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Production and leaf nutrient content of okra influenced by soil management

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A field study was conducted to explore the effect of various rates of organic matter, two water depths, with and without mulching on production of okra (*Abelmoschus esculentus* L.) and leaf nutrient content. This study was done for two years, and the experimental design of randomized blocks in a factorial 5 × 2 × 2 was used, with four replications. The treatments were five rates of organic matter, 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. In general, it can be observed that the results in the two experimental periods are similar; foliar contents and fruit yield were higher in the plants irrigated with greater amount of water, and also increased with the application of organic matter to the soil. The results were not very different with and without soil mulch, since, with the growth of the plants, the canopies of the same shaded the soil avoiding the evaporation of the water.

Key words: *Abelmoschus esculentus,* organic matter, mulching, irrigation.

INTRODUCTION

Okra is a long, dry indehiscent fruit with cylindrical shape and predominantly greenish color, whose scientific name is *Abelmoschus esculentus* L. of the Malvaceae family. Okra which has it origin from tropical Africa was grown in the Mediterranean region, and wild forms are also found in India. This plant was introduced in Brazil with the slave trade and is currently cultivated in several tropical, subtropical and temperate regions of the world. It is a vegetable of relatively low cost of production, possessing a fast cycle, practically no fat, high in fiber, and have several valuable nutrients, for example, protein, vitamin C, vitamin A and folate. Potassium, sodium, magnesium and calcium are the principal elements in pods, which contain about 17% seeds (National Academies, 2006).

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Although it is easy to handle culture for better productivity, the ideal planting should be in soils with sandy-clayey, well drained, rich in organic matter and pH between 6.0 to 6.8 (Oliveira, 2013). The application of organic matter to the soil improves its physical and chemical conditions (Zeraatpishe and Khormali, 2012) by increasing the production of the crops, since the decoposition of this material releases the macro and micronutrients improving the fertility of the soil, improving the structure, aeration, water storage and internal soil drainage (Suthar, 2009).

Also these manures provides an increase in the biodiversity of useful microorganisms that act in the solubilization of various fertilizers in order to release nutrients to the plants and consequently contributes to the increase of productivity and quality of the crops.

In general products of animal origin, such as cattle manure, it undergo a more rapid mineralization process than products of plant origin when subjected to the same conditions of ambient temperature and soil moisture. Regarding soil moisture, it is important to note that for the decomposition of organic matter, release of nutrients to plants and their absorption must be in adequate quantities (Danso et al., 2015).

One of the most important factors for okra production in tropical regions is the availability of water (Tiwari et al., 1998). According to Kumar et al. (2010), okra is traditionally cultivated as a rainy season crop, therefore, it should be cultivated as an irrigated crop during the dry season. The region where the present experiment was installed is semi-arid, with low rainfall and irregular rainfall, therefore, the crop should be irrigated to increase its productivity (Barbosa et al., 2015).

In order to maintain soil moisture, or to reduce water loss through evaporation, the use of mulch on the soil surface is another important factor of cultivation in semi-arid regions, thus increasing the yield of many horticultural crops (Gimenez et al., 2002; Teófilo et al., 2012). Surface mulches can also improve water penetration by impeding runoff and protecting the soil from raindrop splash and reducing soil crusting (Tesfaye et al., 2016).

In this context the objectives of the study were to explore the effect of various rates of the organic matter, two water depths, with and without mulching on production of okra and nutrient content in okra leaves.

MATERIALS AND METHODS

Soils and experimental site

Two year field experiment was carried out at the Agroecology Sector of Paraíba State University (situated 6˚20'38"S, 37˚44'48"W and 275 m above mean sea level; climate BSw'h' type) during two seasons for November to April in 2014 to 2015 and for September to February in 2015 to 2016. The total rainfall of the region in first period was 599 mm, out of which 88% falls in between February and April. In the second period was 230 mm, out of which 85% falls in between January and February. The data observed at meteorological station indicates that the average, maximum and minimum air temperature was 28, 35 and 23°C, respectively.

The average relative humidity in dry months is less than 50%.The experimental soil according to Embrapa (2013) was classified as Eutrophic Fluvic Neosoil with 661g kg^{-1} sand, 213g kg^{-1}silt and 126 g kg^{-1}clay. The chemical properties of the soil were pH 7.0, cation exchange capacity (CEC) 8.08 cmol$_c$ kg^{-1}, organic matter (OM) 18 g kg^{-1}, phosphorous (P) and potassium (K) as 31 and 297 mg kg^{-1} soil, respectively, sodium (Na), calcium (Ca), magnesium (Mg), aluminum (Al) and hydrogen (H) + aluminum as 0.30; 4.63; 2.39; 0.0 and 0.0, cmol$_c$ kg^{-1},respectively. The irrigation water presented CE$_{water}$ = 0.8 dS m^{-1}.

Experimental design

The okra cultivar 'Santa Cruz 47' was sown in randomized blocks in a factorial design 5 × 2 × 2, referring to the following treatments: five rates of organic matter C/N ratio of 18:1 (Table 1), two water depths (50 and 100%) of crop evapotranspiration (ETc mm/day) 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 (30 × 30 × 30 cm), where the okra was cultivated, was prepared with 16 g of simple superphosphate (Ribeiro et al., 1990) and organic matter C/N ratio 18:1 (Table 1), in sufficient rates to raise the content of OM in the soil 1.80 (value existent in the soil) to 2.8; 3.8; 4.8 and 5.8% (0.0; 1081; 2162; 3243 and 4324 g/pit of OM, respectively).These amount of manure dried in the air with 5% humidity, embedded in each pit was obtained through the expression (Equation 1):

$$M = \frac{[(OMR - ROMS) * Vc * Ds * HCM]}{OMCCM} \quad (1)$$

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

Irrigation scheduling and crop management practices

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), 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 = 50%. The variables assigned in the experiment were: coefficient of class A tank (Kp) = 0.75 and varying crop coefficients according to the culture stage were used as Paes et al. (2012).

The sowing was done in the second week of November 2014 and second week of September 2015, with five seeds of okra, per pit. After the thinning, in the first week of December 2014 and October 2015, maintained only one plant per pit. Cover fertilization was done at 20, 40 and 60 days after sowing by applying to the pits 100 and 75 kg ha^{-1} of ammonium sulphate (20% N) and potassium chloride (60% K_2O), respectively (Ribeiro et al., 1990).

The differentiation of the water slides was done at 15 days after sowing (DAS), such as the application of mulch with vegetable detritus (*I. asarifolia*), 5 cm thick in the crown projection (30 × 30 cm). The mean total consumption was 430 mm and 215 mm for the

Table 1. Chemical characterization of organic matter 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	22	855	325	396	230	18:1

OM = organic matter; OC = organic carbon.

100 and 50% ETc slides of the culture, respectively, in the year 2014. In the year 2015 the mean total consumption was 425 mm and 212 mm for the 100% and 50% ETc slides of the culture, respectively.

At the beginning of flowering (45 DAS), leaf D (fourth leaf from the apex of the plant, that is, the intermediate leaf of the plant with maximum photosynthesis) was collected from four plants of each treatment to determine the levels of nitrogen (N), P, K, Ca, Mg and sulfur (S) to evaluate the nutritional status of the crop (Filgueira, 2013).

Harvesting started at 64 DAS, being done twice a week up to 150 DAS; in this period the average weight of green fruits per plant were obtained, expressed in g/plant.

Statistical analysis

Analysis of variance (ANOVA) was conducted on the data from two experiments (two years) using the statistical software Sisvar 5.0 (Ferreira, 2011) and the results were submitted to variance analysis by the "F" test and polynomial regression.

RESULTS

In the period of 2014 to 2015, OM and water depths significantly affected the mineral composition of okra plants with the exception of Mg that was not influenced by the water depths. In the following period, the behavior of these treatments was similar. Soil mulching in the two evaluated periods did not influence the mineral composition of the plants, except for N and S contents in the first period. The interactions of the treatments influenced in different ways both in the mineral composition and in the planting periods (Table 2). In the experiment of 2014/15 N concentration showed a differential response to interaction OM × water depths and soil mulching treatments (Table 2).

The irrigation only with 50% ETc influenced leaf concentration of N, that is, this concentration increased in relation to increasing doses of OM. The maximum value observed 37.58 g kg^{-1} for the estimated dose of 5.8% of the input for the plants irrigated with 50% ETc (Figure 1A), while 36.86 g kg^{-1} of N in plants was irrigated with 100% ETc. In this period, the leaf N content in the cultivated plant in soils with mulch was 37.20 g kg^{-1}; this value was significantly greater than 34.42 g kg^{-1} as observed in plants grown without mulch.

Contrary to what was observed in the previous period, in 2015/16 experiment, the leaf N content was influenced by the interaction of the three factors, that is, OM, soil mulching, water depths in which in the absence of mulching, the highest N value in the dry matter of the leaves in okra irrigated with 50% ETc slide was 42.67 g kg^{-1}. In 100% ETc slide, the data did not fit any mathematical model with a mean of 43.55 g kg^{-1} N in dry matter in okra leaves (Figure 1B). In the plants using mulch, the maximum values of N were 44.05 and 43.50 g kg^{-1} (Figure 1C), for the estimated doses of 2.8 and 4.8 % of OM for the plants irrigated with 100 and 50% ETc, respectively (Figure 1C).

The interactions of treatments, in 2014/15 experiment was influenced in different ways such that the P content in okra leaves adjusted to the linear and quadratic model of 100 and 50% ETc, respectively, with mulch (Figure 2A) and quadratic model of 100 and 50% ETC without mulch (Figure 2B). The highest levels of foliar P were observed as 4.83 g kg^{-1} which was referred to 5.8% maximum dose of OM with treatment 100% ETc and mulch (Figure 2A). With the other treatments, that is, 50% ETc with mulch, 100% ETc and 50% ETc without mulch presented the highest levels of foliar P like 4.06; 4.62 and 4.08 g kg^{-1} corresponding to 4.15; 3.9 and 4.3% of OM, respectively.

Leaf P data in plants irrigated with 100 and 50% ETc and cultivated with mulch were adjusted to the quadratic model, the highest values being observed 3.77 and 3.56 g kg^{-1}corresponding to 4.2% and 3.75% of OM, respectively (Figure 2C). In the absence of mulch, the P data of the plants irrigated with 50% ETc were linearly adjusted, and the highest value was 3.45g kg^{-1}with 5.8% OM. However, irrigation with 100% ETc did not influence leaf P concentration (Figure 2D).

Increasing doses of OM influenced leaf potassium content in okra plants grown in areas with and without mulching. The highest leaf K content, 21.47 and 21.34 g kg^{-1}, were observed with the highest level of OM, 5.8% and 4.85%, applied to the soil with and without mulch, according to the linear and quadratic behavior, respectively (Figure 3A).

However, in the 2015/16 experimental period, leaf potassium content of the okra was influenced by the factors isolated OM. The increasing doses of OM in the soil significantly influenced the quadratic model, thus, the leaf K traits presented the highest level as 20.59 g kg^{-1}, thereby referring to 5.7% as the maximum estimated dose of OM (Figure 3B).

In the two experimental periods the leaf K content was influenced by factor isolated irrigation slides. In this situation the potassium content in okra plants irrigated

Table 2. Summary of variance analysis related to the variables nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and sulfur(S) in leaves of okra and the total weight of fruit per plant (WF) when subjected to treatments, in two years.

Source of variation	DF	Square mean						
		N	P	K	Ca	Mg	S	WF
					2014-2015			
Block	3	ns	ns	ns	ns	ns	ns	ns
OM	4	**	**	**	**	**	**	**
SM	1	**	ns	ns	ns	ns	*	**
Depths (D)	1	**	**	**	**	ns	**	**
OM × SM	4	ns	**	*	ns	ns	*	**
OM × D	4	**	ns	ns	*	**	**	ns
SM × D	1	ns	ns	ns	ns	**	ns	ns
OM × SM × D	4	ns	**	ns	ns	**	**	*
Residue	57	7.05	0.03	2.24	0.61	0.06	0.12	-
CV (%)		7.42	4.50	7.53	4.85	4.26	7.95	15.12
					g kg^{-1}			**g/planta**
General average		35.80	4.07	19.90	16.13	5.59	4.34	618.15
					2015-2016			
Block	3	ns	ns	ns	ns	ns	ns	ns
OM	4	**	**	**	**	**	**	**
SM	1	ns	ns	ns	ns	ns	ns	**
Depths (D)	1	**	**	**	**	**	*	ns
OM × SM	4	**	*	ns	*	ns	**	**
OM × D	4	**	ns	ns	ns	ns	ns	*
SM × D	1	*	**	ns	ns	**	ns	ns
OM × SM × D	4	**	ns	ns	ns	ns	ns	**
Residue	57	2.26	0.03	1.53	1.33	0.11	0.01	-
CV (%)		3.61	5.22	6.35	4.82	6.25	5.64	16.20
					g kg^{-1}			**g/planta**
General average		41.68	3.57	19.49	24.00	5.44	2.01	874.43

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.

with 100% ETc was significantly higher than that observed in plants grown with 50% of ETc, that is, 20.53 and 19.28 g kg^{-1}, respectively, in 2014/15 experimental period, and 20.27 and 18.73g kg^{-1}, respectively, in the 2015/16 experimental period.

The highest leaf Ca content, 17.87 and 16.27 g kg^{-1}, were observed with the highest level of OM, 5.8% and 4.45%, applied to the soil irrigated with water depth 100% and 50% of ETc, according to the linear and quadratic behavior, respectively (Figure 4A).

In treatments of plants with and without mulching, the data adjust to the quadratic polynomial model. The increase of OM stimulated the accumulation of Ca in okra leaves until the values of 24.86 and 25.29 g kg^{-1}, theoretically reached the maximum levels of 3.75 and 4.05 % of OM in the soil with and without mulching (Figure 4B).

In the same way as K, leaf Ca contents were influenced by the factor isolated irrigation slides, that is, the Ca content in okra plants irrigated with 100% ETc was significantly higher than that observed in plants grown with 50% of ETc, that is, 24.71 and 23.30 g kg^{-1}, respectively, in the 2015/16 experimental period.

The highest leaf Mg content, 5.98 and 5.75 g kg^{-1}, were observed with the highest level of 5.8% OM, applied to the soil with mulch, irrigated with water depth 100% and 50% of ETc (Figure 5A). In the soil without mulch, the higher leaf Mg content, 6.39 g kg^{-1}, in plants irrigated with 50% of ETc, also was observed with 5.8% of OM. However, in plants under irrigation with 100% of ETc, the contents did not fit any mathematical model, so were represented by the average of 5.49 g kg^{-1} (Figure 5B).

According to the analysis of variance, Table 2, in the 2015/16 experiment, OM levels significantly influenced

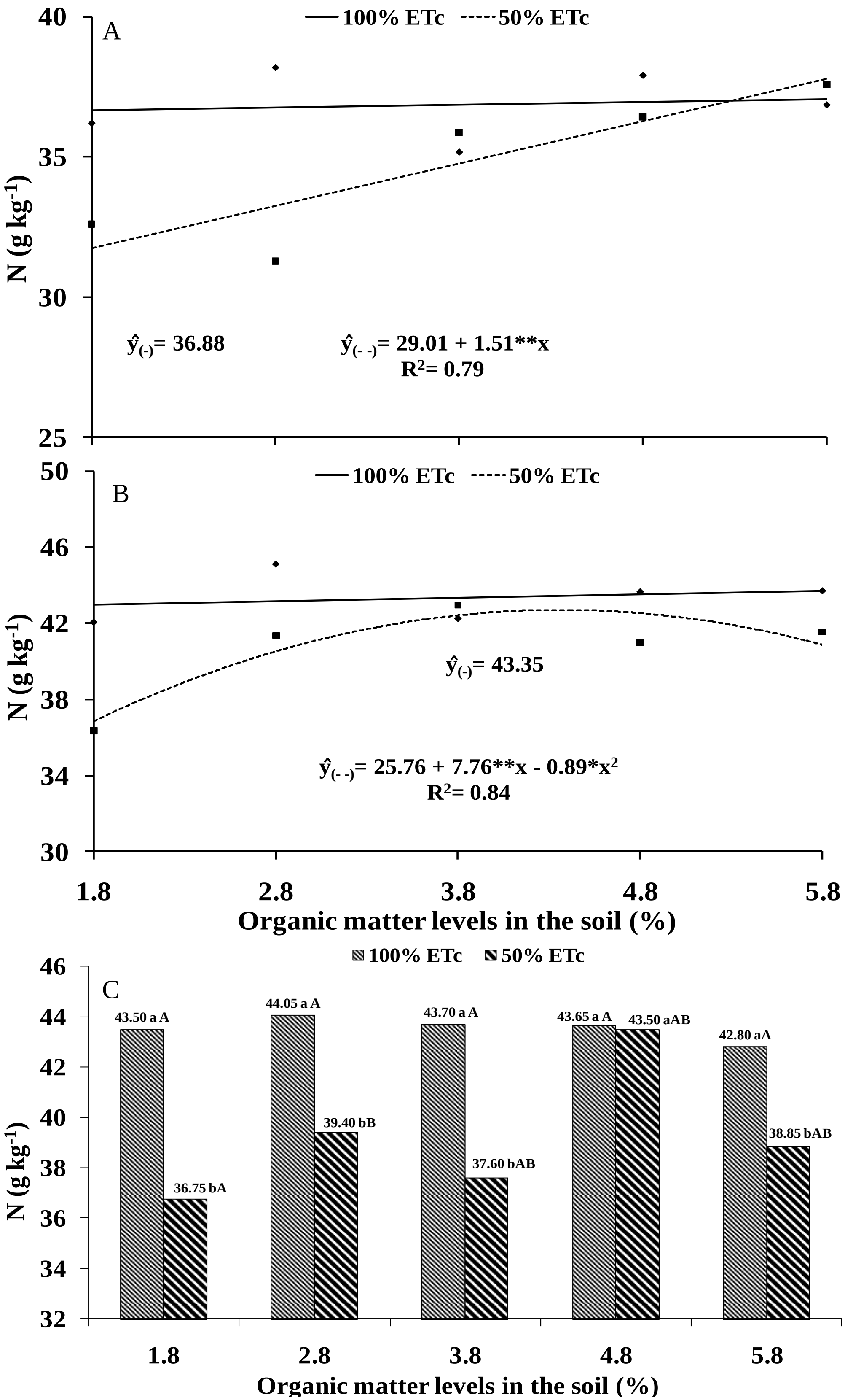

Figure 1. Leaf nitrogen content of okra cultivated under organic matter levels in soil irrigated with 100 and 50% ETc(A) in 2014/15 experiment and under organic matter levels in soil irrigated with 100 and 50% ETc without (B) and with mulch (C) in 2015/16 experiment.

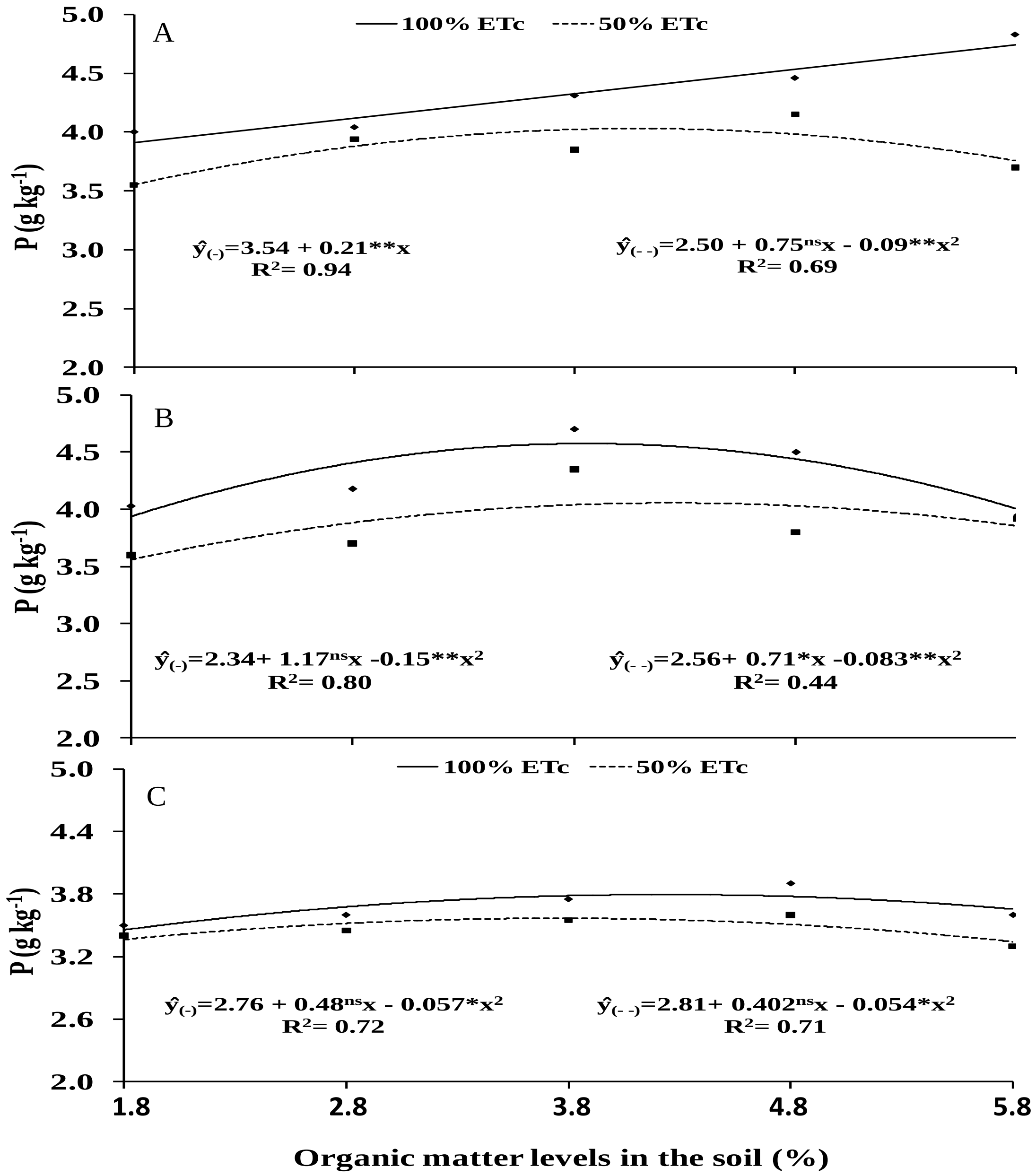

Figure 2. Leaf phosphorus content of okra cultivated under organic matter levels in soil irrigated with 100 and 50% ETc and with (A) and without mulch (B) in the 2014/15 experiment and with (C) and without mulch (D) in the 2015/16 experiment.

foliar Mg contents varying linearly from 5.02 to 5,90 g kg^{-1} for the doses of 1.8 to 5.8% of OM (Figure 6A). The interaction mulching vs water depth also influenced the foliar Mg contents; in the plants irrigated with 100 and 50% ETc the highest leaf Mg contents were 6.0 and 5.21g kg^{-1} (reduction around 13.16%), respectively, with mulch and 5.92 and 4.66 g kg^{-1}(reduction around 21.28%), respectively, without mulch (Figure 6B).

The values of foliar S in the irrigated plants with 100 and 50% ETc cultivated in mulched soil decreased from 4.69 to 3.77g kg^{-1} and from 5.32 to 4.04 g kg^{-1}, causing a reduction of 19.62% and of 24.06%, respectively, between plants treated with 1.8 and 5.8% of OM (Figure 7A). In the 100 and 50% ETc irrigated plants grown in soil without mulching, leaf S values range from 4.49 to 3.41 g kg^{-1} and from 5.38 to 3.78g kg^{-1}, causing a reduction of 25.05% and of 29.74%, respectively, between plants treated with 1.8 and 5.8% of OM (Figure 7B).

The behavior of leaf S of the okra as a function of OM content in the soil in the experiment conducted in 2015/16 (Figure 8) was similar to that observed in the previous experiment (Figure 7), that is, the leaf contents

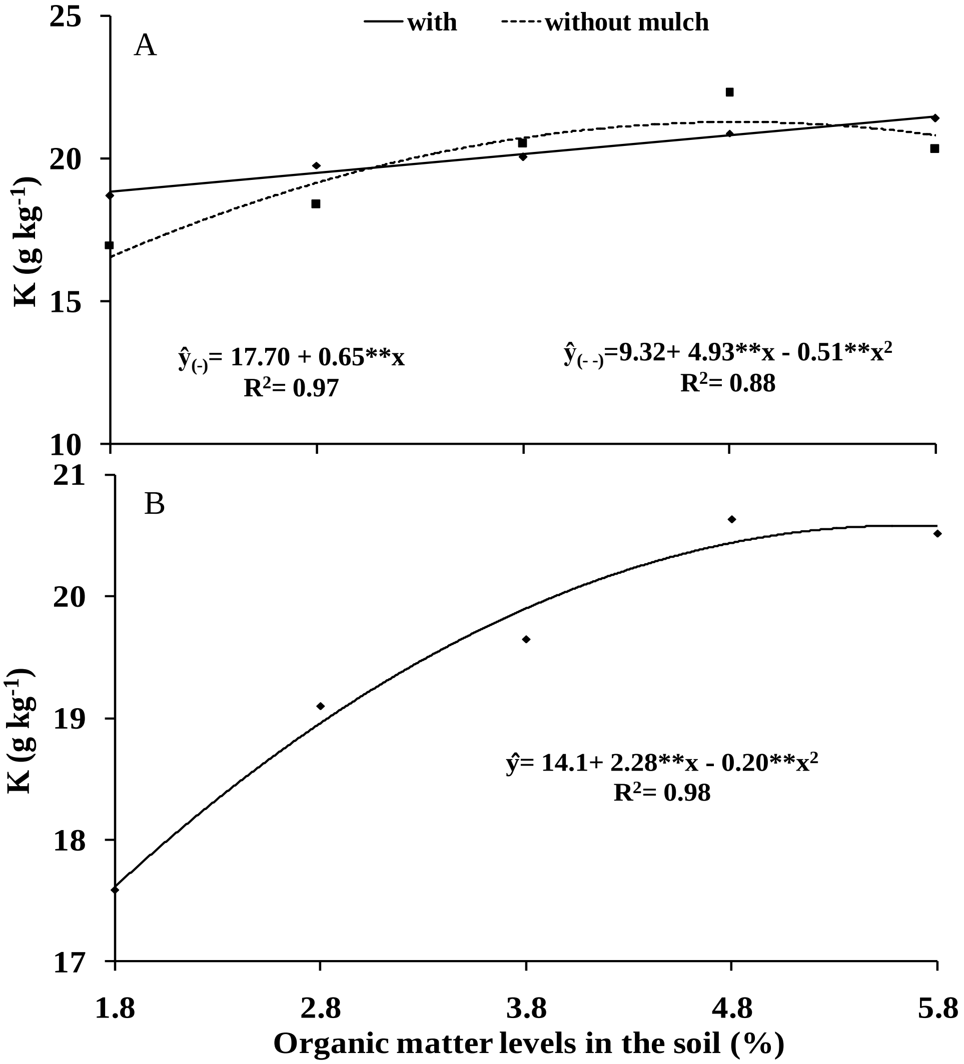

Figure 3. Leaf potassium content of okra cultivated in soil with and without mulching under organic matter levels (A)in the 2014/15 experiment and only under organic matter levels (B) in the 2015/16 experiment.

of this element decreased as a function of the doses increase of OM, both in plants grown in mulched soil and without this cover.

The average S content in the plants irrigated with 100% ETc, 2.04 g kg^{-1}, was significantly higher than in plants irrigated with 50%,that is, 1.98 g kg^{-1}.

As it can be observed, in the two experimental periods, the interaction of water and OM significantly influenced the total weight of the green fruits of okra per plant (Table 2) like Barbosa et al. (2016).

The highest weight of green fruits per plant, were 1061.62 and 706.67 g/plant observed in plants irrigated with water depth of 100 and 50% of ETc, respectively, and cultivated with 5.8% of OM (Figure 9A).

Under the same conditions, soil without mulch, plants cultivated with 100% ETc, presented the higher weight of green fruits per plant as 1066.48, however with water depth of 50% ETC, the date fit with model linear increased with the higher of 734.68 g/plant.

In the experiment corresponding to the period 2015/16, the productions corresponding to weight of green fruits per plant were of 1308.33 and 849.87 g/plant with 4.25 and 4.47% OM (Figure 10A) and 1223.61 and 638.28 g/plant with 5.8 and 5.8% OM (Figure 10B) in relation to irrigated plants with 100 and 50% in ETc, respectively.

In all experimental periods, comparatively, 100% ETc irrigated treatments were superior to those cultivated with 50% ETc with an average superiority of 50%, evidencing the need of irrigation supply in semi-arid climate conditions. The results are consistent with the findings of Ferreira (2014) who observed increased production of okra with increased irrigation depth.

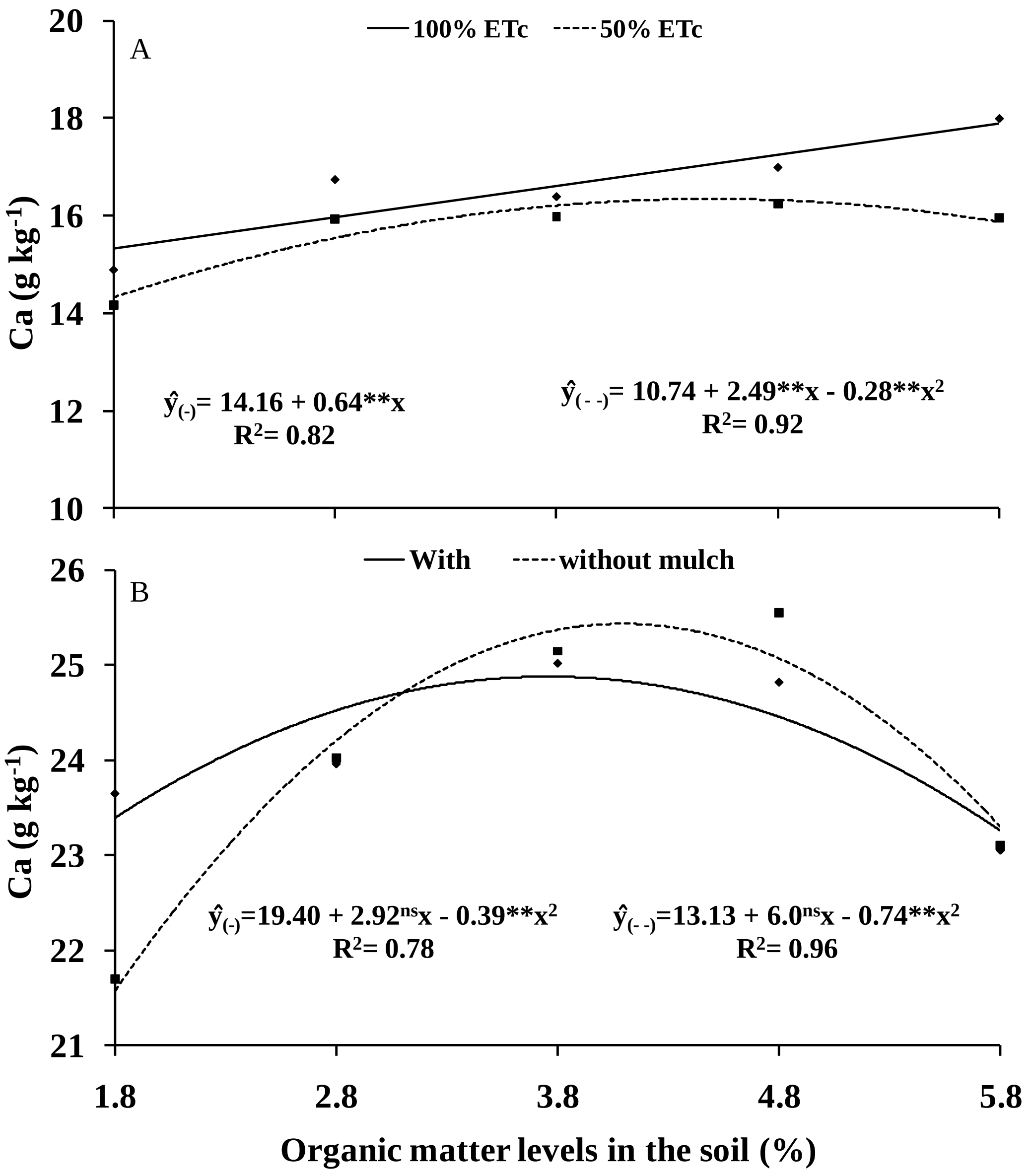

Figure 4. Leaf calcium content of okra cultivated in soil irrigated with 100 and 50% ETc under organic matter levels in the 2014/15 experiment (A) and cultivated in soil with and without mulching under organic matter levels in the 2015/16 experiment (B).

DISCUSSION

In general, the highest levels of leaf elements analyzed were observed in plants cultivated with higher irrigation, that is, 100% ETc. This was due to several reasons, for example, OM applied to the soil in a semi-arid region, that is, hot, with ideal soil moisture, decomposes more rapidly than under the same conditions with reduced humidity. Therefore, with higher humidity, the mineralization is faster making nutrients more available to plants. According to Cavalcante et al. (2010) the increase of OM percentage of the soil increased the N content in the leaves of okra. The same way improves the physical characteristics of the soil, provided greater retention of water in it.

The well-nourished plants, with ideal humidity, present an adequate development, with greater roots surface and consequently, greater contact of the same with the elements and greater absorption. This situation is consistent with Prado (2008) when affirming that the movement of nutrients in the soil is greater under adequate water conditions.

According to Figures 1 to 5, the reduction of the amount of water used in irrigation resulted in lower root

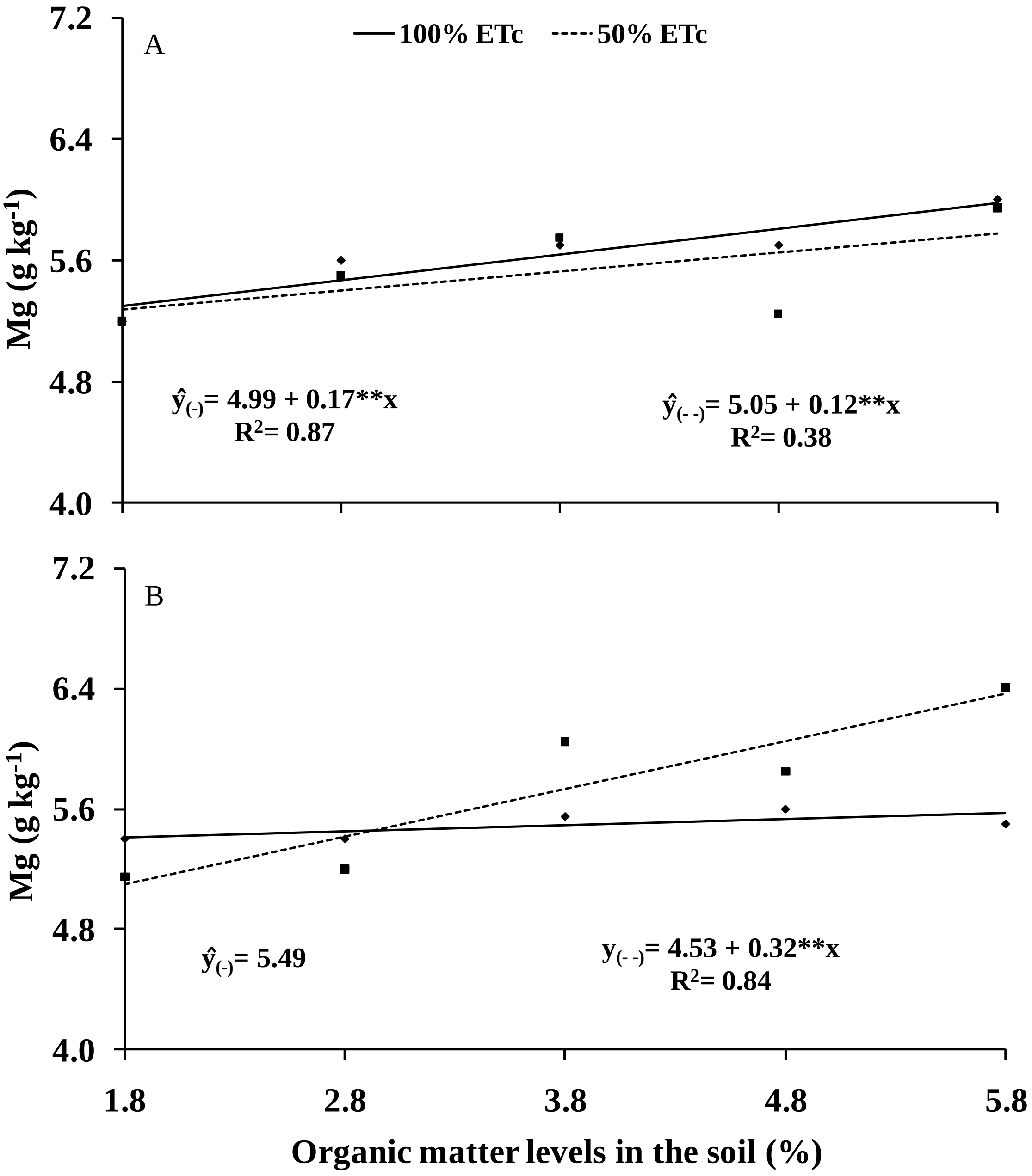

Figure 5. Leaf magnesium content of okra cultivated under organic matter levels in soil irrigated with 100 and 50% ETc and with (A) and without mulch (B) in the 2014/15 experiment.

surface contact with nutrients, and consequently with lower loss of leaf N, P, Ca and Mg accumulation, respectively. Similar results were observed for Panigrahi and Sahu (2013) that found a reduction in foliar concentrations of N, P and K in okra due to the reduction of 50 to 25% of the water available in the soil.

The reduction of the contact of the nutrients with the roots due to the reduction of the water in the soils occurs, probably due to the mass flow, which is the process of the plants to absorb nutrients from the soil solution, for example, Ca (Mauad et al., 2011).

Plants maintained under adequate soil moisture conditions provide higher photosynthetic efficiency with higher rates of respiration and transpiration, and higher energy to overcome root penetration resistance in soil (Hoffmann and Jungk, 1995), resulting in greater absorption of nutrients.

Regarding mulching, treatments with and without mulch presented similar results, possibly because from the 40 days after sowing (DAS), the whole area of the crop was covered with crops and / or mulch, directly interfering, because the interception of the solar rays by the crowns

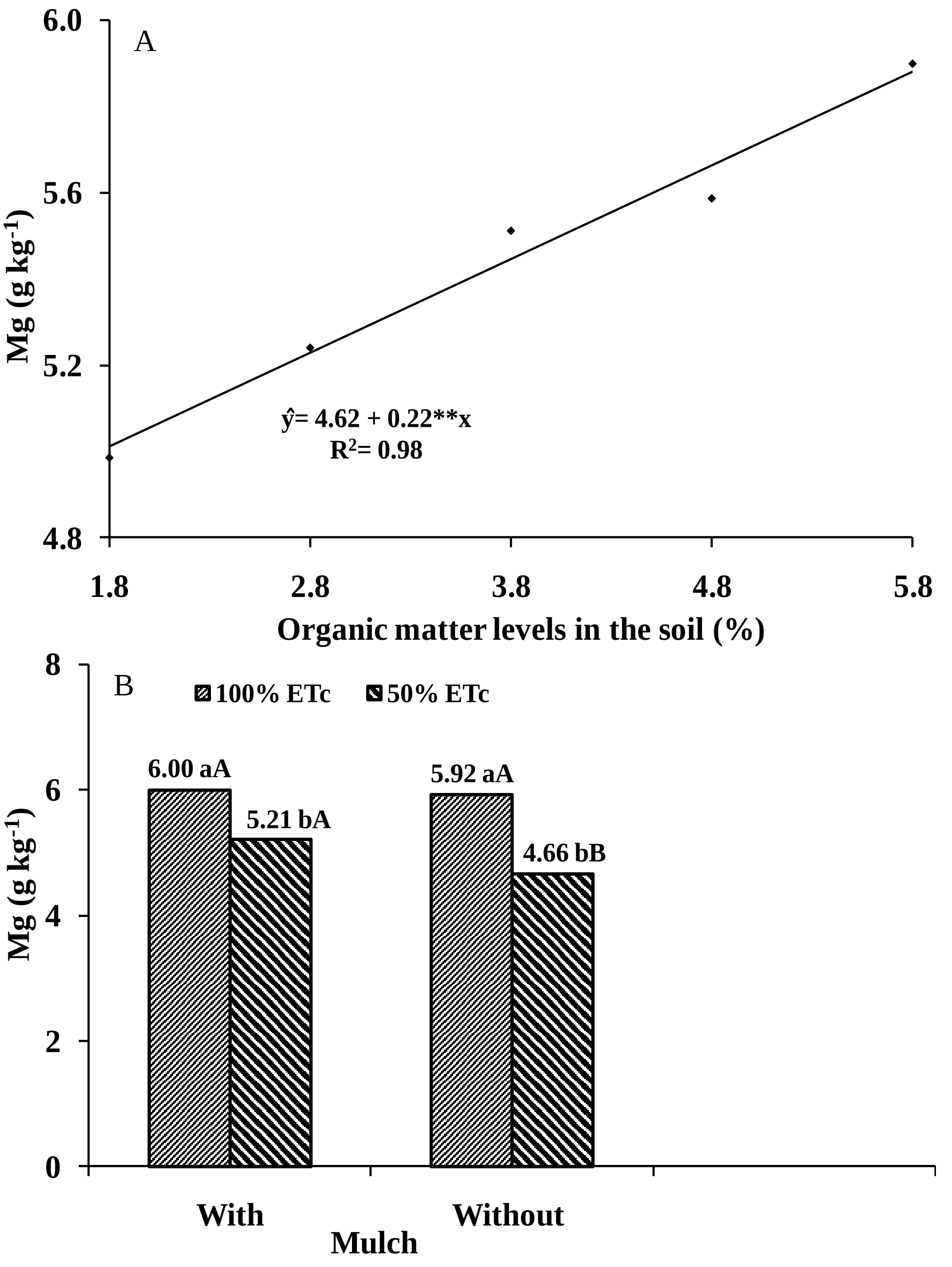

Figure 6. Leaf magnesium content of okra cultivated under organic matter levels (A) and under irrigation with 100 and 50% ETc with and without mulching (B) in the 2015/16 experiment.

of the plants, in both treatments caused decrease of the evaporation of water in the soil, as well as reduction of the temperature.

According to Table 2, soil mulching and the interaction of the soil mulching with the water depths did not have significant effect in the majority of analyzed variables. As can be observed in Figures 7 and 8, the leaf S contents decreased in relation to the increase of OM in the soil according to Barbosa et al. (2016). This should probably be related to the increase in negative charges in the soil due to the decomposition of OM.

Even though S content in the soil was increased because of this decomposition, the sulfate ions repulse from the colloid surface both with negative charges, increased and became free in the soil solution readily to be leached. With the reduction of irrigation, the leaf S contents were higher because of the lower leaching of the sulfate ions.

Probably the reasons for increasing the productivity of okra should be related to the application of OM, which is

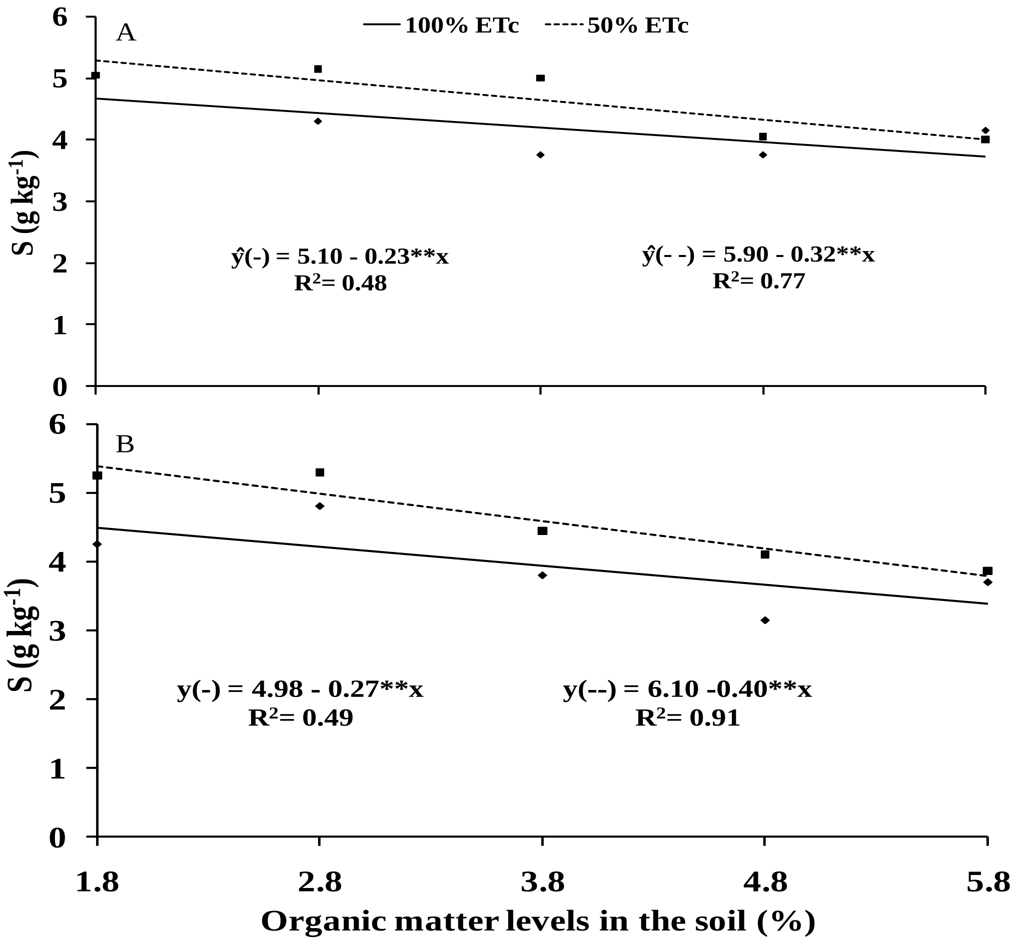

Figure 7. Leaf sulfur content of okra cultivated under organic matter levels in soil irrigated with 100 and 50% ETc and with (A) and without mulch (B) in the 2014/15 experiment.

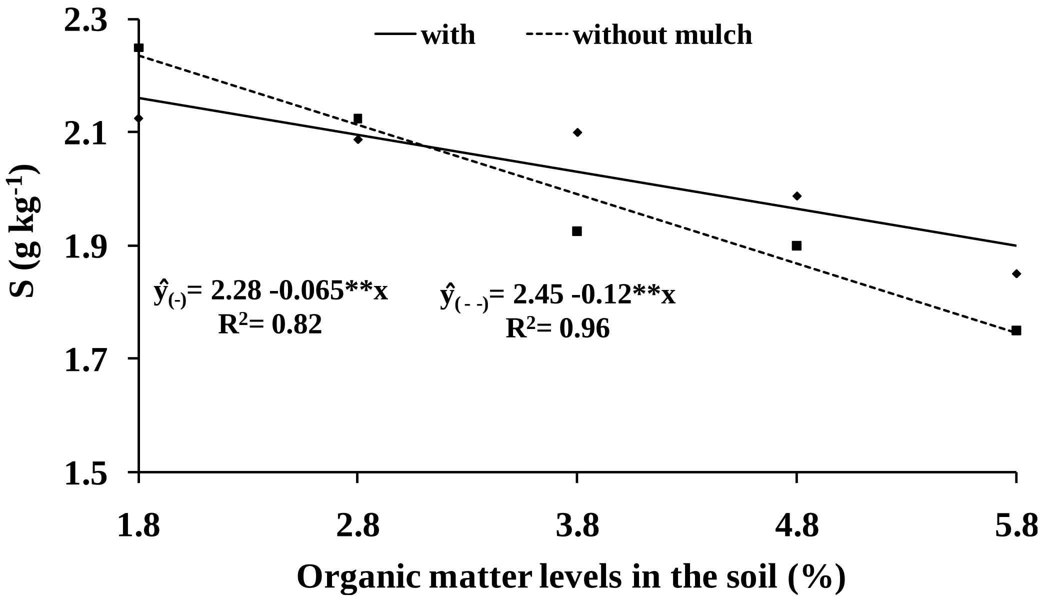

Figure 8. Leaf sulfur content of okra cultivated under organic matter levels in the soil with and without mulch.

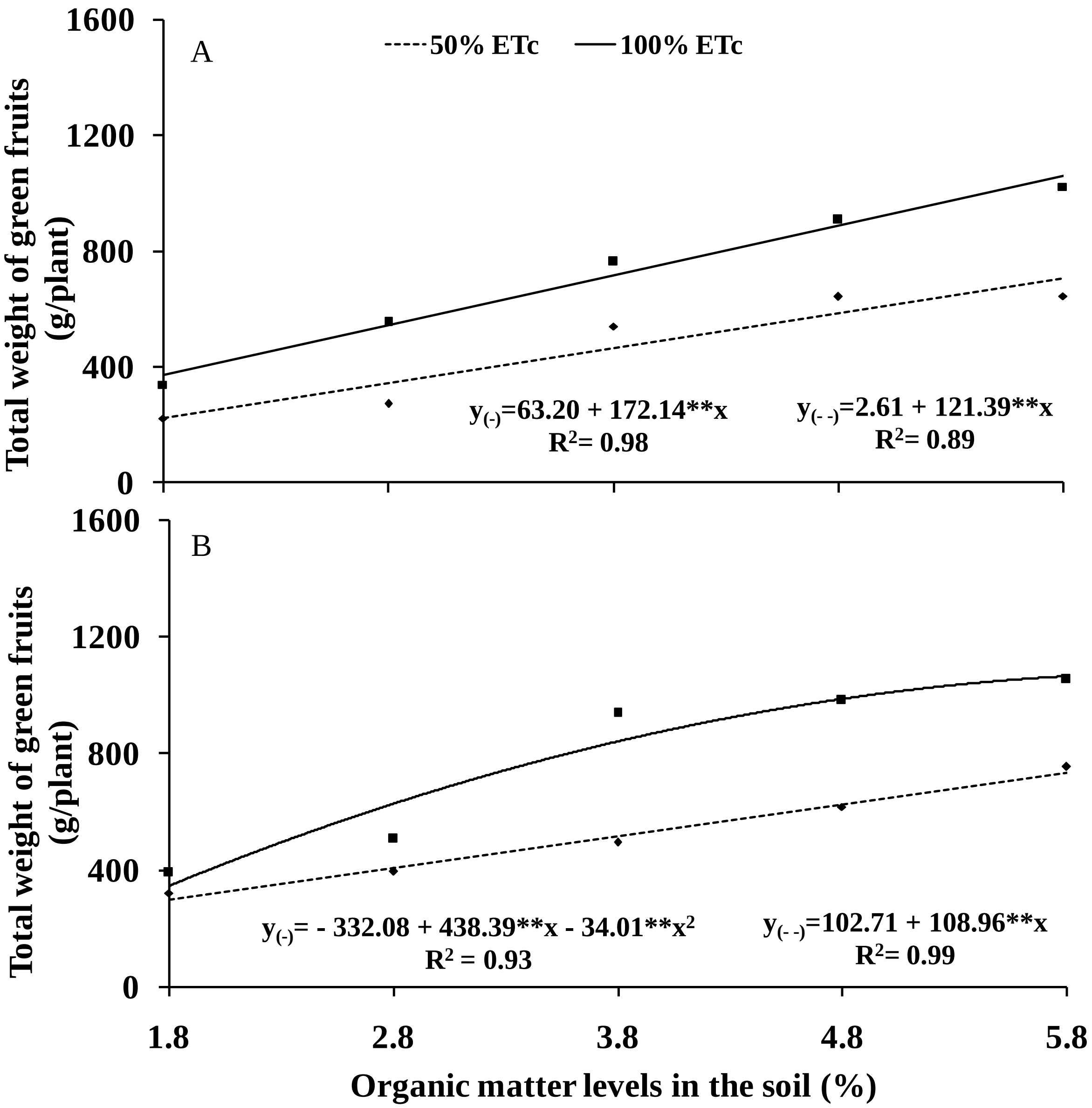

Figure 9. Total weight of green fruits of okra cultivated under organic matter levels in soil irrigated with 100 and 50% ETc and with (A) and without (B) mulch in the 2014/15 experiment.

a source of macronutrients and adequate irrigation, whose amount of water optimizes the transport mechanism of nutrients. Some studies have found increase in the translocation of nutrients to the aerial parts of the plants when soil moisture is above 50% of the water retention capacity (Costa, 1998).

Conclusion

In general, it can be observed that the results in the two experimental periods are similar; foliar contents and fruit yield were higher in the plants irrigated with greater amount of water (100% ETc), and also increased with the application of OM to the soil. The results were not very different with and without soil mulch, since, with the growth of the plants, the canopies of the same shaded the soil avoiding the evaporation of the water. These results indicate that in the improvement of the production of okra in the semiarid region the crop should be irrigated with application of OM to the soil.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

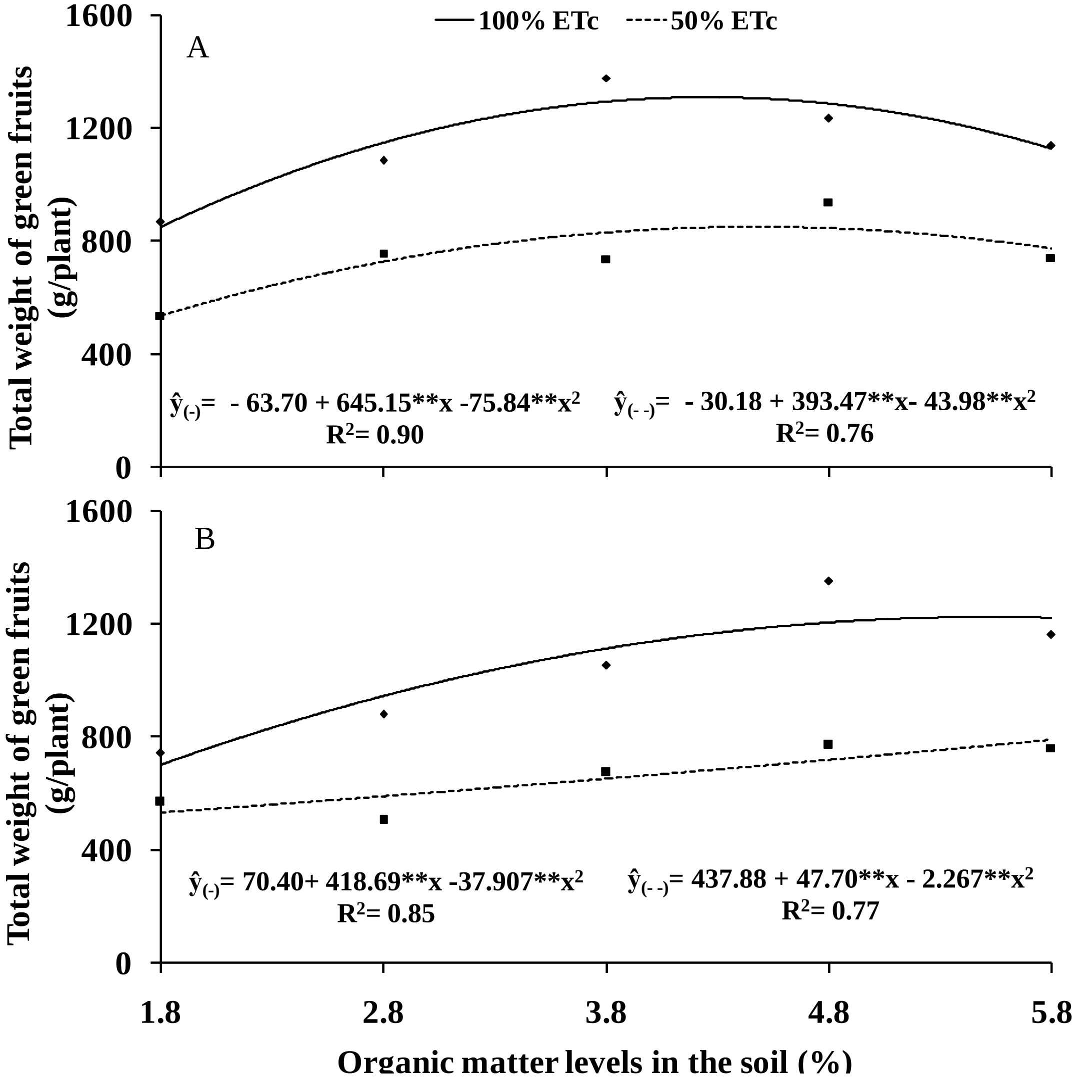

Figure 10. Total weight of green fruits of okra cultivated under organic matter levels in soil irrigated with 100 and 50% ETc and with (A) and without (B) mulch in the 2015/16 experiment.

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