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Impact of soil management and irrigation techniques on water use efficiency in cauliflower cultivation

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The objective of this research is to evaluate the impact of soil management and localized irrigation techniques on water use efficiency in the cultivation of cauliflower. The treatments consisted of 4 different types of soil management: Direct seeding using crotalaria and brachiaria cover crops, a treatment used both in conjunction, and another that employed a conventional system. Two different irrigation techniques were used: Surface and subsurface. The experimental design was completely random in a factorial arrangement (4x2) with four repetitions. Each experimental unit was composed of 20 cauliflower plants, with a density of 1.8 m between rows and 0.5 m between plants. The experiment was carried out in two stages; the first stage consisted of the establishment of the cover crops and the second stage of the planting of cauliflower cv. Avenger in the different treatments. The cover species were cut at ground level 108 days after they had been sown. The cauliflower seedlings were grown in a protected environment and transplanted after 21 days. Irrigation was managed through the use of tensiometry. Water use efficiency was the variable that was analyzed; the Tukey Test at 5% level of probability was applied to the data that was obtained. A combined use of crotalaria/brachiaria cover crops with subsurface drip irrigation is recommended; this was the combination that most efficiently saved water.

Key words: *Brassica oleracea* cv. botrytis, *Crotalaria ochroleuca*, *Brachiaria ruziziensis*, soil management, irrigation.

INTRODUCTION

At present, the problem of poor water use as a consequence of inadequate soil management techniques is prevalent. These techniques are mainly characterized by the excessive clearing of the soil through ploughing or harrowing; this represents an entirely insufficient practice that causes the degradation of the topsoil. For this

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reason, a variety of techniques and strategies are turned to in an effort to increase the productivity of soils and improve water use efficiency.

One of these techniques is the use of vegetation cover such as brachiaria (*Brachiaria ruziziensis*), crotalaria (*Crotalaria ochroleuca*) and/or a combination of both species. Depending on its use, this technique has the capacity to improve the physical, chemical and biological properties of the soil. These plant species also allow for better infiltration and retention of water. Another strategy that is used to improve water use is the deployment of more efficient irrigation systems such as subsurface irrigation, which involves burying irrigation tubing. The main advantage of this technique is the reduction of the volume of water needed, given that water is delivered directly to the radicular system.

Sousa et al. (2015) conclude that the use of mulch leads to better water use in the irrigated cultivation of *Phaseolus vulgaris.* It also aids the soil-water-plant-atmosphere relationship by reducing the temperature and the rate of evaporation and increasing retention of humidity in the soil profile. Furthermore, they mention that the differing rate of crop growth that was seen under the conditions evaluated is due to the water retention achieved by placing mulch on the surface of the soil. Given these factors, the objective of this research was to evaluate the impact of soil management and localized irrigation techniques on water use efficiency in the cultivation of cauliflower.

METHODOLOGY

The experiment was conducted in the area for irrigation experiments of the Faculty of Agricultural Sciences of the Federal University of Grande Dourados. The experimental area is located in Dourados, Mato Grosso do Sul at geographical coordinates 22° 13' 16'' latitude south and 54° 48' 20'' longitude west. In accordance with the Köppen classification (1948), the region has a Cwa climate type (humid subtropical), with rainy summers and dry winters, and an average annual temperature of 22°C. The soil is described as dystrophic red latosol with a very argillaceous texture (EMBRAPA, 2009).

The design of the treatments used was a factorial arrangement (4x2) distributed in an entirely random experimental design. The variables that were evaluated were: soil management and drip irrigation techniques. There were 8 treatments and 4 repetitions, giving a total of 32 experimental units. There were 4 different types of soil management: crotalaria (*C. ochroleuca*), brachiaria (*B. ruziziensis*), a combination of crotalaria and brachiaria and a conventional soil preparation system. There were two different types of irrigation: a surface drip irrigation system and a subsurface drip irrigation system.

Drip irrigation systems were employed. In the first irrigation technique, the drip tapes were installed on the surface of the soil (surface drip). For the other method, they were buried at a depth of 0.20 m (subsurface drip). Each experimental unit held 20 plants with a distance of 0.8 m between rows and 0.5 m between plants; the plants were distributed in simple rows with a density of 25.000 plants/ha. The experiment covered a total area of 8 m^2, with each EU having a length of 3.2 m and a width of 2.5 m. The two central rows were considered to be the useful area. The two plants at each end of these rows were not evaluated in order to avoid the fringe effect, giving a total of 6 plants used to carry out determinations.

The experiment was carried out in two stages: the first consisted of the establishment of the cover crops and the second of the planting of cauliflower under the previously mentioned experimental conditions. 40 days before the sowing of the cover species, a soil dressing was applied at a dosage of 200 g m^2; this was done in accordance with the recommendations of the soil analysis. The cover crops were sown with spacing of 0.45 m between rows; rows contained approximately 40 plants per linear metre. The combination of the two species was achieved by interspersing them; the same distance between plants that is mentioned above was used. No chemical fertilization was employed at this stage. Weeding was carried out manually.

108 days after being sown, the cover species were cut at ground level using a mechanical cutter. This was done when the crotalaria plants began to flower and when the brachiaria was at the milky-grain phase. The biomass of the cover crops was evaluated when they were cut. Before being cut, the brachiaria and the mixed cover (B+C) were chemically dried using Roundup (200 ml of active ingredient per 20 l of water). The preparation of the soil in the conventional system consisted of the use of a subsoiler and a disk harrow; this was done on the same day that the cover crops were cut in the other treatments.

The cauliflower seedlings were grown in polystyrene trays with 128 cells, which had previously been filled with commercial substrate and kept in a protected atmosphere. The Incline variety was used, which is suitable for planting in the region throughout the whole year. 21 days after sowing, when the seedlings displayed the necessary criteria for transplantation (height of 10 cm + 4 to 5 real leaves), they were transplanted to the previously prepared experimental area. The transplant was carried out in holes with an approximate diameter of 0.2 m and an approximate depth of 0.1 m. Before transplantation, fertilization was carried out according to the recommendations of the soil analysis and following the suggestions made by Fontes (1999). A week before transplantation, 150 kg ha^{-1} of N was applied in the form of urea, 300 kg ha^{-1} of P_2O_5 was applied using simple superphosphates, and 180 kg ha^{-1} de K_2O was applied in the form of potassium chloride. As well as chemical fertilization, organic fertilization was carried out using 350 g of commercial substrate per hole. Cover fertilization was carried out at 15, 30 and 45 days after the transplant, with 30, 40 and 30% of the total quantity of coverage fertilizer (100 and 200 kg ha^{-1} of N and K_2O respectively) being applied in the first, second and third period respectively. Foliar fertilization was carried out every seven days from the second week after transplantation onwards; this was done in order to prevent symptoms of nutritional deficiencies. Heringer®'s FHHF Fruit and Vegetable fertilizer was employed; its composition is as follows: 11% N; 11% P; 11% K; 2% Mg; 10% S; 0,15% B; 0,30% Cu; 0,11% Fe; 0,26% Mn; 0,04% Mo and 0,50 % Zn; at a dosage of 1.0 $g.L^{-1}$.

Weed control was carried out in the furrows using a hoe and manually between the cauliflower plants in rows. A notable difference in the amount of weeding carried out was observed; the conventional system was weeded four times during the cultivation cycle, whilst the different systems employing mulch were weeded just once. Given that there were some strong winds that could have hindered the growth of the crop during the experimental, hilling was carried out in order to improve the establishment of the plants.

Chemical control of pests was carried out initially 10 days after transplantation (DAT). Benzoylurea (Nomolt® 150, at a concentration of 25 ml 100 L^{-1} of water), was applied to control thrips (*Thrips tabaci*) and cucurbit beetles (*Diabrotica speciosa*). Caterpillars such as *Spodptera* sp., *Tricop lusiani* and *Pseudo plusiaincludens* appeared 30 and 45 DAT; these were controlled using benzoylurea (Nomolt® 150, at a concentration of 25 ml 100 L^{-1} of water) and thiamethoxam (Engeo Pleno® 247 SC, at a concentration of 50 ml 100 L^{-1} of water). The irrigation management of the cauliflower crop was carried out independently for each treatment. Irrigations were carried out based on readings of soil water tension measured using tensiometers installed at 50% of the effective depth of the radicular system, which is 0.40 m. A set of four tensiometers was installed in each treatment: three at a depth of 0.20 m (decision tensiometers) and one at a depth of 0.40 m (control tensiometer). These were installed in crop rows between two plants with a distance of 0.50 m between tensiometers. The readings were carried out using a puncture tensiometer twice a day: at 09:00 and 15:00. Irrigation depth was determined using equations 01 and 02 in order to restore soil humidity to values corresponding to field capacity. Irrigation was carried out when at least two readings obtained by the sensors installed at a depth of 0.20 m (decision tensiometers) were higher than 15 kPa,

$$\mathrm{NIWR} = \frac{\mathrm{GIWR}}{\mathrm{ae}} \quad (1)$$

Where: GIWR: Gross irrigation water requirement (mm); NIWR*:* Net irrigation water requirement (mm); *ae:* Application efficiency.

$$\mathrm{IA} = \frac{\mathrm{Q}}{\mathrm{A}} \quad (2)$$

Where: *IA:* Intensity of application of the irrigation system in each treatment (mm), *Q:* Total volume of water (L h^{-1}), *A*: Area occupied per plant (m^2).

$$\mathrm{T} = \frac{\mathrm{GIWR}}{\mathrm{IA}} \quad (3)$$

Where: *T:* Duration of operating time of irrigation system in each treatment; GIWR: Gross irrigation water requirement (mm); *IA:* Intensity of application of the irrigation system in each treatment (mm).

Over the first twelve DAT, micro-irrigation was employed using Santeno® tapes; 4 irrigations took place over this period. In this period, watering was carried out for a duration of one hour divided into four applications. This corresponded to an irrigation depth of 15.03 mm h^{-1} in each irrigation. All of the treatments were irrigated with the same quantity of water in order to maintain an adequate microclimate and to favour the establishment of the seedlings.

Two types of irrigation system were used: a surface drip system on the soil surface, and a subsurface drip system buried at a depth of 0.10 m. In-line, self-compensating drips were used, with an output of 3 L hm, DN 16 mm. They were inserted into the tube upon extrusion with a distance of 0.50 m between drips; this was done in order to generate a strip of consistently watered soil. The drip tapes were placed in such a fashion that there was one drip per plant. There was an operating pressure of 10 mca, which was controlled using a regulatory pressure valve inserted at the end of the control head.

The cauliflower plants in the experimental units were harvested manually at 82 DAT. Following the harvest of the inflorescences, evaluations were carried out. The determination water use efficiency (WUE) was obtained according to Equation 04. The commercial product is equivalent (Y_C) and the volume of water applied per hectare (AL) was estimated from the necessary total irrigation applied in each treatment during the growing cycle.

$$\mathrm{WUE} = \frac{\mathrm{Y_C}}{\mathrm{AL}} \quad (4)$$

Where: WUE: Water use efficiency (kg m^3); Y_C: Commercial product (kg planta); AL: volume of water applied per hectare (mm planta). An analysis of variance was undertaken using the F test and afterwards, a comparison of averages was carried out using the Tukey test at 5% level of probability.

RESULTS AND DISCUSSION

Characterization of climatic conditions

Figure 1 shows values related to the maximum, average and minimum air temperatures observed during the period in which the experiment was carried out. Temperatures during the experimental period varied between 6 to 31.7°C, with an average temperature of 21.24°C (Guia Clima-embrapa, 2015). Assuming that frosts occur at temperatures below 4°C, there were no frosts during the course of the experiment.

The maximum average temperature was 27.33°C and the minimum average temperature was 16.38°C. The temperatures that were observed during the experiment provide ideal conditions for the germination, and growth of the crop as for the majority of the cultivation period the temperature was between 13 and 28°C (Strange et al., 2010).

Figure 1 shows the maximum, minimum and average relative air humidity (RH) during the experimental period. The RH during the experiment was 80.8%, the maximum average RH was 95.23% and the minimum average was 56.28%. The RH during the experimental period oscillated between 97 and 28% (GUIA CLIMA-EMBRAPA, 2015).

Figure 2 shows the readings of the decision tensiometers installed in each surface-irrigation treatment. Tension values approaching zero are observed on rainy days, indicating saturation. No large differences in the readings from the different treatments were seen; this could be due to the frequent watering (on average, every two days). In general, the tension readings were higher in the conventional treatments, where they quickly reached higher tension values after a rainy period. After periods of rain, the mulch treatments took longer to show tensiometer readings indicating the need to use the irrigation system. This was due to higher retention and higher availability of water in those treatments; they showed higher microporosity. The higher biomass in these treatments also provided the advantage of lower rates of water evaporation.

Water use efficiency

The number of irrigations (N.I) varied in relation to the different cover species used. Lower irrigation volumes were required when using the crotalaria mulch and the combination of crotalaria and brachiaria; 24 irrigations were carried out using the surface drip irrigation system and the subsurface system. The brachiaria mulch was irrigated 26 times. The conventional system received 32 irrigations, meaning that it showed the highest level of water consumption of the different treatments. Equally,

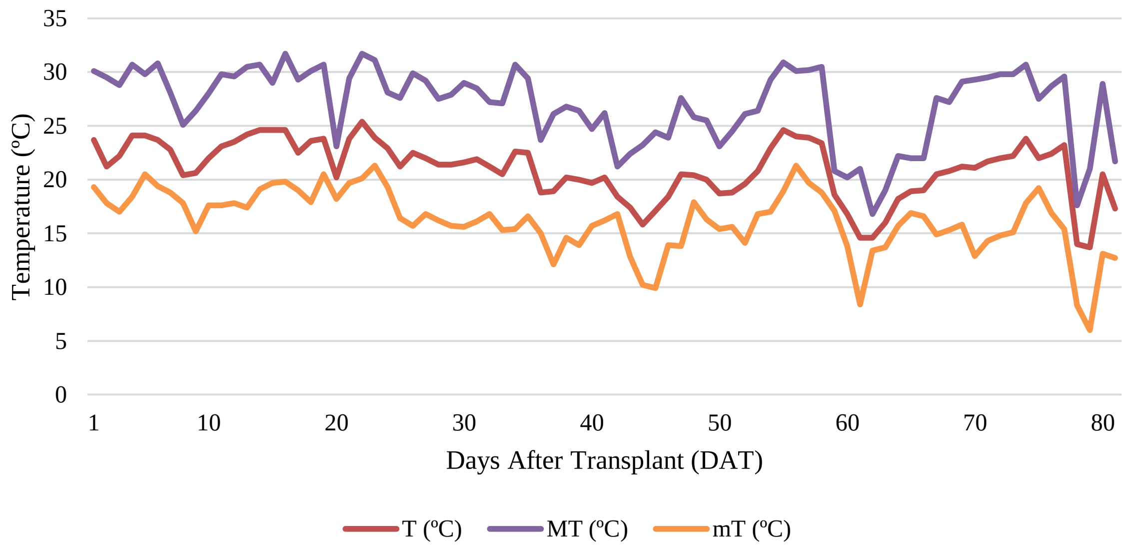

Figure 1. Daily air temperatures during the experimental period: maximum (MT), average (T) and minimum (mT).

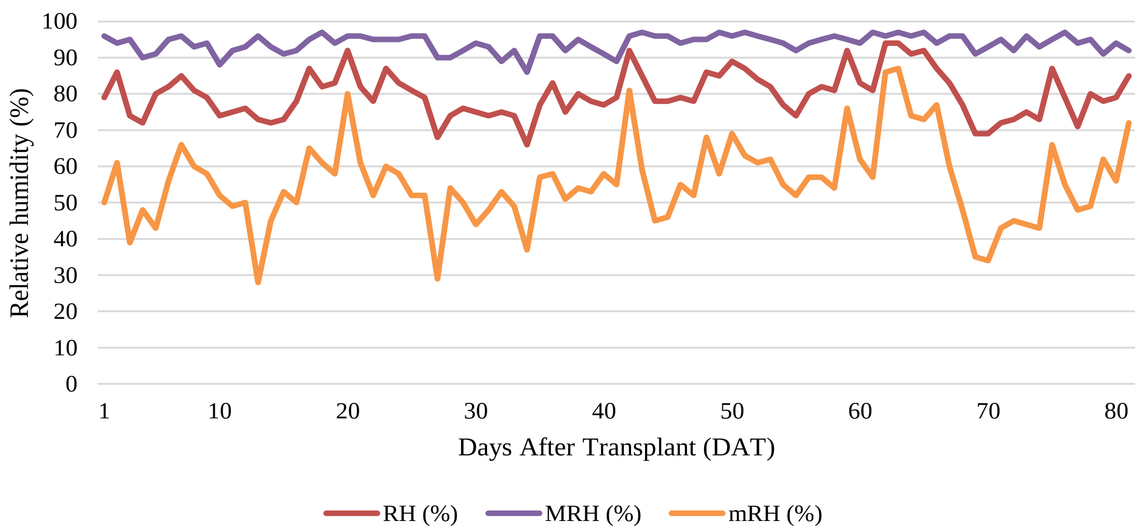

Figure 2. Maximum (MRH), average (RH) and minimum (mRH) relative daily air humidity during the experimental period.

lower total irrigation (T.I) was registered when employing mulches that reduced the number of irrigations (Table 1).

Results that are similar to those obtained in this experiment were observed by Marouelli et al. (2010) when studying water use efficiency in the production of cabbage using different quantities of straw in direct seeding. They observed that the treatments with vegetation cover received between 26 and 28 irrigations during the crop cycle. The conventional system received 32 irrigations. Pereira et al. (2002) also observed a decrease in the number of irrigations in treatments where mulch covered more than 50% of the soil surface, indicating a higher water retention in the soil. This allowed for the application of a lower quantity of water during the crop cycle, favouring the reduction of operational costs related to watering.

Reduction in water use in the treatments with mulch and surface irrigation varied between 5.72 and 15.7%; the brachiaria showed lower levels of water conservation whilst the combination of the two occupied showed higher levels of water conservation; the crotalaria a middle point, with 20.4% reduction in water use in comparison to the quantity of water applied to the treatment with a conventional system. Results with similar parameters to

Table 1. Depth of irrigation applied, number of irrigations in the different treatments, Dourados-MS 2015.

Treatment	Description	Depth of irrigation (mm)				N.I
		I.I	D.I	T.I	api	
CvS	Conventional with surface drip.	66.04	129.54	195.58	6.1	32
CvE	Conventional with subsurface drip.	66.04	122.24	188.28	5.9	32
BrS	Brachiaria with surface drip.	66.04	118.34	184.38	6.4	29
BrE	Brachiaria with subsurface drip.	66.04	107.89	173.93	6	29
CrS	Crotalaria with surface drip.	66.04	89.64	155.68	6.5	24
CrE	Crotalaria with subsurface drip.	66.04	85.94	151.98	6.3	24
CoS	Combination with surface drip.	66.04	98.64	164.68	6.9	24
CoE	Combination with subsurface drip.	66.04	95.15	161.19	6.7	24

I.I: Initial irrigation, D.I: Drip irrigation, T.I: Total irrigation, api: Average per irrigation, N.I: Number of irrigations.

Table 2. Depth of irrigation applied, production and efficiency of water use in the treatments (Dourados-MS, 2015).

Treatment	Description	Irrigation depth applied (mm)	Production (Mg ha^{-1})	WUE (kg m^{3})
CvS	Conventional with surface drip.	195.58	14.25	2.9
CvE	Conventional with subsurface drip.	188.28	14.81	3.1
BrS	Brachiaria with surface drip.	184.38	16.86	3.7
BrE	Brachiaria with subsurface drip.	173.93	16.55	3.8
CrS	Crotalaria with surface drip.	155.68	17.42	4.5
CrE	Crotalaria with subsurface drip.	151.98	18.86	5.0
CoS	Combination with surface drip.	164.68	17.13	4.2
CoE	Combination with subsurface drip.	161.19	18.35	4.6

WUE: Water use efficiency.

those that were studied in this experiment were found when working with direct and conventional seeding systems for melon cultivation. The system that employed mulch increased the efficiency of water use by 23% in comparison to the uncovered soil (Teófilo et al., 2012). The subsurface irrigation method in conjunction with soil management using of brachiaria, crotalaria and a combination of both (B+C) produced a lower water use of 7.6, 19.27 and 14.3% respectively compared to the conventional system.

Table 2 shows the water use efficiency of the different treatments. The crotalaria mulch was observed to be more effective regarding the reduction of water applied in comparison to the brachiaria mulch and the conventional system, which were the least effective treatments. The irrigation system used was a determining factor as differences were seen between the systems. The analysis of averages related to the reduction of water use which was carried out using the Tukey test at 5% level of probability (Table 3) shows that the treatment consisting of the combination of the two cover crops was statistically different from the other treatments. It was superior in relation to the variable of water use efficiency with 5.15 g mm. The treatment using crotalaria was statistically superior (4.11) to the treatment using brachiaria (3.25) and the conventional system (3.01). These last two were statistically similar. Regarding the variable of irrigation systems, the subsurface drip (5.32)–which produced the biggest benefits–and the surface drip (4.38) were statistically different.

One of the factors that allowed for a higher WUE by the crotalaria and the combination of crotalaria and brachiaria was the higher quantity of vegetation cover; 11,2 and 8,9 Mg ha^{-1} of dry material was registered by the crotalaria and the combination respectively. The brachiaria registered 8 Mg ha^{-1}. A higher quantity of dry material led to an increase in productivity and a reduction in the consumption of water. Similar results were obtained in other experiments in which 11,76 Mg ha^{-1} of *C. ochroleuca* dry material was produced (Cesar et al., 2011), and 4,46 Mg ha^{-1} of *B. ruziziensis* dry material in the dry season (Zago et al., 2010).

Another factor that influenced water use efficiency was the root system of the cover crops. Crotalaria has very aggressive, vigorous root system with a taproot. This reduced macroporosity, increased the microporosity of

Table 3. Analysis of averages of impact of treatments on water usage efficiency (WUE) in (g mm). Dourados-MS, 2015.

Soil management	WUE (kg m3)
Combination	5.15[a]
Crotalaria	4.11[b]
Brachiaria	3.25[c]
Conventional	3.01[c]
Irrigation system	
Subsurface drip	5.32[a]
Surface drip	4.38[b]
C.V.: 12.05%	

Averages followed by the same letter are not shown to be different by the Tukey Test at 5% level of probability. C.V.: Coefficient of variation.

the soil and provided conditions that were more favourable for the retention of water in the soil, thus, allowing for more efficient irrigation. Covering the soil prevented the formation of a hard layer which would have promoted the sealing of the surface (Andrade et al., 2009). The subsurface drip irrigation system was shown to be more efficient; water was supplied directly to the radicular zone of the cauliflower plants, allowing for better use and a reduction of the rate of evaporation compared to the surface drip system. Geisenhoff et al. (2015) saw similar results to those found in this experiment. Whilst studying irrigation systems in cauliflower crops, they obtained comparable differences between subsurface and surface systems; the subsurface system produced advantages for production.

Conclusions

The covering of the soil surface allowed for an increase in water use efficiency. The most promising treatment was the combination of *C. ochroleuca* and *B. ruziziensis*, which, in comparison to the conventional system, allowed for a reduction in water use in the cultivation of *Brassica oleracea* cv. Italica. Additionally, the best results were obtained with the subsurface drip irrigation system; the necessary amount of water for the crop was provided with minimal losses.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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