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Effect of organic matter, irrigation and soil mulching on the nutritional status and productivity of okra (*Abelmoschus esculentus* L.) in the semiarid region of Brazil

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Okra (*Abelmoschus esculentus* L) is an important vegetable crop currently cultivated in many parts of the world. The adoption of management strategies to promote the nutritional status and crop productivity in semiarid regions of Brazil is still poorly studied. Thus, this experiment was conducted to evaluate the effect of raising the level of organic matter in the soil, irrigation and soil mulching in the nutritional status and productivity of okra plant in the semiarid region of Brazil. In this study, the experimental design of randomized blocks in a factorial 5×2×2 was used, with four replications. The treatments were five rates of cattle manure, necessary for raising the levels of organic matter in the pits to 1.8, 2.62, 3.44, 4.26 and 5.08%, two water depths (50 and 100%) of crop evapotranspiration, and soil with and without mulch. The elevation of soil organic matter level until 5.08% in conjunction with the implementation of 100% of Evapotranspiration (ETc) water depth and the use of mulch on the soil favored the greatest absorption of nutrients and increased the productivity of okra plant.

Key words: Cattle manure, nutrient absorption, management of water in the soil.

INTRODUCTION

Okra (*Abelmoschus esculentus* L) is a vegetable currently cultivated in many parts of the world (Moyin-

Table 1. Chemical characterization of cattle manure used as a source of organic matter.

N	P	K^+	Ca^{2+}	Mg^{2+}	Na^+	Zn	Cu	Fe	Mn	OM	OC	C/N
g kg^{-1}						mg kg^{-1}				g kg^{-1}		
12.76	2.57	16.79	15.55	4.02	5.59	60.0	22.0	855.0	325	396.0	229.7	18:1

OM = organic matter; OC= organic carbon.

Jesu, 2007). Due to its important role in human nutrition, by providing carbohydrates, proteins, fats, minerals and vitamins, the demand for this culture has increased considerably (Moyin-Jesu, 2007; Phonglosa et al., 2015). Most of the vegetable crops require large amounts of nutrients in a relatively short time, and therefore are considered demanding regarding the nutritional aspect (Coutinho et al., 1993). The nutrient supply is made by means of fertilization, which is often carried out with rates above the recommended, in order to try to avoid nutritional deficiencies (Raij, 1993).

However, prolonged use of mineral fertilizers can increase the acidity of the soil, and reduce the availability of nutrients and organic matter (Agboola, 1974; Aduayi, 1980). The organic matter has buffering action in a wide pH range, due to reactions involving the carboxylic groups of fulvic acids (Mendonça et al., 2006). The elevation of organic matter levels in the soil can promote increased crop yields, especially in sandier soils, by managing to increase the capacity of cation exchange, avoiding major losses by leaching (Santos et al., 2001; Yanfei et al., 2016). In addition, the organic matter is an important way to provide nutrients to plants and may promote greater absorption efficiency, resulting in productivity gain (Sediyama et al., 2009). But the application of large amounts of organic fertilizers can result in high vegetative development, and that may hinder the harvest and cause productivity losses, which explain the importance of studying the optimal rates to be applied (Trani et al., 2008).

For an efficient nutrient absorption by the plants, it is necessary for the soil humidity to be in an adequate amount (Danso et al., 2015). In regions of semiarid climate where low pluviometry is associated with constant irregularity of rainfall, it is necessary to provide water to the culture through the use of irrigation techniques, to increase productivity by optimizing the use of water resources (Barbosa et al., 2015). Another promising alternative to crop management can be the use of mulch on the soil surface, which has been found efficient in reducing hydric loss through evaporation (Teófilo et al., 2012).

However, there are no studies to understand the behavior of okra culture in regions with semiarid climates in Brazil, when adopted this set of techniques. Therefore, this experiment was conducted to evaluate the nutritional status of okra in relation to the elevation of levels of organic matter, irrigation and soil mulching.

MATERIALS AND METHODS

The study was conducted in the field during the period of November 2013 through April 2014, in Paraíba State University UEPB, Campus IV, at the Agroecology sector, in the municipality of Catolé do Rocha (6˚20'38"S, 37˚44'48''W and altitude of 270 m), Paraíba, Brazil. The climate in the region is the BSw'h' type, according to Kõppen classification, characterized as hot semiarid with two distinct seasons, a rainy one with irregular precipitation with an annual average of 800 mm, and another without precipitation. The rainfall (416 mm) in the experiment site was obtained through the meteorological station at UEPB, Campus IV. The rainy season is concentrated between the months of February and April. The average air temperature is 27°C, the soil protected with mulch is around 28ºC and uncovered it is 35ºC. The soil according to Embrapa (2013) was classified as Eutrophic Fluvic Neo-soil. In the first 20 cm of depth it showed 661 and 126 g kg^{-1} of sand, silt and clay, with soil and particle density of: 1.51 and 2.76 g cm^{-3}, respectively, and total porosity 0.45 m^3 m^{-3}. The humidity values at the field capacity, permanent wilting point and available water were 23.52; 7.35 and 16.17%, respectively. As for the chemical characterization, the soil at the same depth presented, according to the methodologies of Embrapa (2011), pH = 7.02; P and K = 53 and 297 mg dm^{-3}; Na^+ = 0.30; Ca^{2+}= 4.63; Mg^{2+}= 2.39; Al = 0.0; H+Al = 0.0 and CTC = 8.08 $cmol_c$ dm^{-3}, respectively; base saturation V = 100% and OM = 1.80%.

The treatments were distributed in randomized blocks in a factorial design 5 × 2 × 2, referring to the following treatments: five rates of cattle manure C/N ratio of 18:1 (Table 1), two water depths (50 and 100%) of crop evapotranspiration (ETc mm day^{-1}) and soil with and without mulching with plant debris of crushed dried parsley (*Ipomoea asarifolia*) in a layer 5 cm thick, with four replications, totaling 80 plots. The plot consisted of three lines 3.2 m long, spaced 1 m, with an area of 6.4 m^2. Each line had nine plants totaling 27 plants per plot.

The pits were opened in the dimensions of 30 cm × 30 cm × 30 cm, with spacing of 1 m between rows and 0.4 m between plants and prepared with soil material from the first 30 cm, along with 16 g pit^{-1} (84 kg ha^{-1} P_2O_5) of simple superphosphate (20% P_2O_5) (Ribeiro et al., 1999) and cattle manure C/N ratio 18:1 (Table 1), in sufficient rates to raise the content of organic matter in the soil 1.80 to 2.62; 3.44; 4.26 and 5.08%. The soil, the fertilizer and the cattle

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Table 2. Values for each rate of organic matter applied and their respective equivalence in the pits.

Rates of organic matter applied (%)	Cattle manure values (g hole^{-1})	Kg ha^{-1} of cattle manure
1.80*	0.00	0.00
2.62	886.00	22.150
3.44	1773.00	44.325
4.26	2659.00	66.475
5.08	3546.00	88.650

*Value existent in the soil.

manure were homogenized and subsequently inserted in the pits. The amount of manure dried in the air (Table 2) with 5% humidity, embedded in each pit was obtained through the expression suggested by Bertino et al. (2015):

$$M = \frac{[(OMR - ROMS) * Vc * Ds * HCM]}{OMCCM}$$

Where M = amount of cattle manure to be applied per pit (g); OMR = organic matter rate to be increased in the soil (g kg^{-1}); Vc = crown volume; Ds = soil density; = ROMS rate of organic matter in soil (g kg^{-1}); OMCCM = organic matter content in cattle manure (g kg^{-1}); HCM = humidity of cattle manure dried in the air.

The sowing was done in the second week of November 2013, with five seeds of okra (*A. esculentus* (L.) Moench) cultivar Santa Cruz 47, per pit. The thinning was performed when the plants had three true leaves in the first week of December, keeping only the strongest plant per pit.

Cover fertilization with nitrogen and potassium was made in function of crop yield and soil analysis at 20, 40 and 60 days after sowing (Ribeiro et al., 1999). The nitrogen and potassium were given in rates of 100 and 75 kg ha^{-1}, respectively, using as source the ammonium sulphate (20% N) and potassium chloride (60% K_2O).

The irrigation of the plants was carried out daily by the method of localized irrigation, adopting the drip system, according to the crop evapotranspiration ETc (mm day^{-1}). The calculation was based on the reference evapotranspiration (Eto, mm day^{-1}), estimated by the class A tank and corrected by the Kc of culture according to the development stage of the plant, obtaining the consumptive use (Cu) considering the wet area percentage (P) = 50%. Thus, for the purposes of calculating the depth of daily net irrigation (DDN = ETc), we used DDN = Cu × P/100 (mm day^{-1}); from this value, we determined the depths applied corresponding to 50 and 100% DDN which were applied daily and the application time used as a way of reducing the water volume (CE_{water} = 0.8 dS m^{-1}), that is, the time was reduced by half of what was offered on the water depth 100% of ETc. The variables assigned in the experiment were: Coefficient of class A tank (Kp) = 0.75; varying crop coefficient according to the culture stage (Kc) = 40 days after sowing was used Kc of 0.68; from 41 to 70 days, 0.79; 71 to 120 days, 1.00, as suggested by Paes et al. (2012). The flow of the drippers (q) = 2.15 L h^{-1} was obtained through field testing with the emitters installed at every 0.2 m on the line, that is, resulting in an area (AS) = 0.2 m^2 per emitter, as suggested by Paes et al. (2012).

In the beginning of flowering, at 65 days after sowing, the third leaf of three central plants was cropped of each plot for determination of N, P, K, Ca, Mg and S of the plant, to assess the nutritional status of the culture (Filgueira, 2007), adopting the methodologies proposed by Malavolta et al. (1997), and at the end of the crop cycle the productivity was evaluated. The results were submitted to variance analysis by the "F" test and polynomial regression, using the statistical software Sisvar 5.0 (Ferreira, 2011).

RESULTS AND DISCUSSION

The interaction between water depths, levels of organic matter and soil mulch is significant, except for the foliar levels of N and S (Table 3). The absorption of nutrients by plants is dependent upon a number of factors, such as the availability of these elements in the soil and appropriate humidity conditions, in function of most being absorbed at a greater proportion by the mass flow, which explains the significant effect of triple interaction, included in the crop yield (Kamaluldeen et al., 2014; Siyal et al., 2016). The exception of the statistical significance of N and S on this interaction may be the result from the spacing adopted in the experiment (1 × 0.4 m), which provided the closure of the entire area at 40 days after sowing, minimizing the effect of this factor. Considering nitrogen responds to the effects of irrigation and soil organic matter, and the accumulated levels of S vary according to the levels of organic matter added to the soil (Table 3).

Increased levels of organic matter stimulate the accumulation of nitrogen in the foliar dry matter of the okra to the highest value of 43.15 g kg^{-1}, the estimated maximum level of 3.80% of the input. The fertilizations with higher levels compromised the absorption of nitrogen (Figure 1A). The increase in leaf nitrogen content to the observed manure level occurs because the organic matter is a nitrogen source, releasing it slowly, avoiding losses of N in the soil by denitrification and leaching, as it happens at a greater proportion when inorganic fertilizers are applied (Barbosa, 2015).

The reduction of the water depth from 100 to 50% ETc resulted in the loss of nitrogen foliar accumulation in the early flowering of the plants from 43.36 to 39.55 g kg^{-1}, resulting in a loss of 8.8% (Figure 1B). This may be the result from decreased contact of nitrate and ammonium ion with the root due to the low humidity (Prado, 2008).

Regardless of the soil with and without cover, higher foliar levels of phosphorus were observed in plants irrigated with the highest water level (100% ETc) (Figure 2). In the treatments with mulch (Figure 2A), the highest P concentrations were 3.79 and 3.44 g kg^{-1} relating to the maximum rates estimated 4.58 and 4.37% in plants with water depths of 100 and 50% of crop evapotranspiration (ETc). It is noticed that the difference in the reduction of

Table 3. Summary of variance analysis related to the variables nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S) and productivity (Prod.) in leaves of okra variety Santa Cruz, when subjected to levels of organic matter in the soil, water depths, with and without soil mulch.

Source of variation	Square mean							Prod.
	DF	N	P	K	Ca	Mg	S	
Block	3	ns	ns	ns	ns	ns	ns	ns
OM	4	*	*	*	**	*	**	**
SM	1	ns	ns	ns	ns	*	ns	**
Depths (D)	1	**	**	*	**	*	ns	**
OM x SM	4	ns	*	**	ns	ns	ns	ns
OM x D	4	ns	ns	ns	**	**	ns	**
SM x D	1	ns	ns	ns	ns	ns	ns	ns
OM x SM x D	4	ns	*	**	*	*	ns	*
Residue	57	-	-	-	-	-	-	-
CV (%)		7.42	7.43	10.07	6.89	7.81	8.52	15.10
					g kg^{-1}			kg ha^{-1}
General average		41.45	3.54	19.40	24.60	6.12	2.05	7736.88

Significant at 5% (*) and 1% (**) of probability by F test; (ns) not significant; DF = degree of freedom; CV% = coefficient of variation; OM= organic matter; SM = soil mulching.

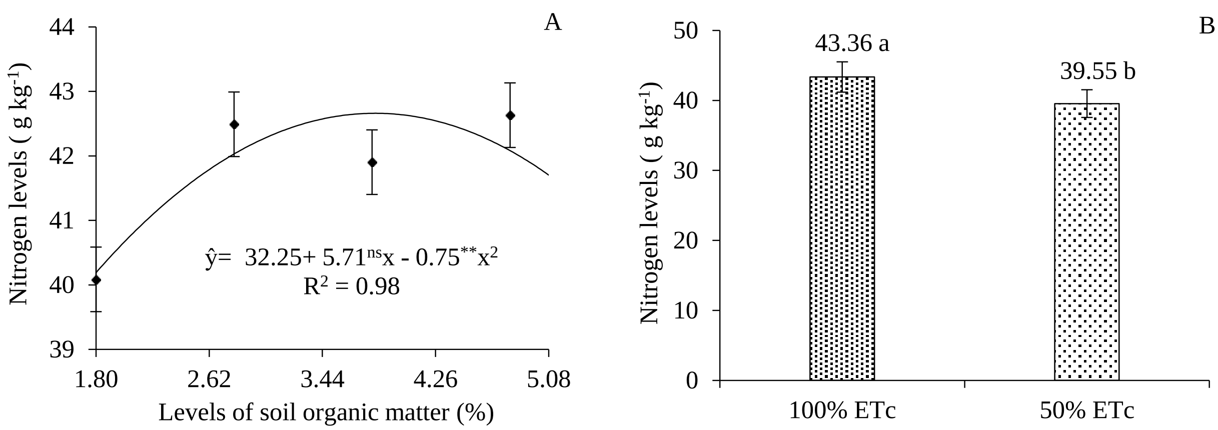

Figure 1. Nitrogen content in okra leaves, depending on the levels of organic matter (A) and water depths (B).

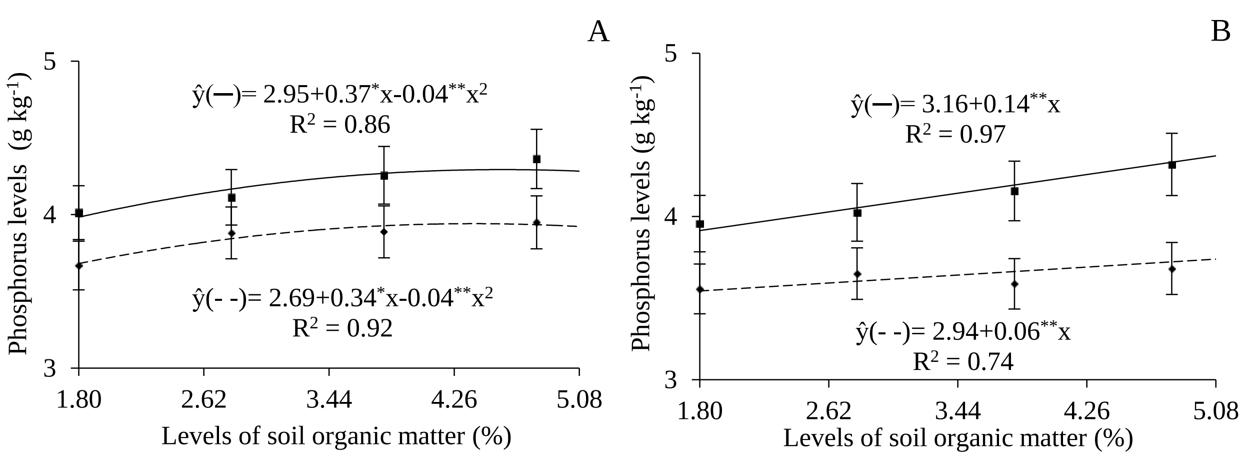

Figure 2. Phosphorus content in okra leaves depending on the levels of organic matter, irrigation with 100% (—) and 50% ETc (---), in a soil with (A) and without mulch (B).

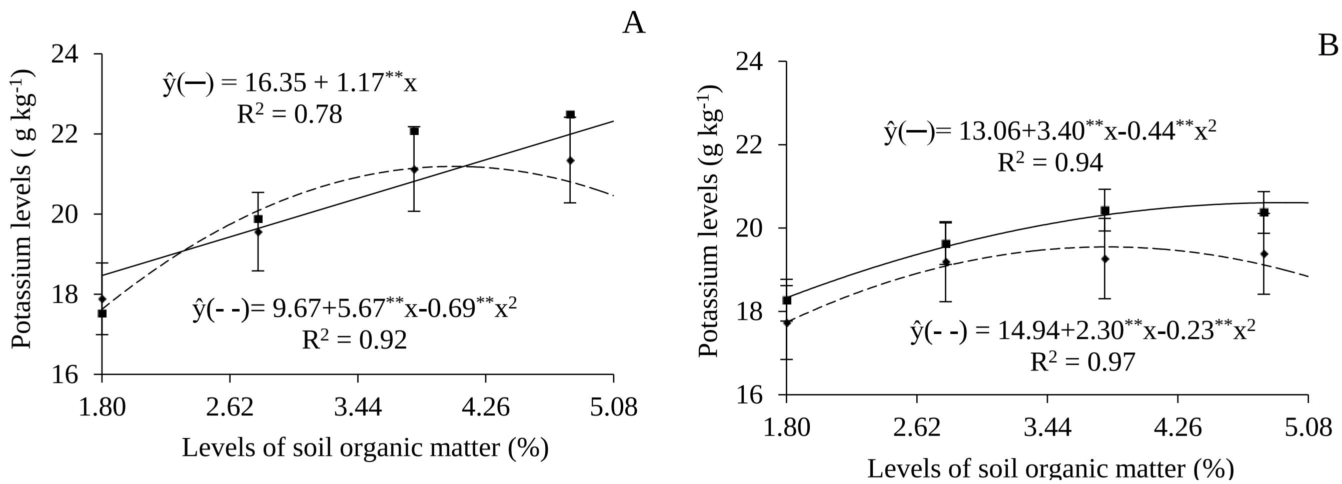

Figure 3. Potassium content in dry matter of okra leaves, depending on the levels of organic matter in the soil, with (A) and without mulch (B), irrigated with 100% ETc (—) and 50% ETc (---).

the water supply from 100 to 50% ETc resulted in a loss of foliar accumulation of P higher than 9%.

In plants from the soil without mulch the rate of organic matter linearly increased phosphorus foliar levels, to the levels of 0.139 and 0.059 g kg^{-1} per unit increase of provided organic matter (Figure 2B). The highest levels were 3.86 and 3.23 g kg^{-1} in the treatments with higher rates of the organic input in plants irrigated with water depth of 100 and 50% of ETc, respectively. As also recorded in plants of the soil with coverage, the reduction of water supply from 100 to 50% ETc resulted in loss of P accumulation of 18.9%.

Cattle manure levels possibly increased the amount of organic phosphorus in the soil, which was then converted to inorganic forms which the plants are able to absorb through the reaction catalysed by enzymes such as phosphatase, produced by soil microorganisms. The metabolic efficiency of microorganisms in the production of this enzyme may improve with increasing soil humidity and temperature, up to a certain limit (Zumsteg et al., 2013; A'Bear et al., 2014), which may have contributed to the increased availability of phosphorus in the soil. This explains the major foliar P in the treatments with 100% of ETc in relation to 50%, and also the small superiority of P value in the treatment that received the highest water depth, without soil mulch.

The results are in accordance with Medeiros et al. (2005), who verified an increase in N and P content in the shoot of rice plants, due to the increase of water content in the soil. In most cases, adequate levels of soil humidity and properly nourished plants express higher photosynthetic efficiency with higher respiration and perspiration rates, and larger energy to overcome the resistance to the penetration of roots into the soil (Hoffmann and Jungk, 1995; Stone, 1985), resulting in an increased nutrient absorption, in general, including the phosphorus that is a not so mobile element in the soil, in which the form of $H_2PO_4^-$ is absorbed on a greater proportion on the diffusion process.

In the plants of the soil with mulch, irrigated with water depth corresponding to 100% of ETc, the potassium content increased linearly in 1.744 g kg^{-1} of K^+ per unit increase of the applied organic input, with the highest value 22.31 g kg^{-1} at the highest rate provided. In the same coverage conditions, the plants treated with irrigation water depth of 50% of ETc had foliar potassium levels elevated to the maximum value of 21.17 g kg^{-1} at the highest estimated rate of 4.1% organic matter applied to the soil (Figure 3A). In plants of the treatments with no mulch, the increase in organic matter stimulated the foliar accumulation of potassium to the values of 20.61 and 19.53 g kg^{-1}, on the maximal rates of 3.82 and 4.88% of soil organic matter, respectively, between the plants irrigated with the water depths of 100 and 50% of crop evapotranspiration (Figure 3B). By relating the major values 21.11 and 23.16 g kg^{-1} (Figure 3A) and 19.53 and 20.61 g kg^{-1} (Figure 3B) between plants irrigated with water depths of 50 and 100% of ETc, it is perceived that the reduction was 8.7 and 5.2% between the plants of the soil with and without mulch.

Comparatively to the phosphorus, the data for potassium indicate similar behavior among plants irrigated with the water depth 50% of ETc, but differentiated between soil with and without mulch. The highest percentage loss of 18.9% of phosphorus foliar content occurred in plants without soil mulching and the greatest potassium loss (8.7%) in the plants on soil protected against losses through evaporation.

The results of 19.53 and 20.61, 21.11 and 23.16 g kg^{-1} are lower than those presented by Cavalcante et al. (2010), at a rate of 15% of cattle manure, when studying rates and sources of organic fertilizers in the

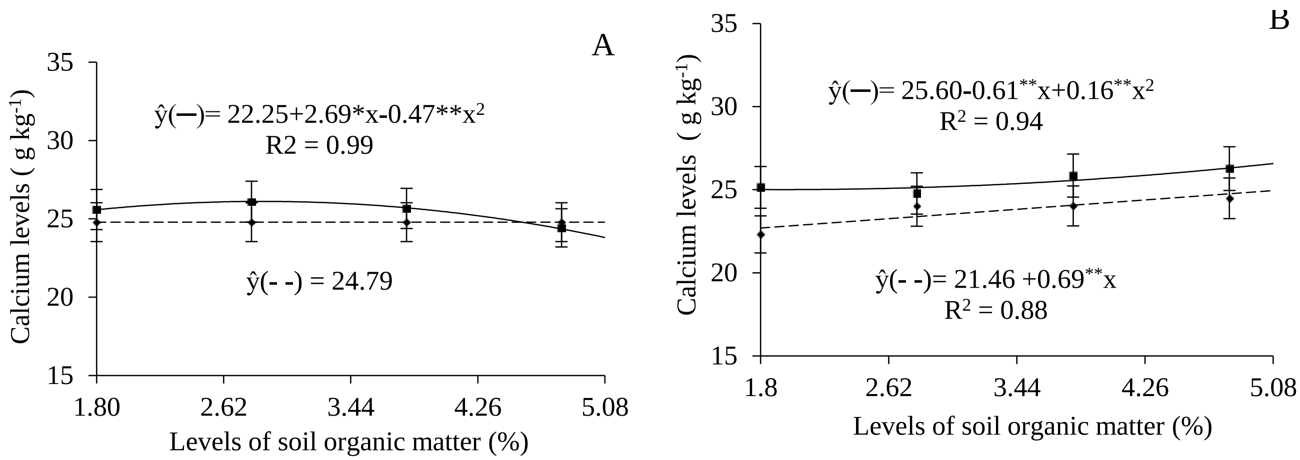

Figure 4. Calcium content in dry matter of okra leaves, depending on the levels of organic matter in the soil, with (A) and without mulch (B), irrigated with 100% ETc (—) and 50% ETc (---).

macronutrient content in okra leaves, possibly due to the cattle manure used in their experiment have higher potassium content (26.2 g kg^{-1}), compared to 16.9 g kg^{-1} K^+ present in the manure used in this experiment (Table 1).

In the soil with mulch and irrigation with water depth of 100% ETc, the levels of organic matter provided increased the foliar contents of Ca^{2+} in the plants to 26.11g kg^{-1} corresponding to the estimated amount of 2.86% of organic fertilizer. However, in plants under irrigation with 50% of ETc, the contents did not fit any mathematical model, so were represented by the average of 24.79 g kg^{-1}. Through the relation of the respective values, we verified that the reduction of water depth from 100 to 50% of ETc caused a 5.1% decline in the foliar accumulation of calcium by the okra plant (Figure 4A).

In the plants on the soil without mulch, the calcium levels were increased linearly with rates of organic matter regardless of irrigated with 50 or 100% of crop evapotranspiration (Figure 4B). The level of 5.8% of organic matter in the soil was responsible for the highest calcium content in the dry matter of okra leaves with averages of 27.38 and 25.43 g kg^{-1}, without mulch on the soil surface, irrigating the plants with 100 and 50% of ETc, respectively. The beneficial effect of organic matter may be related to the improvement of the physical, chemical and biological conditions of the soil, increasing the availability of calcium to the plants, a fact confirmed by Lopes and Guilherme (2007). These results differ from Cavalcante et al. (2010), who observed decrease in calcium content in the dry matter of okra leaves with increase of the cattle manure rate. Comparatively, the plants grown without water stress, regardless of soil cover, had higher levels of N, P, K and Ca^{2+} in the dry matter of okra leaves for the same treatments under water deficit in the soil. The contact ion-root occurs differently for the nutrients, being N, Ca and Mg by mass flow, while P and K through diffusion. Regardless of how the ion-root contact occurs, the elements must be present in the soil solution for the plant absorption to occur (Mauad et al., 2011). In view of this, the reduction of N and Ca^{2+} levels supplied by mass flow was due to the reduction of water content in the soil. On the other hand, for P and K, the decrease in content under increased tension is explained by the fact that the reduction of soil humidity decreases the thickness of the water film, increasing tortuosity, thereby hindering diffusion (Stone, 1985).

In the soil with mulch, foliar contents of Mg^{2+} decreased linearly with the levels of organic matter in plants irrigated with 100% of the ETc. The reduction of 0.285 g kg^{-1} for each unit increase of the organic input, corresponding to the decrease from 6.98 to 6.4 g kg^{-1} and loss of 15.56% between the plants in the soil with 1.80 to 5.08% of organic matter. Probably the greatest soil moisture provided by the mulch plus the water depth of 100% of ETc contributed for the occurrence of Mg^{2+} leaching. In these treatments, in the plants irrigated with water depth of 50% ETc, the Mg^{2+} content increased depending on the organic matter to the greatest value of 5.77 g kg^{-1}, at the maximum rate 3.51% (Figure 5A). These results partly differ from those obtained by Cavalcante et al. (2010) who recorded an increase in Mg^{2+} content in the dry matter of okra leaves with the increment of organic sources in the soil.

In the soil without mulch (Figure 5B), the higher levels of soil organic matter increased the magnesium content in the foliar dry matter of the plants to 6.82 and 6.14 g kg^{-1} corresponding to the estimated rates of 4.32 and 5.02% in plants irrigated with 100 and 50% of ETc. In general, the organic material influences the absorption of Mg^{2+} by the plants in accordance with Malavolta (1997), that organic matter reduces the losses of this secondary macronutrient through leaching by increasing its

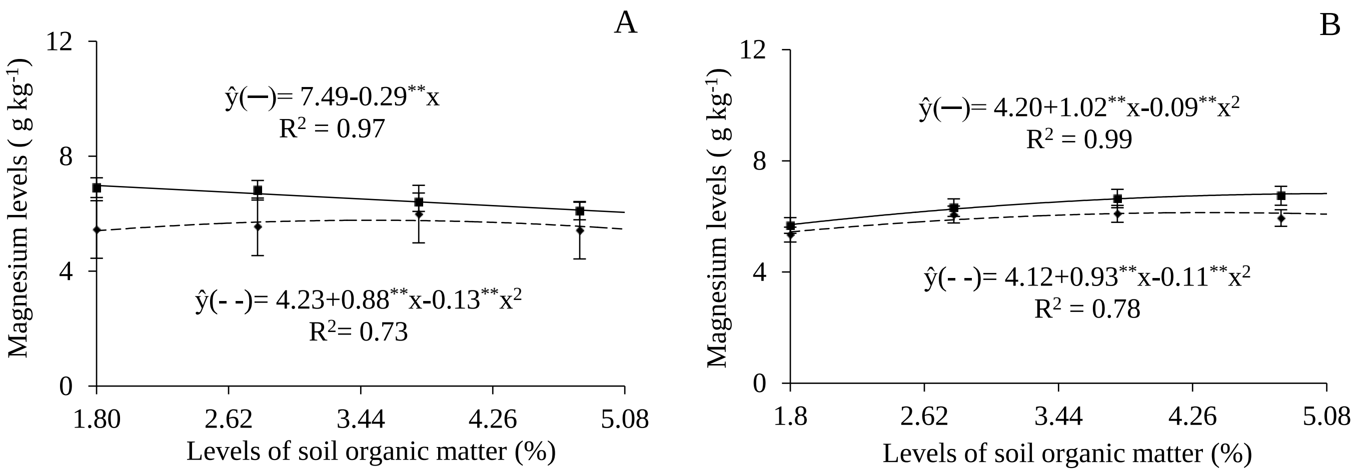

Figure 5. Magnesium contents in the dry matter of okra leaves, depending on the levels of organic matter in soil, with (A) and without mulch (B), irrigated with 100% ETc (—) and 50% ETc (---).

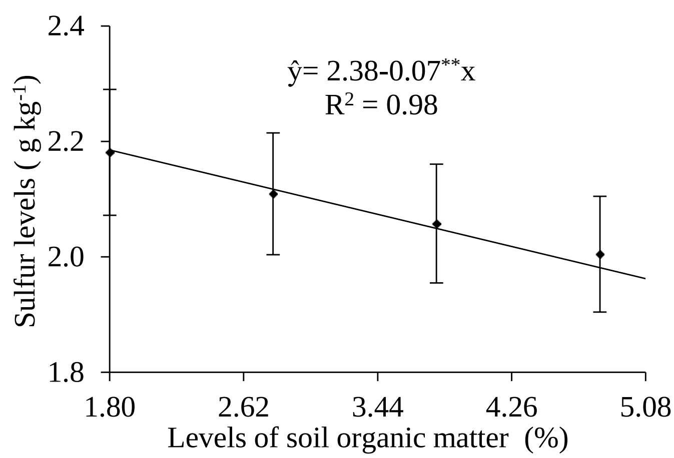

Figure 6. Sulfur content in the dry matter of okra leaves, depending on the levels of organic matter in the soil.

availability to the plants, as concluded also by Souza et al. (2005), with lettuce.

Among the studied nutrients, sulfur was the only one whose foliar levels of okra plant responded only to the levels of organic matter in the soil (Table 3). As shown in Figure 6, the increase in levels of organic matter added to the soil compromised the accumulation of S in the foliar dry matter at the level of 0.068 g kg^{-1} per unit increment of applied organic input. The values decreased from 2.18 to 1.96 g kg^{-1}, causing a reduction of 11.22% between plants treated with 1.80 and 5.08%, respectively. The values oscillated were among the lower limits required by most vegetable and fruit plants (Malavolta et al., 1997). This reduction may be related to the prevalence of the sand fraction in the soil and with the increased organic matter, rich in negative charges and pH dependent, contributed to the repulsion of the sulfate ion, a fact confirmed by Nogueira and Melo (2003), since they found lower sulfur content at 0 to 20 cm of the soil compared to the depth of 0 to 40 cm, after performing liming. The foliar levels of macronutrients in the plants at the beginning of flowering were obtained in the order: N> Ca> K> Mg> P> S, sequence also presented by Cavalcante et al. (2010).

The productivity of okra depending on the levels of organic matter in the soil in the presence and absence of mulch on the soil surface provided productions of (13584.43 and 9292.36 kg ha^{-1}) and (12815.21 and 9159.58 kg ha^{-1}), irrigating plants with 100 and 50% in ETc, respectively, reached the highest level of soil organic matter (Figure 7A and B). The production values obtained in the treatment of plants irrigated with 100% ETc approached the national average, which is 15000.00

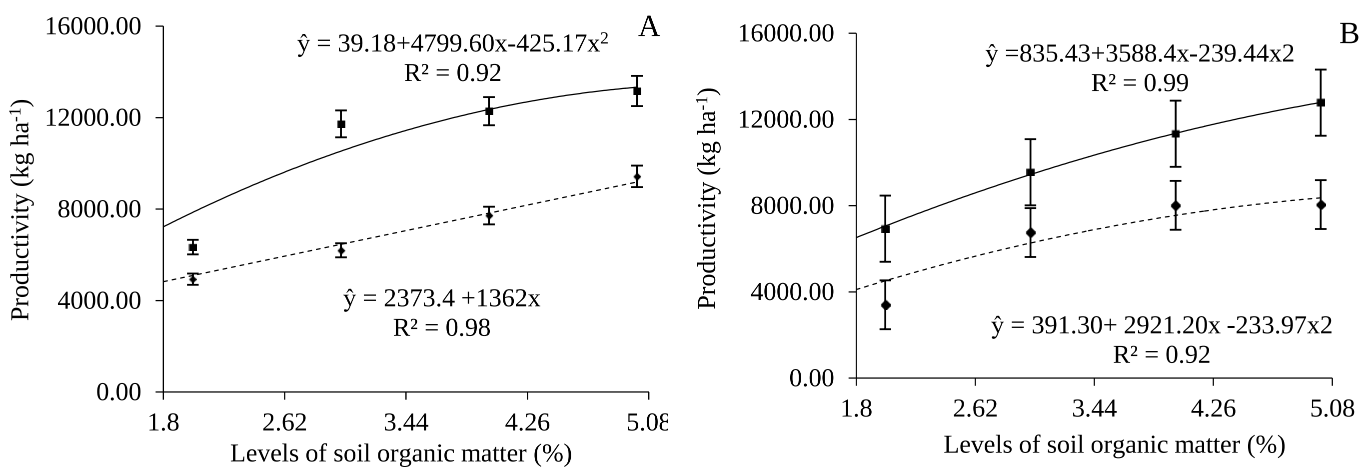

Figure 7. Okra productivity, depending on the levels of organic matter in the soil, with (A) and without mulch (B), irrigated with 100% ETc (—) and 50% ETc (---).

to 20000.00 kg ha^{-1} as reported by Filgueira (2007), and also in agreement with the results of Oliveira et al. (2003), who obtained 16701.00 kg ha^{-1} when assessing the yield of okra, cultivar Santa Cruz, in function of N rates. The increase in the okra productivity in function of organic matter levels in the soil is due to the input be the source of the macronutrients studied (Table 1). Nitrogen is the nutrient that provides greater response towards the productivity of okra (Filgueira, 2007), and foliar content of this element (43.15 g kg^{-1}) on the leaf were above the range considered appropriate (32.6 to 37.1 g kg^{-1}) as reported by Malavolta (1997). We also believe that 100% water depth of ETc has optimized nutrient transport mechanisms, since it is possible to observe higher foliar content of almost all the elements, in a water depth of 100% of ETc, which explains the higher productivity of the crop in this condition, as some studies have found increased the translocation of nutrients to the aerial parts of the plants when soil moisture is above 50% of the water retention capacity (Ruiz, 1986; Costa, 1998).

Conclusion

The results suggest that the management used in this study is an important strategy to promote the nutritional status of the okra plant and increase its productivity. It is recommended to increase the level of organic matter in the soil until 5.08%, the application of a water depth of 100% of ETc and the adoption of mulch to achieve higher productivity. It is important to note that in conditions of low water availability, water depth of 50% of ETc can also be used, in case a previous study was able to verify the economic viability in the region, considering a productivity drop of 31.59%.

Conflicts of Interests

The authors have not declared any conflict of interests.

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