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Response of broccoli to soil water tension under drip irrigation

Produção de brócolis irrigado por gotejamento, sob diferentes tensões de água no solo

Bartolomeu Félix Tangune[1*]; Geraldo Magela Pereira[2]; Rovilson José de Sousa[3]; Rafael Frees Gatto[4]

Abstract

We evaluated the effect of different soil water tensions on the production of broccoli cultivated in a protected environment under drip irrigation in order to establish criteria for the adequate management of irrigation. A completely randomized block design was used, comprising six treatments and four replicates. The treatments included six soil water tensions (15, 30, 45, 60, 75 and 90 kPa). Soil water tension was monitored with granular matrix sensors installed at depths of 0.2 m (decision sensors) and 0.4 m (seepage control sensors). Total and marketable fresh weight of broccoli heads, average diameter of marketable heads, height of marketable heads, and total and marketable yield were greatest when the soil water tension at a depth of 0.2 m was 15 kPa, at which the mean values of the evaluated variables were 0.84 kg, 0.76 kg, 20.5 cm, 11.7 cm; 26.5 t ha^{-1}, and 23.7 t ha^{-1}, respectively. Treatments did not significantly affect efficiency of water use or height of marketable heads.

Key words: Scheduling irrigation, vegetable crop, protected environment

Resumo

Objetivou-se, avaliar o efeito de diferentes tensões de água no solo sobre a produção de brócolis, cultivado em ambiente protegido e irrigado por gotejamento, de forma a estabelecer critérios para o manejo adequado da irrigação. O experimento foi conduzido na Universidade Federal de Lavras, no período de Maio a Agosto de 2012. O delineamento experimental foi em blocos completos casualizados, com seis tratamentos e quatro repetições. Os tratamentos foram constituídos de seis tensões de água no solo (15, 30, 45, 60, 75 e 90 kPa). As tensões de água no solo foram monitoradas com base nos Sensores de Matriz Granular, watermark® instalados a 0,2 e a 0,4 m de profundidade. Dos resultados, concluiu-se que para a obtenção de maiores valores de massa fresca total e comercial, diâmetro médio da inflorescência, altura da inflorescência, produtividade total e comercial, as irrigações devem ser realizadas quando a tensão de água no solo estiver em torno de 15 kPa, à uma profundidade de 0,2 m. Os maiores valores atingidos foram de 0,84 kg; 0,76 kg; 20,5 cm; 11,5 cm; 26,47 t ha^{-1} e 23,71 t ha^{-1}, respectivamente. A variação da tensão de água no solo não produziu efeito significativo na eficiência no uso de água e na altura da inflorescência comercial.

Palavras-chave: Manejo da irrigação, olerícola, ambiente protegido

[1] Engº Agrº, Mestre, Escola Superior de Desenvolvimento Rural, Universidade Eduardo Mondlane, Moçambique. E-mail: tanguneb@gmail.com

[2] Prof. Titular, Bolsista de Produtividade do CNPq, Depto de Engenharia, Universidade Federal de Lavras, UFLA, Lavras, MG, Brasil. E-mail: geraldop@deg.ufla.br

[3] Prof. Titular, Depto de Agricultura, Universidade Federal de Lavras, UFLA, Lavras, MG, Brasil. E-mail: rovilson@dag.ufla.br

[4] Engº Agrícola, Mestre, Universidade Federal de Lavras, UFLA, Lavras, MG, Brasil. E-mail: rafaelfgatto@hotmail.com

[*] Author for correspondence

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Introduction

Broccoli, a member of the Brassicaceae, constitutes a botanical variety belonging to the same species as wild cabbage (*Brassica oleracea* L.), a plant native to Europe and possibly also West Asia. Morphologically, broccoli resembles the cauliflower, especially during its vegetative state but also later in its life cycle when it produces a dark-green central compact inflorescence composed of small floral buds and tender peduncles (FILGUEIRA, 2000).

Producers may adopt different broccoli culture systems depending on their investment capacity and the regions where their farms are located (STRANGE et al., 2010). According to Alvarenga (2004), culture systems may be divided into open-air and protected systems, and the latter may be further sub-divided into geoponic, hydroponic, and aeroponic systems. Plant culture in protected systems has gained worldwide acceptance, as these systems allow producers to use small areas more efficiently, to predict crop outcome, and to obtain higher yield and quality (QUEIROZ et al., 2005).

Broccoli requires adequate soil moisture for maximum yield and quality, especially during the formation of the inflorescence (STRANGE et al., 2010). Jenni et al. (2001) showed that a consistent water supply reduces the incidence and severity of brown beads in the broccoli head for both direct seedlings and transplants. Excess irrigation usually reduces yield and quality of the produce, as it causes excessive plant growth, retards fruit maturation, leaches soluble nutrients (N and K), and facilitates the onset of disease as well as physiological problems such as loose flower heads or the formation of hollow stems (STRANGE et al., 2010). Moreover, excessive watering increases farm energy costs and accelerates wear of the irrigation system (CARRIJO et al., 1999). Thus, whether plants effectively use their supply of water constitutes crucial information for producers (MARQUES, 2003).

According to Carvalho and Oliveira (2012), irrigation management utilizing granular matrix sensors (GMS) allows for the remote evaluation of soil water tension in the range of 0 to 200 kPa, which is the range where a majority of water flow occurs. However, few studies have focused on GMS for the management of irrigation for horticulture. Previous work on yield and net return of vegetables during the winter under different levels of pan evaporation replenishment yielded a maximum irrigation production efficiency for broccoli of 59 kg ha^{-1} mm^{-1}, which corresponded to 60% of cumulative pan evaporation (IMTIYAZ et al., 2000). Another previous study using the Marathon broccoli cultivar showed that higher irrigation frequencies resulted in better marketable yield, whereas low water supply induced floral bud malformations and the formation of bracts in the inflorescence (SAN BAUTISTA et al., 2005).

According to Faria et al. (1998), both an excess and a deficiency of soil moisture may negatively affect yield and quality. These effects result from low soil aeration in the case of too much water and decreased plant transpiration in the case of water deficit. Nevertheless, effects vary depending on the magnitude of the problem in any production system.

In light of this current body of knowledge, the present work aimed at evaluating the effect of varying soil water tension on the production of drip-irrigated broccoli in a protected system. Our main objective was to establish criteria for proper irrigation management.

Materials and Methods

Experiments were conducted at a greenhouse of the Engineering Department of the Federal University of Lavras (UFLA, from the original Portuguese), between May and August of 2012. UFLA is located in the south of the state of Minas Gerais at an altitude of 918 m, a latitude of 21º 14' S, and a longitude of 45º 00' W.

Lavras has a humid subtropical temperate (mesothermal) climate (Köppen's climate classification Cwa), with dry winters and rainy summers (DANTAS et al., 2007). Mean temperature during the coldest month ranges between 3ºC and 18ºC, while during the summer it reaches 22.1°C in February.

The greenhouse was 30 m long, 7 m wide (total area = 210 m²), and had an arched metal framework 4.5 meters high at its highest point. The upper part of the framework was covered with transparent, 0.15-mm thick, anti-UV polyethylene film, and the sides were protected with an anti-aphid screen. The soil used was classified as the equivalent to a red oxisol (latossolo vermelho distroférrico) (EMBRAPA, 1999).

A randomized complete block design was employed, with six treatments and four replications. Treatments included six soil water tensions (15, 30, 45, 60, and 90 kPa), as determined by sensors installed at a depth of 0.2 m. The latter included three Watermark® GMS per treatment that indicated when and how much irrigation was needed (decision sensors), one other GMS per treatment was placed at a depth of 0.4 m to assess loss of water by deep percolation and nutrient leaching. In total, forty-eight sensors were installed in 12 randomly assigned experimental blocks, with a space between sensors of 0.4 m. Readings were conducted twice daily, in the morning between 8 and 9 am and in the afternoon between 2 and 3 pm.

Each experimental block measured 0.8 m in width and 2.4 m in length (total area = 1.92 m²). Blocks were composed of two rows 0.8 m apart, with 0.4 m between plants. Useful blocks were composed of six plants, three per row, where one plant at the beginning and two at the end of the rows were discarded.

A drip irrigation system was used with auto-compensating polyethylene tubes (model NaanPC-DN 16) in the lateral lines. Drip holes (emitters) 0.90 mm in diameter were 0.3 m apart and had an average flow of 1.7 L h^{-1}. These tubes were connected to polyethylene sub main lines (DN16) and the latter to PVC tubes (DN35; PN40) fitted with electrical valves at the control head. Valves were activated by a programmable control system, previously set to provide the water required to elevate initial moisture (θ_i, cm^3 cm^{-3}) to field capacity (θ_{Fc}, cm^3 cm^{-3}), which was determined to have a tension of 10 kPa.

Irrigation times (Ti, h) were calculated from the gross irrigation requirement (GIR, mm), according to Equation 1:

$$T_i = \frac{GIR * A}{e * q_a} \quad (1)$$

where:

$$GIR = \frac{NIR}{(1-K) * UD}; \quad (2)$$

$$NIR = (\theta_{Fc} - \theta_i) * Z; \quad (3)$$

$$K = 1 - Ea; \quad (4)$$

A = plant area, m^2;

e = emitters per plant;

NIR = net irrigation requirement, mm;

q_a = average emitter flow, L h^{-1};

Z = depth of the root system, mm;

Ea = application efficiency;

K = constant that takes into account system salinity and efficiency.

The uniformity of distribution (UD) was calculated as per the equation and procedure recommended by Merriam and Keller (1978, cited by CABELLO, 1996). Equation 4 was applied in Equation 2, because we observed a loss by percolation that was greater than the need for soil washing.

From the date when treatments started on June 21 until July 5, water was supplied to meet the requirements at a depth of 0.2 m. After this period until harvest, water was supplied to meet the requirements at a depth of 0.4 m. Prior to the beginning of treatments, between June 11 and 19, irrigation was provided by micro-sprinkling with Santeno® tape, with a total depth of 29 mm per treatment applied. On June 20, the Watermark® GMS were installed and irrigation was discontinued. On the following day, the treatments were started along with drip system irrigation, which lasted until harvest at 78 days after treatment (DAT).

The "single-head" cultivar Avenger, which is recommended for the fresh-produce market as well as for processing, was used in the experiments. Seedlings were acquired in Lavras, MG, and transplanted at the 4-leaf stage with a stem diameter between 4 and 8 mm, at a depth of 0.05 m and the spacing described above.

Preplant fertilization took into account soil chemical analysis as per Fontes (1999). Top dressing was provided via ferti-irrigation according to the recommendations of the same authors, whereas foliar sprays were performed according to Trani et al. (1996).

Evaluated variables included total fresh weight, marketable fresh weight, average diameter, and height of marketable heads, total yield, marketable yield, and water use efficiency. Data were submitted to analysis of variance by the F test and regression analysis with 5% to 1% probability using Sisvar 4.0 software (FERREIRA, 2000).

Results and Discussion

Average air temperature inside the greenhouse during the experiments was 18.7°C and relative air humidity 64.0%. This temperature lies within the range recommended by Casseres (1980), who reported an ideal maximum temperature of 23.8°C for the growth and development of broccoli. In fact, other authors have shown that although broccoli may be cultivated worldwide, temperatures above 30°C may cause deformation of the inflorescence in more sensitive cultivars (BJÖRKMAN; PEARSON, 1998). On the other hand, prolonged exposure to temperatures below 10°C causes early buttoning (HAYNES et al., 2003). Air humidity during the experiments also fell within the optimal range of 60% to 75% (INFOAGRO, 2007). Protected systems may reduce luminosity between 20% and 40% (depending on the plastic cover), especially in locations with low irradiation (ALVARENGA, 2004), resulting in increased air humidity. Under these circumstances, the development of foliar diseases must be guarded against.

Table 1 shows the depth of water applied after the beginning of treatment (IRRIG), the total depth of water applied (TOT), the average depth per irrigation (API), and the number of irrigations (NI). TOT increased with decreasing soil water tension, reaching a maximum value at a tension of 15 kPa, when NI was also greater (Table 1). Similarly, Thompson et al. (2002) found that lower tension treatments for broccoli received greater amounts of water.

Table 1. Soil water tensions at a depth of 0.2 m, depth of irrigation water applied before treatment (INIT) and after the beginning of treatment (IRRIG), total water applied (TOT), average depth per irrigation (API), and number of irrigations (NI).

Tension (kPa)	Depth of irrigation water applied (mm)				NI
	INIT	IRRIG	TOT	API	
15	29	422.6	451.6	11.12	38
30	29	276.7	305.7	25.15	11
45	29	216.8	245.8	30.97	7
60	29	137.1	166.1	34.28	4
75	29	145.8	174.8	36.45	4
90	29	114.0	143.0	38.0	3

Total and marketable fresh weight of broccoli heads were significantly ($p < 0.01$) affected by soil water tension (Table 2). The highest values for these variables, 0.84 and 0.76 kg, respectively, were obtained at 15 kPa (Figure 1). These values are higher than the value of 0.46 kg previously reported for the Avenger cultivar at the same soil water tension (MELO et al., 2010). A lower value (0.73 kg) was also reported for the Marathon cultivar in a study of single-head broccoli performance during the summer (VARGAS et al., 2006).

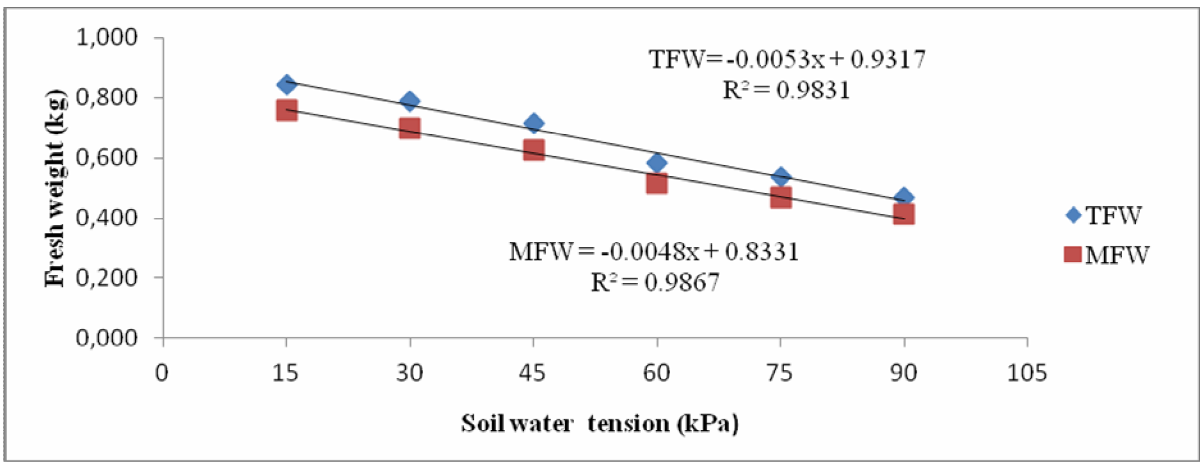
Coelho (2005), in a study of irrigation management for single-head broccoli culture in protected systems, reported total and marketable fresh weights of 0.69 and 0.61 kg, respectively. Other authors have reported comparatively low fresh weights for the single-head cultivars Baron and Hana Midori, with values of 0.43 and 0.36 kg, respectively (TREVISAN et al., 2003). Altogether, these results indicate that our results reflected good performance at 15 kPa.

Table 2. Summary of analysis of variance and regression for the variables total fresh weight (TFW, kg) and marketable fresh weight (MFW; kg) of broccoli.

Sources of variation	DF	Mean square	
		TFW	MFW
Tension	5	0.088 **	0.073 **
Block	3	0.049 ns	0.032 ns
Residue	15	0.017	0.015
Average	-	0.654	0.580
C.V. (%)	-	20.40	21.47
Linear	1	0.436**	0.364 **
Quadratic	1	0.000 ns	0.000 ns
Cubic	1	0.003 ns	0.002 ns
Deviations	2	0.001 ns	0.000 ns

ns not significant with the F test.
** and * significant at 1% and 5% probability, respectively, by the F test.

Figure 1. Broccoli total fresh weight (TFW) marketable fresh weight (MFW).



The average diameter of broccoli heads was highly affected by treatment ($p < 0.01$; Table 3). At 15 kPa, a maximum diameter of 20.5 cm was obtained. Simple linear regression explained diameter variation as a function of soil water tension, i.e., increasing tension linearly reduced head diameter (Figure 2). This pattern may have resulted from the fact that at lower tensions, more water was provided at a higher frequency (Table 1), probably contributing to formation, growth, and volume of heads. Previous work on the effects of soil water tension under drip irrigation using the Patriot cultivar at a tension of 28 kPa with mulching and tensions of 12, 20, 28, 36, and 45 kPa without mulching obtained head diameters ranging between 14.6 and 16.6 cm, with no significant differences among treatments (REYES et al., 2005). Other authors obtained diameters greater than 16 cm with sprinkler irrigation (LALLA et al., 2010). Despite the fact that different cultivars and conditions were applied, together these results indicate that broccoli performed well at 15 kPa in the current study.

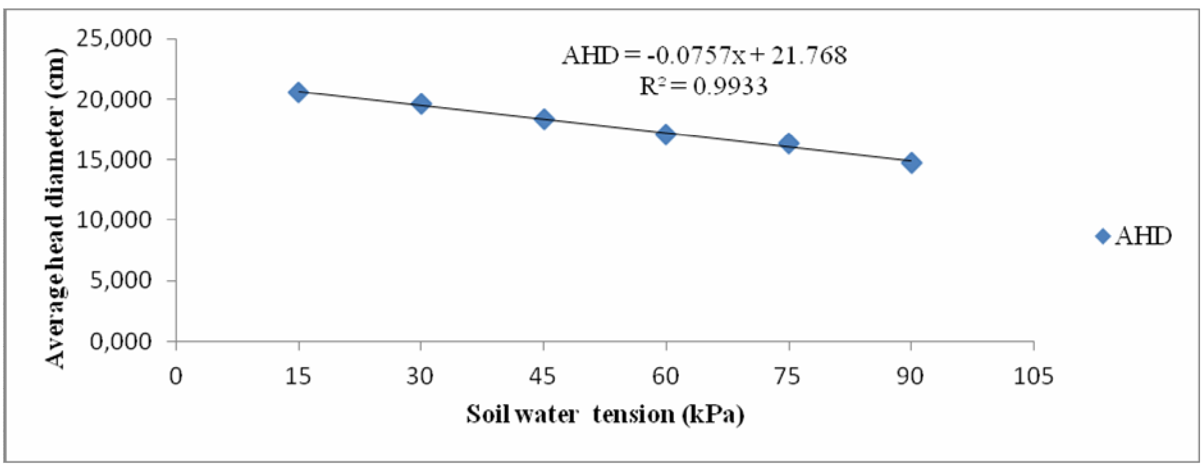
The optimal spacing for broccoli is 1.0 x 0.5 m (CECÍLIO FILHO et al., 2012). Thus, we could have increased head diameters by increasing spacing between plants. Indeed, we found that competition between plants was highest at tensions of 15 and 30 kPa.

Table 3. Summary of analysis of variance and regression for the variable average head diameter (AHD; cm) of broccoli.

Sources of variation	DF	Mean square
		AHD
Tension	5	26.972 **
Block	3	13.504 ns
Residue	15	4.552
Average	-	17.540
C.V. (%)	-	12.16
Linear	1	127.575 **
Quadratic	1	3.893 ns
Cubic	1	1.785 ns
Deviations	2	0.804 ns

ns not significant with the F test.
** and * significant at 1% and 5% probability, respectively, by the F test.

Figure 2. Broccoli average head diameter (AHD).



Ayas et al. (2011), working on the effects of water deficits on the yield of the Monet cultivar in protected systems and applying 100%, 75%, 50%, 25%, and 0% of pan evaporation every 2 days, obtained average head diameters of 24.5, 22, 16.5, 11, and 9.5 cm, respectively. In agreement with our results, treatments receiving more water yielded larger plants, and at the 100% and 75% levels, heads were even larger than in our study. Naturally, this effect does not go on indefinitely, and at some point excess water will negatively affect the plants.

Table 4 shows that no significant effect of water tension on the head height could be detected. Nevertheless, a tendency towards shorter heads with increasing tension was detected, with heights of 11.7 cm at 15 kPa and 9.7 cm at 90 kPa. Similarly, a previous study reported decreased head height with reduced irrigation (AYAS et al., 2011).

Table 4. Summary of analysis of variance and regression for the variable average head height (AHH; cm) of broccoli.

Sources of variation	DF	Mean square
		AHH
Tension	5	2.206 ^{ns}
Block	3	3.142 ^{ns}
Residue	15	1.018
Average	-	11
C.V (%)	-	9.18

^{ns} not significant with the F test.
** and * significant at 1% and 5% probability, respectively, by the F test.

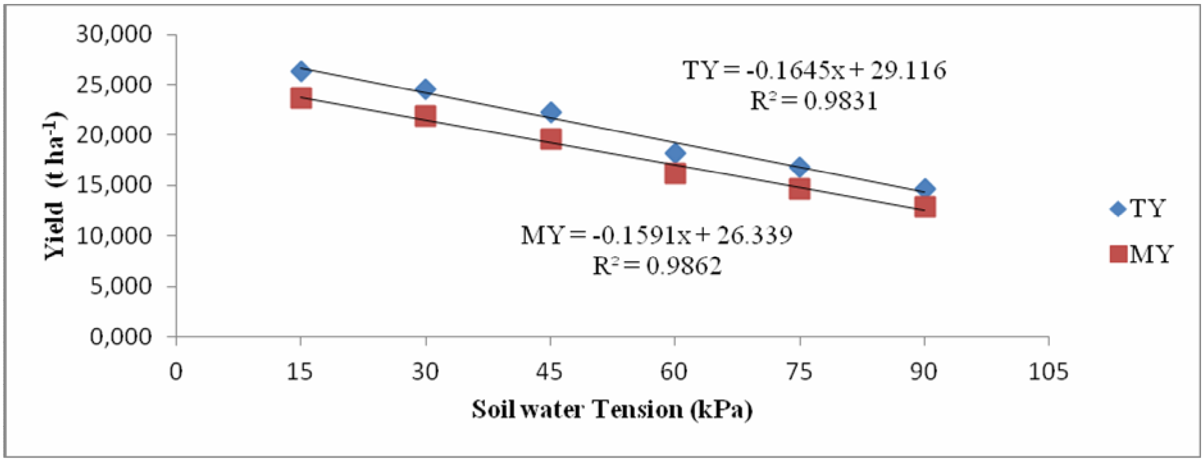
Table 5 shows that total and marketable yield were significantly affected by soil water tension. The highest yield values were observed at 15 kPa and the lowest values were observed at a water tension of 90 kPa, with total yield ranging between 26.5 and 14.6 t ha^{-1} and marketable yield ranging between 23.7 and 12.9 t ha^{-1}. In fact, reducing tension linearly increased total and marketable yield ($p < 0.01$, Figure 3). As we did not reach a plateau in the curve, further reductions in tension may further improve yield up to the point where reduced soil aeration starts negatively affecting the plants.

Table 5. Summary of analysis of variance and regression for the variables total yield (TY; t ha^{-1}) and marketable yield (MY; t ha^{-1}) of broccoli.

Sources of variation	DF	Mean square	
		TY	MY
Tension	5	86.745 **	72.176 **
Block	3	46.773^{ns}	31.980 ^{ns}
Residue	15	17.446	15.345
Average	-	20.478	18.140
C.V. (%)	-	20.40	21.59
Linear	1	426.396**	356.064 **
Quadratic	1	0.110 ^{ns}	0.734 ^{ns}
Cubic	1	3.608 ^{ns}	2.409 ^{ns}
Deviations	2	1.805 ^{ns}	0.835^{ns}

^{ns} not significant with the F test.
** and * significant at 1% and 5% probability, respectively, by the F test.

Figure 3. Broccoli total yield (TY) and marketable yield (MY).



Thompson et al. (2002), studying underground drip irrigation enriched with nitrogen with tensions of 4, 12.3, and 25 kPa, obtained marketable yields of 10.3, 10.6 and 9.7 t ha^{-1}, respectively. In the aforementioned work by Ayas et al. (2011), the application of 100% and 75% of pan evaporation corresponded to marketable yields of 29.2 and 27.5 t ha^{-1}, respectively, which are higher than the yields obtained in the present study. However, those experiments were performed with different irrigation techniques. Similarly, Kumar and Senseba (2008) obtained a higher maximum yield of 32.4 t ha^{-1} when irrigating broccoli with 150% of pan evaporation in India, but they did not use a single-head cultivar.

Babik and Elkner (2002), obtained a lower yield (22.6 t ha^{-1}) with irrigation and application of 600 kg ha^{-1} of N. Other studies have also reported lower yields than the ones we observed. Trevisan et al. (2003), assessing the yield of different cultivars in the state of Rio Grande do Sul, obtained a maximum total yield of 16.3 t ha^{-1} with the early Piracicaba cultivar, and Erdem et al. (2010) reported a maximum marketable yield of 8.1 t ha^{-1} when irrigating broccoli with 50% of pan evaporation and an irrigation interval of 7 days. The differences described above may result from a number of factors, including differences in cultivars, techniques, and regions.

The maximum total and marketable yields observed in the present work fall within the range indicated by Sousa et al. (2011) for drip-irrigation systems that maintain a soil water tension between 10 and 20 kPa.

Table 6 shows that no significant effect of treatment on the efficiency of water use could be detected. Nevertheless, there was a tendency towards increased efficiency with increasing water tension. The maximum efficiency of 97.1 kg ha^{-1} mm^{-1} was found at 60 kPa. This value is higher than that previously reported by Imtiyaz et al. (2000), who found a significant effect of tension on efficiency.

Table 6. Summary of analysis of variance and regression for the variable water use efficiency (WUE; kg ha^{-1} mm^{-1}) of broccoli.

Sources of variation	DF	Mean square
		WUE
Tension	5	992.367 ^{ns}
Block	3	850.437 ^{ns}
Residue	15	312.978
Average	-	79.15
C.V. (%)	-	22.35

^{ns} not significant with the F test.
** and * significant at 1% and 5% probability, respectively, by the F test.

Conclusions

Total and marketable yield of broccoli, total and marketable fresh weight of heads, and average head diameter were maximized when drip irrigation maintained a soil water tension of approximately 15 kPa at a depth of 0.2 m. Soil water tension did not significantly affect water use efficiency or height of marketable heads.

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