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Influence of organic mulching on drip irrigation management of cabbage cultivation

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ABSTRACT

Irrigation has been pointed out in recent decades as the major consumer of water. Considering the need for a rational use of water resources and the importance of mulching for planting, this study evaluated the effect of organic mulching (sugarcane straw) under soil water storage for cabbage crop development. This research was conducted at CCA/UFSCar, and the experimental design was a completely randomized design with four replications and two treatments with and without sugarcane straw. Water application was performed by a drip irrigation system and irrigation management was determined from data collected by TDR. The use of organic mulching did not interfere with cabbage productivity under greenhouse conditions. The straw presents efficiency for reduction of soil evaporation and, consequently, increases water-use efficiency. The soil cover made it possible to save up to 28.1 mm (14.5%) of the water depth.

Keywords: sugarcane straw, TDR, trickle irrigation, water resources.

Influência da cobertura morta orgânica no manejo da irrigação por gotejamento do cultivo de repolho

RESUMO

A irrigação tem sido apontada nas últimas décadas como o maior consumidor de água. Considerando a necessidade de um uso racional dos recursos hídricos e a importância da cobertura morta para o plantio, o objetivo deste estudo foi avaliar o efeito da cobertura morta orgânica (palha de cana-de-açúcar) sob o armazenamento de água no solo para o desenvolvimento da cultura do repolho. Esta pesquisa foi conduzida no CCA/UFSCar e o delineamento experimental foi inteiramente casualizado, com quatro repetições e dois tratamentos com e sem palha de cana-de-açúcar. A aplicação de água foi realizada por um sistema de irrigação por gotejamento e o manejo da irrigação foi determinado a partir dos dados coletados pelo TDR. O uso da cobertura orgânica não interferiu na produtividade do repolho em condições de casa de vegetação. A palha apresenta eficiência para redução da evaporação do solo e, consequentemente, aumenta a eficiência do uso da água. Foi possível economizar até 28,1 mm (14,5%) de profundidade da água através da cobertura do solo.

Palavras-chave: irrigação localizada, palha de cana-de-açúcar, recursos hídricos, TDR.

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1. INTRODUCTION

In recent years, the intensive and sustainable use of natural resources in agriculture has been the subject of several studies, with water and nutrients being the most limiting factors of agricultural production. According to Urbano *et al.* (2017), agricultural activity is responsible for 70% of the world's freshwater consumption; in Brazil this index reached 67.2% in 2016 and the forecast is that by 2030 the removal of water from natural resources will increase by 30% (ANA, 2017). Irrigation systems need to be operated with high levels of uniformity and efficiency in order to reduce water losses, leading to a rational food production in a growing world population. In this scenario, the search for more efficient irrigation methods that require fewer water resources and provide better results in productivity and quality has been intensified (Santoro *et al.*, 2016).

Localized irrigation has been gaining ground for being one of the most efficient methods of water application, and the drip system has been recommended for most crops. In localized irrigation, water is applied in small volumes and high frequencies directly to the root zone of plants in order to maintain the moisture in the root zone close to the field capacity, allowing the best water use (Bizari *et al.*, 2016). In addition, drip irrigation has several advantages, such as an increased water-use saving, potential to provide optimal management conditions for the development and productivity of plants, possibility of introducing a high level of automation, reducing the use of labor, and reducing the incidence and spread of phytopathogens.

In addition to irrigation management, other cultivation practices are necessary for the crop to produce its maximum potential, such as the use of organic mulching on the soil. Soil coverage with plant residues is presented as an agricultural practice that conserves the natural processes that maintain a stable temperature and reduces natural water losses by the evaporation process on the soil surface, providing an increase in water-use saving (Cortez *et al.*, 2015). In this case, straw acts as a mechanical and thermal barrier on the soil, providing better water conservation (Murga-Orillo *et al.*, 2016). Moreover, this practice allows maintaining or increasing soil organic matter content and mobilizing and recycling nutrients from residue decomposition (Silva *et al.* 2011), being effective for weed control (Moraes *et al.*, 2013).

Considering the need for a rational use of water resources and the importance of mulching for planting, this study evaluated the effect of organic mulching (sugarcane straw) under soil water storage for cabbage crop development.

2. MATERIAL AND METHODS

The experiment was carried out in a greenhouse located in the experimental area of the Department of Natural Resources and Environmental Protection of the Center of Agricultural Sciences of the Federal University of São Carlos (DRNPA/CCA/UFSCar), Araras, SP, Brazil (22°18′00″ S, 47°23′03″ W, and altitude of 701 m). According to Köeppen system, the regional climate is classified as a mesothermal climate with warm and humid summers and dry winters.

The predominant soil in the experimental area is a very clayey Red Latosol (Oxisol) according to the Brazilian Soil Classification System (Santos *et al.*, 2013). The analyses for characterizing soil physical and chemical attributes (Table 1) were conducted at the Laboratory of Soil Fertility and the Laboratory of Soil Physics of the UFSCar following the methods described by EMBRAPA (2011).

The experimental design was a completely randomized design with two treatments and four replications alternately arranged. Treatments consisted of beds with (T1) and without (T2) sugarcane straw, which were used as controls.

Table 1. Physical and chemical characteristics of the soil, 0-0.20 m depth.

Parameters	Units	Content
Sand	%	20
Silt	%	19
Clay	%	61
Field capacity	$m^3\ m^{-3}$	0.34
Permanent wilting point	$m^3\ m^{-3}$	0.17
Total porosity	$m^3\ m^{-3}$	0.51
Bulk density	$kg\ m^{-3}$	1300
Soil particle density	$kg\ m^{-3}$	2650
Basic infiltration velocity	$cm\ h^{-1}$	13.20
pH H_2O	-	6.00
Phosphorus	$mg\ dm^{-3}$	68.00
Organic matter	%	28
Potential acidity	$mmol_c\ dm^{-3}$	26.00
Potassium	$mmol_c\ dm^{-3}$	2.50
Calcium	$mmol_c\ dm^{-3}$	31.00
Magnesium	$mmol_c\ dm^{-3}$	13.00
Sum of basis	$mmol_c\ dm^{-3}$	46.30
Cationic exchangeable capacity	$mmol_c\ dm^{-3}$	72.30
Base saturation	%	64
Sulfur	$mg\ dm^{-3}$	72.00
Boron	$mg\ dm^{-3}$	0.10
Copper	$mg\ dm^{-3}$	4.80
Iron	$mg\ dm^{-3}$	92.00
Manganese	$mg\ dm^{-3}$	1.80
Zinc	$mg\ dm^{-3}$	1.40

The greenhouse had eight beds 2.1 m wide and 2.1 m long, totaling an area of 4.41 m^2. Each bed was composed of 28 plants of the hybrid cabbage Astrus Plus (*Brassica oleracea* L. var. *capitata* L.), whose seedlings were transplanted manually, spaced 0.70 m between rows and 0.30 m between plants in a triangular configuration.

Relative air humidity and temperature were monitored daily over the experimental period by using a meteorological station installed inside the greenhouse. The necessary phytosanitary treatments were also carried out, as well as manual weed elimination.

The amounts of nutrients applied via fertigation were determined considering Table 1 and following the doses according to Raij *et al.* (1997). Planting fertilization was carried out with a solid fertilizer in a half-moon application of 7 g potassium sulfate plant^{-1}, 0.6 g potassium nitrate plant^{-1}, 25 g single superphosphate plant^{-1}, 1.4 g calcium nitrate plant^{-1}, and 0.5 g boric acid plant^{-1}. Topdressing fertilization was carried out via fertigation every fortnight until 60 days after planting, with1.4 g potassium nitrate plant^{-1} being applied and 3g calcium nitrate plant^{-1} per application.

After manual seedling transplanting and planting fertilization, 9 t ha^{-1} of sugarcane straw were distributed in the beds (Pereira *et al.*, 2002) (Figure 1).

Water application was performed by a drip irrigation system with 4 L h-1 self-compensating emitters installed near each plant base. Two TDR probes with 0.20 m long rods were buried vertically within the working area of each bed.

Figure 1. Greenhouse after planting fertilization and sugarcane straw distribution and detail in the bed with organic mulching.

Before the beginning of the experiment, a test was performed to verify the uniformity of water distribution of the localized irrigation system. In this test, flow rates were measured in four emitters per bed, one per lateral row. Water application uniformity was estimated using the flow rate of each assessed emitter as a function of the Christiansen's uniformity coefficient (CUC), determined by the Equation 1 described by Andrade *et al.* (2017) and Santoro *et al.* (2016):

$$\mathrm{CUC} = 100\left[1 - \sum_{i=1}^{n} \frac{(q_i - q_m)}{N_{qm}}\right] \tag{1}$$

Where:

q_i - flow rate of each emitter (L h^{-1});
q_m - average flow rate of emitters (L h^{-1});
N_{qm} - number of emitters.

Irrigation management was determined from data collected daily by using a Campbell Scientific® TDR100, thus maintaining soil moisture in the root system area at field capacity (0.34 m^3 m^{-3}) and avoiding water stress of plants. In addition, management was performed separately for each treatment. Readings were registered daily at 7:00 h and irrigation applied three times a day (8h00, 12h00, and 17h00).

TDR probe provided the apparent dielectric constant (Ka) of soil, which was replaced in Equation 2 (Souza *et al.*, 2017), obtained from the calibration for this soil.

$$\theta = 0.000005Ka^3 - 0.0003Ka^2 + 0.0161Ka^1 + 0.0132 \tag{2}$$

Where:

θ - soil moisture;
Ka - apparent dielectric constant of soil.

Irrigation water depth was calculated by means of soil moisture content of each treatment, as Equation 3.

$$NID = \left(\theta_{fc} - \theta_{TDR}\right) \times d_{eff} \times 1000 \tag{3}$$

Where:

NID - net irrigation water depth (mm);
θ_{fc} - soil moisture at field capacity;
θ_{TDR} - soil moisture obtained with Souza *et al.* (2017) equation;
d_{eff} - effective root depth (0.25 m).

TDR probe also provided values of soil electrical conductivity. However, Equation 4 (Souza *et al.*, 2017) was necessary to suit the soil used.

$$EC = 0.0303 + (4.602 \times EC_{TDR}) - (0.7 \times \theta) \quad (4)$$

Where:

EC - soil electrical conductivity (dS m^{-1});
EC_{TDR} - electrical conductivity provided by TDR (dS m^{-1});
θ - soil moisture obtained with Souza *et al.* (2017) equation.

Cabbage was harvested about 90 days after planting the seedlings, only 10 plants were selected, corresponding to the useful area of the bed, not considering the border plants. Harvested plants were weighed in an analytical balance in order to obtain the fresh mass of each bed.

After harvesting, a foliar analysis was performed to verify the mineral composition of cabbage leaves of both treatments, including the macronutrients nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and sulfur (S), and the micronutrients boron (B), copper (Cu), iron (Fe), manganese (Mn), and zinc (Zn). For this analysis, samples were obtained by removing four wrapping leaves from the cabbage heads of the useful area of each bed, totaling 32 diagnostic leaves.

At the end of the experiment, the water use efficiency (WUE - kg m^{-3}) was estimated through the relationship between productivity of each treatment and the amount of water used during the crop cycle.

The results of soil moisture, water depth, soil electrical conductivity, and fresh mass were analyzed statistically by means of the t-test at 5% significance level using the software R version 3.2.0 (R Core Team, 2015).

3. RESULTS AND DISCUSSION

During the cabbage cultivation cycle, three flow tests were carried out to determine the distribution uniformity of the emitters after a six-minute system run time. It was possible to obtain a uniformity coefficient of 94.1% and an average flow of 4.04 L h^{-1}.

The averages of temperature and relative air humidity during the experimental period were 23°C and 77%, ranging from 18.4 to 27.1°C and 64.7 and 91.9%, respectively (Figure 2). These conditions were favorable for crop growth, as observed by Silva Júnior (1989), who states that cabbage production is favored in mild climate conditions.

Regarding soil moisture variation during the cabbage cycle (Figure 3), sugarcane straw provided 3.7% increase in the average soil water storage, decreasing the water depth to be applied by irrigation when compared to the treatment without organic mulching. A statistically significant difference was observed between the average moisture of treatments, with a p-value equivalent to 0.001367.

Stone and Moreira (2000) observed that mulching efficiency from crop residues is the most important factor to explain the higher water content found in soils under the no-tillage system when compared to the conventional system, since straw acts in the first phase of the water evaporation process, reducing the rate of daily evaporation due to the reflection of radiant energy. In addition, Ferreira et al. (2015) reported that the highest water conservation in the mulch system was related to the straw remaining on the soil surface, providing a greater reflection of the incident solar radiation and, therefore, acting as a barrier against water evaporation.

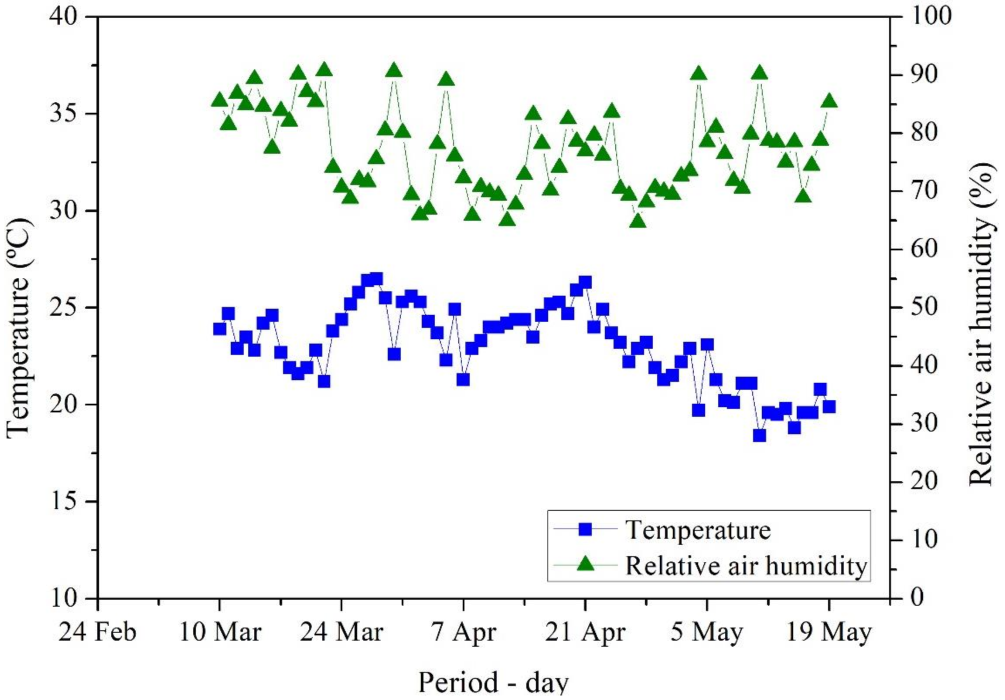

Figure 2. Daily averages of temperature and relative air humidity of the greenhouse during the experimental period.

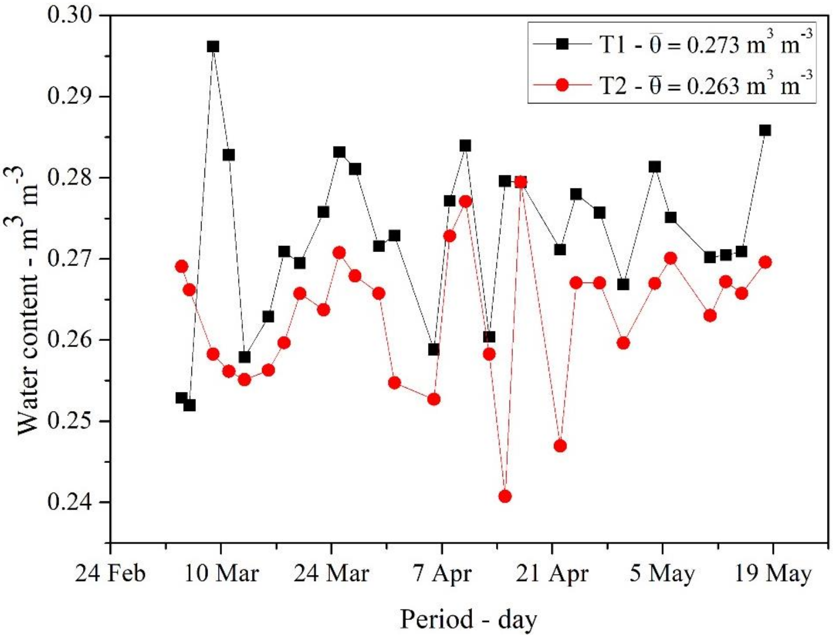

Figure 3. Variation and average soil water content during cabbage cycle for different treatments (T1- with sugarcane straw and T2 - without sugarcane straw).

The total water depth applied during the cabbage cycle was determined by means of the data collected daily (Figure 4). The total water depth was 165.4 mm with the mulching treatment and 193.5 mm in the treatment without sugarcane straw. Comparatively, a 28.1 mm savings of water was observed in the organic mulching treatment, T1. According to the statistical test, a significant difference was observed in the water depths between treatments, with a p-value equivalent to 0.0002400.

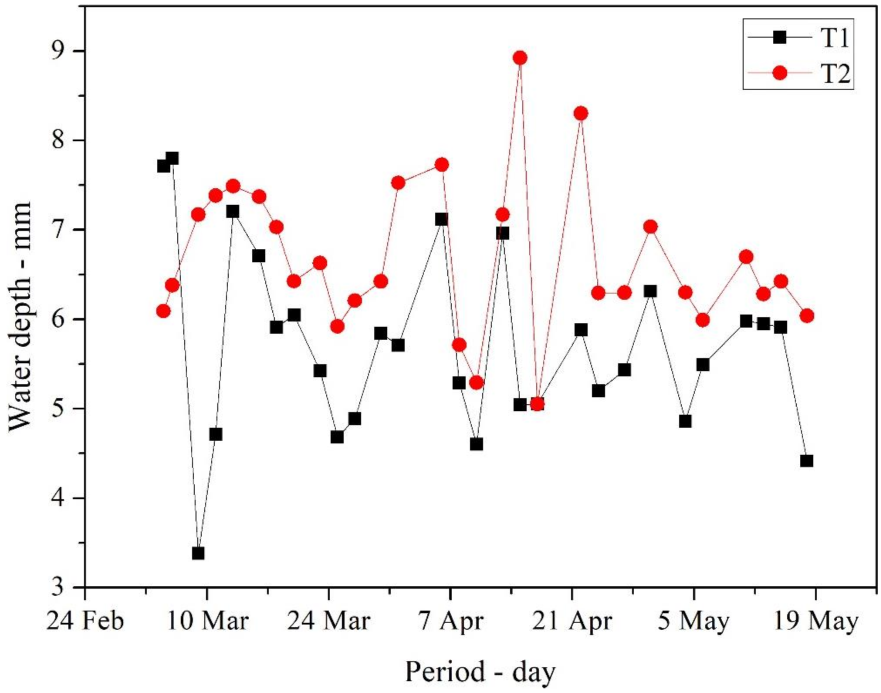

Figure 4. Water depths applied daily during the cabbage cycle.

The values of soil electrical conductivity during the cabbage cycle obtained from data collected through TDR100 are shown in Figure 5. The averages of treatments with and without organic mulching were 0.0198 and 0.0183 dS m^{-1}, respectively. The statistical analysis showed no significant difference between treatments, with a p-value equivalent to 0.8426. Thus, organic mulching did not influence soil electrical conductivity, i.e., it did not retain salts in the soil and did not alter the availability of nutrients to the plants, acting on this variable in a similar way to the treatment without sugarcane straw.

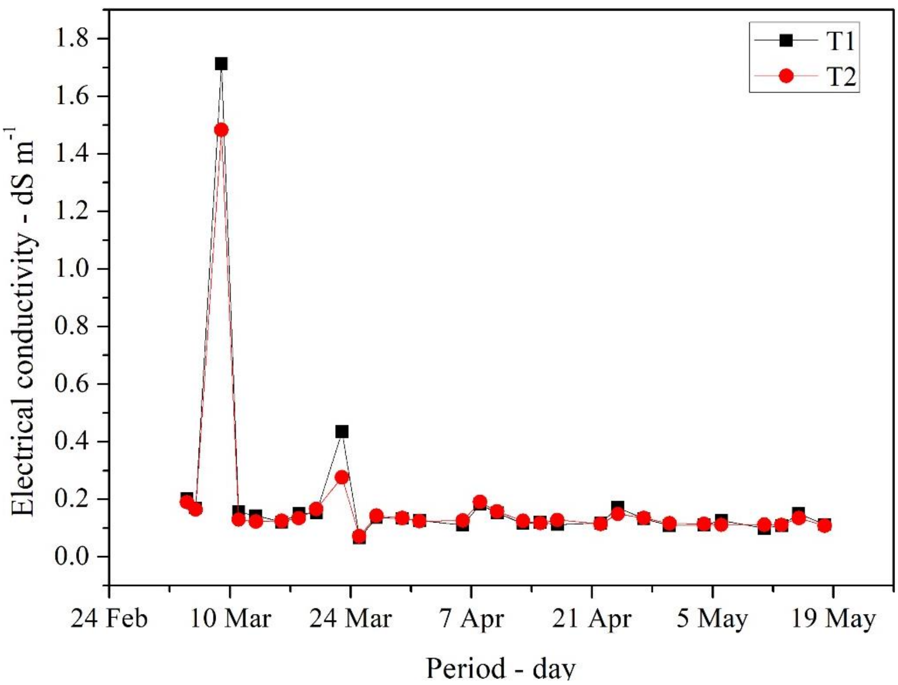

Figure 5. Soil electrical conductivity during the cabbage cycle.

Two electrical conductivity peaks can be noticed in both treatments when analyzing Figure 5. This behavior may be explained by the drip irrigation, which tends to decrease the content of salts near the plant, thus reducing soil electrical conductivity over the days after the peak, and by the fertigation carried out on March 9 and 23, which contained potassium nitrate. According to Bonini *et al.* (2014), the values of electrical conductivity found are within the limits of normality, since a soil is considered as saline when its values exceed 4 dS m^{-1}, which may impair crop development.

The sugarcane straw provided a greater functionality for the reduction of water evaporation and the economics of the applied water depth, not interfering with the productivity parameter, T1 - 54.2 t ha^{-1} and T2 - 55.2 t ha^{-1}. No significant difference was observed regarding the fresh mass of each treatment, with a p-value equivalent to 0.7904. This result is in accordance with Moura *et al.* (2006), who also observed that the plant stand, productivity, diameter, height, and compactness of cabbage heads were not significantly affected by treatments, i.e., productivity and quality of cabbage in the mulching treatment were similar to those obtained in the treatment without mulching, even with a lower amount of water (Figure 6).

Also, considering the volume of water applied through irrigation, water-use efficiency (WUE) was 32.8 kg m^{-3} in the treatment with cabbage cultivated with mulch and 28.5 kg m^{-3} in plants without soil cover. The WUE result confirms that to produce the same amount of cabbage with straw it is necessary to provide approximately 85.5% of the water demanded for the conventional system. According to Medrano *et al.* (2015), this greater WUE is due to the presence of organic mulching in an adequate amount, reducing the losses by water evaporation from the soil profile. This water saving is in accordance with Freitas and Landers (2014), who reported an average reduction in the demanded water for irrigation of 15% in systems that use mulching on the soil when considering different crops. In fact, straw provides a slower depletion of water in the soil, increasing the irrigation shift and the application of less water during the crop cycle, in addition to favoring a reduction in the operational irrigation costs.

Figure 6. Plants from the treatment without (A) and with sugarcane straw (B).

A possible reason for this insignificant difference in cabbage production may be related to the irrigation management. In this case, irrigation was carried out individually for each treatment in order to maintain the root system area with moisture in the field capacity and with a sufficient amount of water to supply the water requirements of plants, i.e., without excesses or deficits, avoiding plant stress.

No significant difference was observed between treatments for leaf analysis (Table 2).

Thus, the levels of macro- and micronutrients were similar for plants submitted to the treatments with and without organic mulching.

Table 2. Average mineral composition of macronutrients (g kg^{-1}) and micronutrients (mg kg^{-1}) in the cabbage leaves for both treatments.

Treatment	N	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Zn
1	43.50	1.97	16.05	38.41	5.92	8.03	20.25	73.30	168.28	91.56	38.17
2	44.50	1.99	12.80	39.66	6.33	8.53	24.75	11.33	194.72	96.07	24.96

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Other studies have shown results different from those found in our study. Faber *et al.* (2001) found that root system growth in the superficial soil layers can be favored by the presence of mulching, facilitating the absorption of nutrients such as phosphorus, which is accumulated in the superficial layers due to its low mobility. In addition, Bremer Neto *et al.* (2008) stated that the balance between mineralization and immobilization of soil N could be affected by mulching distribution in order to reduce its availability to plants and require complementary fertilization of this nutrient.

The insignificant difference in nutrient content between treatments may be due to the short duration of the experiment. In the study of Mendonça *et al.* (2019), for example, notice that 110 days is a short time to observe soil salinization due to the fertigation in the tomato crop.

4. CONCLUSIONS

The use of organic mulching did not interfere with cabbage productivity under greenhouse conditions. The straw increases the efficiency of irrigation since it reduces soil evaporation, and consequently increases water-use effectiveness. The soil cover made it possible to save up to 28.1 mm (14.5%) of water depth.

5. ACKNOWLEDGMENTS

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