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WATER USE BY BROCCOLI PLANTS (*Brassica oleracea F,* var. Italica)

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1 ABSTRACT

Broccoli (*Brassica oleracea F,* var. Italica) plants were transplanted to four lysimeters (116 cm x 116 cm and 150 cm depth), two of them maintained at 40 cm and two at 50 cm water table. Other two lysimeters, one for each level, received grass (*Paspalum notatum,* F.) to measure Reference Evapotranspiration (EToLY). Surrounded area received 2,500 m^2 of broccoli plants with soil water potentials ($_s$) maintained higher than –30 kPa. The results allowed to conclude: - there were no statistical differences between the plant parameters from 40cm lysimeters and the surrounded area; - the Class A Pan, Radiation-FAO, Penman-FAO and Penman-Monteith Reference Evapotranspiration (ETo) methods, in this order, had significant correlations to the data obtained from 40 cm water table level lysimeter; - the Kc (crop coefficient) broccoli values ranged from 0.88 to 1.42 for KcLY (Lysimeters), 1.24 to 2.14 for KcA (Class A Pan), 1.19 to 1.71 for KcPM (Penman-Monteith), 0.95 to 1.42 for KcPF (Penman-FAO) and 0.82 to 1.49 for KcR (Radiation-FAO) from stages II to V; - the plant water using ranged from 4.09 to 6.25 mm/day for 40 cm water level, and 2.68 to 5.25 mm/day for 50 cm water level for the same stages, respectively. The lysimeters at 50 cm water level yielded 64,3% less inflorescences and 8.1% lower water using efficiency than the plants from 40 cm water level lysimeters.

KEY WORDS: irrigation, evapotranspiration, broccoli.

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2 RESUMO

Plantas de brócolos foram transplantadas para 4 lisímetros de 116 x 116 de área x 150 cm de profundidade, sendo dois mantidos com 40 cm e outros dois com 50 cm de nível de lençol freático. Outros dois lisímetros foram usados para medir a evapotranspiração de referência (EToLy) com grama batatais nos mesmos níveis de água. Os lisímetros foram colocados no meio de uma cultura de brócolos com área de 2500 m^2, com o potencial de água do solo mantido acima de –30kPa. Os resultados permitiram que se concluísse: - não houve diferenças estatisticamente significativas entre os valores de área foliar, pesos de matéria seca das folhas e das inflorescências entre as plantas de fora e de dentro dos lisímetros de nível de água de 40 cm; - os métodos do tanque Classe A, FAO-Radiação,

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Penman-FAO e Penman-Monteith, nesta ordem, correlacionaram-se significativamente com os dados obtidos no lisímetro de grama de nível 40 cm; - os lisímetros com brócolos e nível de 50 cm tiveram produtividade 64,3% menor e mostraram eficiência de uso de água 8,1% menor que os de 40 cm e 2,68 a 5,25 mm de evapotranspiração por dia, não sendo, portanto, indicados para a medir-se EToLY; - os valores dos coeficientes de cultura variaram de 0,88 a 1,42 para KcLY (lisímetro de 40 cm), de 1,24 a 2,14 para KcA (tanque Classe A), de 1,19 a 1,71 para KcPM (Penman-Monteith), de 0,95 a 1,42 para KcPF (Penman-FAO) e de 0,82 a 1,49 para KcR (FAO-Radiação) para os estádios II a V, respectivamente.

UNITERMOS: brócolos, coeficiente de cultura, evapotranspiração de referência.

3 INTRODUCTION

The success of the irrigation involves accurate measurement of water loss. Lysimeters offer good accuracy for these determinations, being a reference for other methods, such as those based on meteorological elements which need adjustments through coefficients.

The Reference Evapotranspiration (ETo) can be determined through models that integrate the factors affecting the phenomenon. For Mantovani (1994), the Penman-FAO, Penman-Monteith, Class A Pan and FAO-Radiation methods showed the best results in Southern of Spain. However, the choice for the cheapest, more simple and accurate methods regards to the purpose of the determinations and the technical and material resources available. For Bernardo (1989), the lysimeter is the most accurate method to determine ETo, when correctly used. Among the several kinds of lysimeters, Villa Nova & Reichardt (1989) commented that the constant level lysimeter is the most used method for the water loss determination due to its easiness of handling and accuracy.

Few studies have been done on broccolis water use in Brazil. According to Filgueira (1987), the irrigation depth for this crop reaches about 30 cm from surface. The sub irrigation showed better results than other irrigation methods for cabbage plants and the best results came from 30 to 70 cm water level depth for medium texture soil (DOORENBOS & PRUITT, 1979). Shih (1985) studied different depths of water table level close to the surface in the same soil and found similar evaporation data in relation to Class A Pan. Similar results were related by Israelsen (1974) which showed that evapotranspiration from water table level close to soil surface was significantly correlated to Class A Pan evaporation data. However, due to difficulties from direct determinations, the use of indirect measurements is utilized with good results. Klar (1988) commented that Class A Pan evaporation provides an integration of meteorological element effects: radiation, wind, air temperature and air humidity and, according to this author, there is interference of the inherent plant factors such as stomata and leaf reflection. For this reason, a crop coefficient (Kc) becomes indispensable for the necessary correction. According to Doorenbos & Kassan (1979), Kc can be defined as the relation between the maximum crop evapotranspiration (ETm) and reference evapotranspiration (ETo). Evidently, each plant developmental stage has a specific Kc.

The objective of this study was to evaluate the water consumption and the broccoli crop coefficients (Kc) through the following methods: Class A Pan, Penman-Monteith, Penman-FAO, Radiation-FAO and constant level lysimeters.

4 MATERIAL AND METHODS

The experiment was carried out in the Agricultural Engineering Department - FCA -

UNESP, Botucatu - SP, 22^0 and 52 ' South Latitude and 786 m Altitude. The total area was 2,500 square meters, being cultivated with broccolis (*Brassica oleracea*, L, var. Italic). A medium texture soil (44% sand, 15% of silt and 41% of clay, 1.38g/cm^3 bulk density at 30 cm depth) was used. The climatological data were obtained from a weather station, next to the experiment. The water used in lysimeters was the same utilized to supply the Botucatu city.

A group of six lysimeters was set up in the center of the area: two received batatais grass (*Paspalum notatun*, F) and the other four received broccoli plants. The lysimeters were built with fiberglass and resin, with 3mm wall thickness, 116cm x 116cm exposition surface, 150cm depth and filled with 10cm of flints in the bottom, covered with bidin OP-30 and soil from the area, in an attempt to maintain the original soil profile. The soil was stabilized through constant irrigation before crop planting. A reservoir (20cm diameter and 120cm height) to supply and measure the water loss for each lysimeter was connected to a 10cm diameter open pipe, equipped with float, which was placed in a corner and inside the lysimeters for maintaining the established water level. A tunnel (400cm length, 200cm width and 200cm height), covered with soil (70cm layer) from the area, was connected to the lysimeters for collecting drainage water, if necessary. A removable and transparent plastic cover for each lysimeter was used to protect from natural or artificial rainfall. A sprinkler irrigation system was used for maintaining soil water potential above -30 kPa in the 30cm superficial layer, out of lysimeters.

Broccoli was sowed in trays on June 29. Four plants, spaced 90cm x 70cm, were transplanted to the four lysimeters on August 1st: Two were maintained at 40cm water table and other two, 50cm from the surface of the soil. The same water levels (40 and 50cm) were applied to other two lysimeters, but grass (*Paspalum notatum*, L) was used instead broccoli to obtain ETo from lysimeter (EToLY). These water levels were based on experiments of Alves and Klar, 1996 for the same soil. The soil fertilization followed soil analysis and was completed with three applications of ammonium sulfate in the soil and leaf application of sodium molibdate.

In order to record the soil water potential variation, two tensiometers were set up in each lysimeter and in 20 points of the surrounded area. A neutron probe also was used to measure soil water content.

The harvest occurred between 75 to 90 days from the day of transplanting, according to instructions of Filgueira, 1987. The behavior of plants from lysimeters and surrounded area were compared through weight, diameter and dry matter of the head, dry matter of leaves and leaf area. The leaf area (LA) of plants from lysimeters was obtained from a regression equation between LA and two measurements of leaves to avoid destroying plants. The plant dry matter was determined at stove (70^o C).

The Reference Evapotranspiration (ETo) was evaluated by different methods: Hydric Balance through lysimeter with grass (EToLY), Class A Pan (EToA), Penman-Monteith (EToPM), Penman-FAO (EToPF) and Radiation-FAO (EToR), according to Doorenbos and Pruitt, 1977, and Doorenbos and Kassan, 1979. The Kp values for Class A Pan followed the equation of Allen and Pruitt (1991). The crop coefficients or crop factors (Kc) were obtained from the ratio of maximum brocolli evapotranspiration (ETc) and the different methods to measure ETo. The water use efficiency (WUE) was determined between dry matter and the broccoli evapotranspiration (Klar, 1988).

The partition in stages for broccoli crop followed the recommendation of Doorenbos & Kassan (1979): I. 20-30 days, from seeding to the beginning of the vegetative development; II. 30-35 days - vegetative development; III. 20-30 days - intermediate stage; IV. 10-20 days, final stage; V. 10 days, crop harvest.

5 RESULTS AND DISCUSSION

The results of broccoli productivity and leaf area from both water level treatments were compared to those from surrounded plants through "t" test. The leaf area (LA) was obtained by the regression equation, where L and l are leaf measures and LA is the leaf area:

$$LA = 0.8744\ Ll - 11.277; \qquad r = 0.99^{**}$$

Dry matter (DM) of the leaves was obtained by the equation:

$$DM = 0.0053\ LA - 21.365; \qquad r = 0.96^{**}$$

The yield of broccoli inflorescence (head) from plants inside lysimeter was calculated through an equation comparing the diameter (Dh) and the weight (W) of heads:

$$W = 0.2542\ Dh - 0.0383; \qquad r = 0.98^{**}$$

The biometric measurements and yields of the plants from surrounded area did not show statistical differences from plants of the 40 cm water level lysimeter. On the other hand, the same phenomenon did not occurred for plants from 50cm lysimeters (Table 1). Consequently, plants from 40cm treatment had better soil conditions in relation to air, water and nutrient availability. Despite the plants in lysimeters had showed lower but not significant yields than the surrounded plants, the results suggest that the 40cm treatment can be used as evapotranspiration reference for the conditions studied. The water use efficiency (WUE) for broccoli plants in lysimeters had 0.62 and 0.57kg dry matter per m^3 of water, for 40 and 50cm water levels, respectively, which is another parameter to prove that the 40cm water table level can be used as EToLY.

The regression equations of ETo based on daily values are in Table 2. The correlation data showed that Penman-FAO method were the closest to lysimeter values, followed by Radiation-FAO, Penman-Monteith and Class A Pan Methods. The Class A Pan (-28.8%) and Penman-Monteith (-16.7%) had lower values in relation to lysimeters, while Radiation-FAO and Penman-FAO showed the opposite, +11,6% and +2,7%, respectively. Bastos (1994), Barbieri (1981), and Costa (1989) also reached higher values for Radiation in relation to Class A Pan and Penman methods.

According to "t" test, all linear equations showed positive and significant correlations. The Class A Pan presented the best adjustment followed by EToR. According to Sanchez-Toribio et al. (1991) the Class A Pan method showed the best performance among the other methods studied (Penman-FAO, Radiation and Blaney-Criddle), also using lysimeter data as reference.

Generally, the ETo methods used in this study were very sensitive to solar radiation oscillations. Kramer confirms this affirmative (MAENO, 1993): "the main factor affecting evapotranspiration is solar radiation, because it is the energy source for transferring liquid water to vapor".

Table 1. Means of leaf area (cm^2), productivity (kg/ha), leaf (g) and inflorescence (kg/ha), dry matter (g) and diameter area (cm^2) of plants in and out lysimeters.

Parameters	Treat. 50cm Lysimeters	Treat. 40cm Lysimeters	Outside
Leaf area	9.605 a	10.984 a	10.281 a
Diameter area	203.0 b	275.5 a	284.7 a
Leaf dry matter	53.73 a	65.08 a	56.68 a
Infl. dry matter	135.03 a	182.20 a	198.60 b
Productivity	3.347 b	5.202a	5.446 a

Table 2. Linear regression equations and correlation (r) analysis among EToLY against EToA, EToPM, EToPF and EToR - daily value basis.

Linear Regression	Correlation (r)	Equation Coeff. a	b
EToA = 1.039 EToLY – 1.474	0.86**	**	**
EToPM = 0.767EToLY +0.287	0.74**	*	**
EToPF = 1.034 EToLY - 0.043	0.77*	*	**
EToR = 1.533 EToLY - 1.878	0.85*	**	**

** = 1% probability; * = 5% probability; ns = non significant

The daily lysimeter evapotranspiration averages based on five-days, together with the total loss of water during all plant cycle, are showed in Table 3. Statistical analysis (“t” test) did not show significant differences between the evapotranspiration of the two 50cm level lysimeters, and the same results were found in relation to both 40cm level.

Table 3. Daily water loss averages for stages II to V and total evapotranspiration averages for 40 and 50cm water level for broccoli plants in the lysimeters.

Stage	40cm water level	50cm water level
II	4.09 mm/day	2.68 mm/day
III	4.84 mm/day	4.91 mm/day
IV	5.52 mm/day	4.85 mm/day
V	6.25 mm/day	5.25 mm/day
Total	368.75 mm	305.85 mm

The variation between the 50cm lysimeters was 8.85mm and between the 40cm was 7.95mm for all periods, which shows very small differences between the same level lysimeters and the good performance of the equipment. The plant water use had an increase, following the broccoli growth, from 2.68 mm/day for stage II until 5.25 mm/day for stage V (50cm level) and from 4.09 to 6.25 mm/day for stages II and V (40cm level), respectively. The total evapotranspiration was 305.85 and 368.75mm for 50 and 40cm levels, respectively, with 17% difference between them. Cury (1985), studying evapotranspiration in cabbage, found 376mm at 45cm water level, obtained under similar meteorological (winter time) and soil conditions of this experiment.

The difference between both water levels shows that other water level experiments must be developed, including different soil and meteorological conditions.

The Kc values increased constantly, with respect to the crop development, reaching the highest values at the last stage for all ETo models studied (Table 4). Moreover, in order to control the irrigation, it becomes necessary to have the Kc values of all crop stages. The 50cm level lysimeters had lower inflorescence broccoli productivity (64.3% and 61.5% in relation to 40cm lysimeter and outside plants, respectively) and only 83% of the evapotranspiration obtained from the 40 cm water level lysimeters. For this reason, just the values from 40cm lysimeters are considered in Table 4. Therefore 40cm level lysimeter had better results with respect to the main objectives of this study: to determine the best Kc for broccoli crop and the correlations between KcLY and the estimated methods. Evidently, as it was previously showed, the values from 50 cm water level do not represent the maximum evapotranspiration, not in line with the ETo definition. Consequently, the best option is to use the results from 40 cm water level, considering the data obtained. On the other hand, the best option depends on several factors, such as: the cheapest, the easiest, and the most sensitive method for the local conditions, because all methods, here studied, were statistical suitable. It is convenient to emphasize that this study is based on sub irrigation method.

Table 4. Crop coefficients of lysimeter reference evapotranspiration of 40 cm water level (KcLY) for broccoli crop (stages II to V) and the Class A Pan (KcA), Penman-Monteith (KcPM), Penman-FAO (KcPF) and Radiation-FAO (KcR) values.

Stage	KcLY	KcA	KcPM	KcPF	KcR
II	0.88	1.24	1.19	0.95	0.82
III	1.12	1.50	1.21	1.00	0.98
IV	1.30	2.03	1.49	1.18	1.22
V	1.42	2.14	1.71	1.42	1.49
Average	1.18	1.72	1.40	1.14	1.13
Correl. (r)		0.98 ns	0.92 ns	0.92 ns	0.97 ns

n.s – no significant differences between measured (KcLY) and estimated Kc's

6 CONCLUSIONS

1. The Class A Pan, Radiation-FAO, Penman-FAO, and Penman-Monteith Reference Evapotranspiration methods, in this order, were statistically significant in relation to the data obtained from 40 cm water level lysimeter.

2. The water use of plants varied from 4.09 for stage II to 6.25mm/day for stage V for 40cm lysimeter and from 2,68 to 5,25mm/day for 50cm lysimeter. The total water use for the cycle was 368.75 and 305.85mm for 40 and 50cm water levels, respectively.

3. Plants from 40cm lysimeters yielded 96% of inflorescences of surrounded plants, showing the validity to use this water table for reference evapotranspiration studies. On the other hand, the 50cm water table, whose plants had only 61,4% yield from surrounded plants, is not recommended for these studies.

4. The Kc (crop coefficient) broccoli values varied from 0.88 to 1.42 for EToLY (lysimeters), 1.24 to 2.14 for KcA (Class A Pan), 1.19 to 1.71 for KcPM (Penman-Monteith), 0.95 to 1.42 for KcPF (Penman-FAO), and 0.82 to 1.49 for KcR (Radiation-FAO) from stages II and V.

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