANOVA was used for analysing differences between the irrigation and organic fertilizers on plant dry biomass, crude protein, and macronutrient contents (e.g., N, P, K, Ca, Mg and S). Data sets were arcsin square root transformed, but the results are presented in their original scale of measurement. We present the mean of the two studied growing seasons. When necessary, Tukey's LSD post hoc comparison test was conducted. Pearson correlation analysis was used to assess the relationships among plant growth (e.g., plant dry biomass and crude protein) and plant nutritional status (e.g., macronutrient contents). All statistical analyses were conducted using R (R Core Team, 2018).

Results and Discussion

We found significant differences for the interaction between the organic fertilization and irrigation for shoot dry biomass ($p < 0.001$). The highest values of shoot dry biomass (16.55 ± 0.95 Mg ha^{-1}) were found in the plots where compost was applied in combination with the irrigation system. For crude protein, we found significant differences for the interaction between the organic fertilization and irrigation ($p < 0.001$). The highest values of this variable (15.41 ± 1.37%) were found in plots where green manure was applied in combination with the irrigation system. No difference was found between the effects of green manure and compost fertilization in plots where irrigation was applied for crude protein. On average, the irrigation group was higher in shoot dry biomass (> 354.81%) and crude protein (> 195.42%) than no irrigation group (Table 3).

Our results emphasize the positive influence of compost combined with irrigation on plant dry biomass and crude protein of pearl millet plants. Essentially, we wanted to understand how the organic fertilizers combined with irrigation improves the plant biomass production, nutritional value of plant biomass (i.e., measured by shoot dry biomass and crude protein content) and plant nutritional status of pearl millet plants cultivated in semi-arid conditions of the Brazil considering these approaches as a sustainable farming system for regional farmers of this ecoregion. In this context, our work tested two real problems that the regional farmers are fighting every single day into the Brazilian semi-arid: a) the most effective organic fertilizer aiming high biomass production associated with high quality of the fodder - because in most of the cases organic farmers spend a plenty of money buying organic fertilizers, such as bovine, swine and/or goat manure, to support their own fields; and b) a safety way to use the water irrigation in annual crop plants avoiding soil salinity that decrease plant performance and soil quality - because Sumé has a history of soil salinization through irrigation.

The use of compost combined with the irrigation increased shoot dry biomass by 723.38% when compared with control without irrigation. Indeed, this result is not surprising considering that irrigation during vegetative growth stage affects cell multiplication and increasing plant growth (Litvin et al., 2016). Similar findings were reported by Ozer et al. (2020), who stated that black cumin plants growth decreased in drought stress conditions. According to Heidari et al. (2019) and Borges et al. (2019), organic fertilization systems combined with irrigation may enhance plant biomass production by improving the following processes: i) mass flow and root absorption processes (e.g., improving the uptake of P, Ca, Mg and S that are considered nutrients with high chemical reaction to soil particles in tropical ecosystems); ii) soil microbial community that improves the decomposition rate of organic fertilizers (e.g., increasing soil N availability); iii) soil reaction in plant rhizosphere by extrusion of H^+; and iv) soil biota and microbiota activity (e.g.,

Table 3. Shoot dry biomass (Mg ha^{-1}) and crude protein (%) of pearl millet plants cultivated on a Luvissolo (mean ± SD, n = 40).

Organic fertilizers	Shoot dry biomass (Mg ha⁻¹)		Crude protein (%)	
	Irrigation	No irrigation	Irrigation	No irrigation
Control	5.03 ± 0.48 dA	2.01 ± 0.06 cB	9.76 ± 0.86 cA	4.76 ± 0.52 cB
Green manure	7.96 ± 0.51 cA	2.18 ± 0.08 cB	15.41 ± 1.37 aA	6.77 ± 0.74 bB
Goat manure	13.58 ± 0.68 bA	2.98 ± 0.09 cB	12.37 ± 1.10 bA	5.12 ± 0.56 cB
Bovine manure	13.80 ± 0.55 bA	3.85 ± 0.10 bB	13.23 ± 1.17 bA	7.25 ± 0.79 bB
Compost	16.55 ± 0.95 aA	4.40 ± 0.11 aB	14.94 ± 1.32 aA	8.67 ± 0.95 aB
Factor	**F-value**		**F-value**	
Organic fertilizers (OF)	13.79***		15.33***	
Irrigation system (IS)	10.99***		13.98***	
Interaction (OF x IS)	10.56***		14.41***	
Variation coefficient (%)	14.55		9.23	

Within organic fertilizers, means with different lower-case letters are significantly different by LSD test at the 5% significance level. Within irrigation system, means with different capital letters are significantly different by LSD test at the 5% significance level after performing two-way ANOVA; *** $p < 0.001$.

decomposers, microregulators and litter transformers). Also, we must consider the climate conditions of semi-arid regions, accordingly the work done by Wang et al. (2014), water uptake by roots increase in high soil temperature conditions, and therefore appeared to improve both mass flow and root absorption through increased stoma density as a physiological water conservation mechanism. Huang et al. (2019), highlight the importance to consider the water quality used during the irrigation that may lead to soil salinization processes. Our results show that irrigation was enough to sustain high values of shoot dry biomass, crude protein, and plant nutritional status. The observed effects of water irrigation (pH, electrical conductivity, and sodium adsorption ratio values of t 7.8, 0.9 dS m^{-1} and 0.61, respectively) use in our study could be explained by drought stress hypothesis (Wang et al., 2014).

The crude protein showed a significant correlation with shoot dry biomass of pearl millet plants during the field experiment. Statistical analysis indicated that irrigation treatment resulted in high crude protein (9.57-13.52%) during the field experiment (Figure 3).

For crude protein, the use of compost or green manure as organic fertilizers in plots where irrigation was applied,

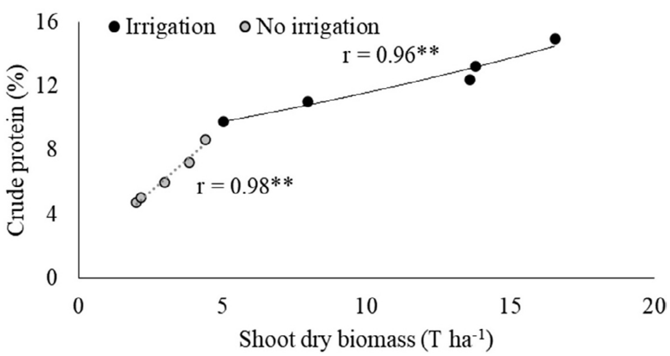

Figure 3. Pearson correlation coefficients (R) between crude protein (%) with shoot dry biomass (Mg ha^{-1}) of pearl millet plants cultivated on a Luvissolo. All Pearson correlation coefficients were significant ($p < 0.01$)

showed the highest values of this variable than the other treatments. Thus, this result support our second hypothesis that compost and goat manure as soil organic amendments improve crude protein within plant biomass through their chemical composition. Crude protein content is the main quality/nutritional component of the annual crop fodder and seeds that depends on the nutritional and physiological level of the plants during plant growth and seed formation (Ozer et al., 2020). In our experiment, irrigation could promote organic fertilizer decomposition rate, especially green manure. We found a strong relationship between plant N and S contents with crude protein. Thus, we cannot exclude the results described by Borges et al. (2019) and Choudhary et al. (2019), that described both compost and goat manure as excellent organic sources of N and S, that in our study were both regressors affecting crude protein content in pearl millet plants cultivated on a Luvissolo. This phenomenon can be supported by the results on the plots where goat manure and compost were incorporated. These results agree with the study done by Duan et al. (2019), which reported that agroecosystems with constant organic amendments increase: i) plant yield; ii) plant nutritional status; and iii) plant resistance to drought and pathogens which directly influence plant biomass nutritional composition.

There were significant effects of the organic fertilization and irrigation interaction on plant macronutrient contents (plant N, K, Ca, Mg, P and S content: $p < 0.01$; $p < 0.05$; $p < 0.05$; $p < 0.01$; $p < 0.05$; and $p < 0.01$, respectively). During the field experiment, irrigation (independently of the organic fertilization treatment) significantly increased plant N, P, K, Ca, Mg and S contents (Table 4). For plant N, K, and P content, we found the highest values with irrigated plots fertilized with goat manure (24.6 ± 0.73, 45.75 ± 2.20, 2.00 ± 0.22 g kg^{-1}, respectively), whereas for plant Ca, Mg and S content, we found the highest values in plots where irrigation was applied combined with compost (6.77 ± 0.47, 4.39 ± 0.54, 1.47 ± 0.13 g kg^{-1}, respectively).

Table 4. Plant N, P, K, Ca, Mg, and S contents (g kg^{-1}) of pearl millet plants (mean ± SD, n = 40).

Organic fertilizers	Irrigation system	N	P	K	Ca	Mg	S
		g kg^{-1}					
Control	Irrigation	21.03 ± 0.63 bA	1.72 ± 0.17 bA	42.25 ± 1.95 bA	6.10 ± 0.61 aA	3.52 ± 0.26 cA	1.41 ± 0.10 aA
Green manure		21.55 ± 0.64 bA	1.75 ± 0.17 bA	40.75 ± 1.85 bA	6.50 ± 0.65 aA	3.87 ± 0.28 bA	1.43 ± 0.11 aA
Goat manure		24.60 ± 0.73 aA	2.00 ± 0.22 aA	45.75 ± 2.20 aA	5.62 ± 0.56 bA	3.82 ± 0.29 bB	1.42 ± 0.09 aA
Bovine manure		23.80 ± 0.71 aA	2.00 ± 0.18 aA	45.25 ± 2.10 aA	6.53 ± 0.55 aA	3.95 ± 0.39 bB	1.44 ± 0.17 aA
Compost		24.90 ± 0.74 aA	2.00 ± 0.23 aA	40.30 ± 2.02 bA	6.77 ± 0.47 aA	4.39 ± 0.54 aA	1.47 ± 0.13 aA
Control	No irrigation	5.45 ± 0.92 cB	1.00 ± 0.17 bB	21.50 ± 2.60 aB	3.89 ± 0.66 bB	3.60 ± 0.61 bA	1.09 ± 0.18 bB
Green manure		10.25 ± 1.74 aB	1.25 ± 0.21 aB	21.75 ± 2.60 aB	3.59 ± 0.61 bB	3.50 ± 0.59 bA	1.29 ± 0.21 aB
Goat manure		10.88 ± 1.84 aB	1.25 ± 0.24 aB	22.50 ± 2.80 aB	4.37 ± 0.74 aB	4.71 ± 0.80 aA	1.22 ± 0.20 aB
Bovine manure		11.30 ± 1.92 aB	1.05 ± 0.18 bB	21.75 ± 2.60 aB	4.45 ± 0.75 aB	4.17 ± 0.71 aA	1.22 ± 0.21 aB
Compost		8.87 ± 1.50 bB	1.05 ± 0.17 bB	23.23 ± 2.91 aB	3.93 ± 0.67 bB	4.20 ± 0.71 aA	1.23 ± 0.21 aB
Factor		**F-value**	**F-value**	**F-value**	**F-value**	**F-value**	**F-value**
Organic fertilizers (OF)		13.79***	7.41*	7.93*	9.44*	8.39*	15.33***
Irrigation system (IS)		10.99***	11.33**	18.33***	10.12**	9.17*	13.98***
Interaction (OF x IS)		19.91***	6.32*	7.89*	9.56*	7.83*	14.41***
Variation coefficient (%)		13.44	8.76	15.44	11.23	10.84	9.84

Within organic fertilizers, means with different lower-case letters are significantly different by LSD test at the 5% significance level. Within irrigation system, means with different capital letters are significantly different by LSD test at the 5% significance level after performing two-way ANOVA; * $p < 0.05$, ** $p < 0.01$, and *** $p < 0.001$.

Table 5. Multiple linear regression between plant dry biomass, crude protein, and macronutrient contents of pearl millet plants under irrigation and organic fertilization.

Dependent variable	Regressors	Equation	R^2	*F*-value	*p*-value
Plant dry biomass (PDB, Mg ha^{-1})	Plant P and Mg contents (g kg^{-1})	PDB = -28.5** + 12.5***P + 4.2*Mg	0.82	10.91	< 0.01
Crude protein (CP, %)	Plant N and S contents (g kg^{-1})	CP = -7.64* + 0.32**N + 9.19**S	0.84	13.91	< 0.01

The pearl millet plants in irrigated plots were characterized by the faster growth rate, no visual deficiency symptoms and higher transpiratory rate (data not shown) that created a positive response into the biomass production process. On the other hand, we identified: i) severe visual N, K and Ca deficiency symptoms; and ii) initial visual P deficiency symptoms in pearl millet plants cultivated in plots with no irrigation treatment. It agrees with the works done by Scagel et al. (2019) and Wang et al. (2019), that reported visual macronutrient deficiency symptoms of basil and maize plants under water-stressed conditions. Although our experiment was not designed to directly test whether irrigation affects lead transpiratory rate and water use efficiency (e.g., we just analysed the young fully expanded leaves in 5 plants before flowering between 09 and 11 h WST using an infrared gas analyser - ACD, LCPro SD Model, Hoddesdon, UK). We must consider that the pearl millet plants showed high transpiratory rate and water use efficiency on plots where irrigation was applied.

Multiple linear regression equations developed between: i) plant dry biomass and plant content of macronutrients ($p < 0.01$); and ii) crude protein and plant macronutrient contents ($p < 0.01$), indicate that the regression coefficient obtained between plant dry biomass, crude protein and different regressors were 0.82 and 0.84, respectively (Table 5). These results indicate that there is a generally significant relationship between i) plant dry biomass and plant macronutrients such as P and Mg; and ii) crude protein and plant N and S contents.

Irrigation and organic fertilization are important factors to farming systems and these two practices act as key-role to sustainable agriculture in semi-arid ecoregions (Souza et al., 2015). Alternative annual plant species (e.g., pearl millet), especially plants which could be used as both food and livestock resources, were determinants to improve regional farming systems at Brazilian semi-arid ecoregion. In our study, pearl millet farming system under irrigation and organic fertilization were characterized by high biomass production and high macronutrient contents. For all studied variable, we found a strong influence of irrigation. Among the organic fertilizers that we tested in our study, the best organic sources were bovine manure, compost, and goat manure. These results agree with Souza et al. (2015) and Duan et al. (2019), who reported these three organic sources as the most efficient soil organic amendments. These authors also concluded that in a long-term farming system there is an exponentially positive effect of organic fertilization on soil fertility, plant growth, plant yield and biomass quality.

Conclusion

Over the short-term experiment, the use organic amendments like compost or green manure combined with the irrigation showed high plant dry biomass, crude protein and plant macronutrient contents on pearl millet plants cultivated on a Luvissolo in field conditions.

Our findings suggest that organic amendments with high contents of N and K, such as compost and green manure, had positive effects on crude protein content within pearl millet dry biomass.

The results of our study highlight the importance of considering irrigation and organic fertilization as sustainable agricultural practices, based on a sustainable way to improve both food and forage production. Thus, the short-term utilization of both studied practices may exploit positive plant-soil feedback.

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