

SOIL SOLUTION DYNAMICS FOR DRIP FERTIGATION MANAGEMENT IN BELL PEPPER CROP

BRUNO DE LIMA SANTORO¹; REGINA CÉLIA DE MATOS PIRES²; JOSÉ GEANINI PERES³ E CLAUDINEI FONSECA SOUZA³

¹Doutorando, Faculdade de Engenharia Agrícola, Universidade Estadual de Campinas, Campinas, SP. blsantoro@hotmail.com

²Pesquisadora, Instituto Agronômico de Campinas, Campinas, SP. rcmpires@iac.sp.gov.br

³Professor, Departamento de Recursos Naturais e Proteção Ambiental, Centro de Ciências Agrárias, Universidade Federal de São Carlos, Rodovia Anhanguera, km 174, 13600-970, Araras, SP. jogepe@cca.ufscar.br; cfsouza@cca.ufscar.br

1 ABSTRACT

The success of drip irrigation compared to various other irrigation systems is attributed primarily to its superior water delivery to plant root zones and high efficiency in water use. This work aimed at studying the distribution and storage of soil solution in the soil profile, and the uptake of nutrients through the roots of pepper plants, irrigated through a drip fertigation system at two flow rates, 2 and 4 L h⁻¹. The experiment was conducted within a greenhouse with plants grown in a medium-textured Oxisol for 120 days. Water and ionic concentration were concurrently measured using TDR probes in the soil profile (at depths ranging from 0.1 to 0.6 m). The root system of plants irrigated with drippers of 4 L h⁻¹ had an area of 69.3 cm² while plants irrigated with drippers of 2 L h⁻¹ presented an area of 45.2 cm². The yield of pepper plants were 0.19 kg m⁻² and 0.27 kg m⁻² for treatments with 2 L h⁻¹ and 4 L h⁻¹, respectively, supporting the results obtained for nutrients distribution and root development. There was higher tendency for nutrient loss in the treatment with 2 L h⁻¹, increasing risks of groundwater contamination. The dripper with flow rate of 4 L h⁻¹ was more efficient at distributing and storing water and nutrients in the soil profile, which improved the crop yield.

Keywords: reflectometry; soil solution management; drip irrigation

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DINÂMICA DA SOLUÇÃO DO SOLO PARA O MANEJO DA FERTIRRIGAÇÃO
POR GOTEJAMENTO NA CULTURA DO PIMENTÃO

2 RESUMO

A irrigação por gotejamento possibilita a aplicação de água e nutrientes na região das raízes da planta e tem contribuído para obtenção de elevada eficiência no consumo da água e dos nutrientes. Essa vantagem tem contribuído pelo aumento no interesse na adoção deste método de irrigação em relação a outros, no entanto, adequado manejo da água e dos nutrientes deve ser adotado. Neste contexto, o objetivo foi avaliar a distribuição e armazenamento de solução do solo e a absorção de nutrientes de raízes de plantas de pimentão aplicados por fertirrigação em irrigação por gotejamento com emissores com vazões distintas, 2 e 4 L h⁻¹. O experimento

foi conduzido em ambiente protegido, sendo as plantas cultivadas em Latossolo Vermelho de textura média por 120 dias. A umidade e a concentração iônica foram simultaneamente medidas utilizando sondas de TDR instaladas no perfil do solo (a cada 0,1 m até 0,6 m de profundidade). O sistema radicular das plantas irrigadas com gotejadores de 4 L h⁻¹ apresentou uma área de 69,3 cm², enquanto que as plantas irrigadas com gotejadores de 2 L h⁻¹ apresentaram uma área de 45,2 cm². A produtividade de pimentão atingiu 0,19 kg m⁻² e 0,27 kg m⁻² nos tratamentos com emissores com vazão de 2 e 4 L h⁻¹, respectivamente. Houve uma tendência de perda de nutrientes no tratamento com 2 L h⁻¹, aumentando os riscos de contaminação das águas subterrâneas. A adoção do gotejador com vazão de 4 L h⁻¹ foi mais eficiente na distribuição e armazenamento de água e nutrientes no perfil do solo, o que melhorou o desenvolvimento do sistema radicular e a produtividade.

PALAVRAS-CHAVE: reflectometria, manejo da solução no solo, irrigação por gotejamento

3 INTRODUCTION

Irrigation is a common technique used for supplying water requirements of crops, which usually improves the crops and yield quality. The use of areas previously considered unsuitable for cultivation becomes possible regardless of water deficits. It is also an important factor to stabilize the production.

Considering the tendency of decreasing water availability for irrigation, drip irrigation has been recommended as a new irrigation technology with potential to achieve significant savings in the use of water resources (RIVERA et al., 2008). Using this technique, the water is applied in small quantities and with high frequency in the plant roots, keeping the soil water content close to field capacity in this region.

An adequate estimative of shape and dimensions of the wetted bulb is very important for determining the correct number of emitters per plant and their location in relation to a plant or a row of plants (SOUZA; FOLEGATTI; OR, 2009). The overestimation of percentage of wet soil might reduce the system efficiency resulting in the waste of water, energy and nutrients, whereas its underestimation might cause plant water stress, insufficient nutrient uptake through plant roots and yield loss. Given the above, it is important to properly estimate the wetted bulb dimensions, taking into account the dripper flow, the soil type, the time of operation system and the plant roots dimension (MAIA, 2010).

Fertigation is defined as the application of soluble fertilizers through irrigation, allowing optimum use of fertilizers by different cultures thus obtaining remarkable results in crops yield and quality. This technique can be used with a drip irrigation system (OLIVEIRA; VILLAS BOAS, 2008). The doses of fertilizers recommended for each crop can be fractioned according to its nutritional necessities. The technique makes optimum use of inputs, increasing the efficiency of nutrients uptake and the application flexibility, and decreases labor and costs of operation (MELO et al., 2009).

Considering the benefits of applying fertilizers through drip irrigation, there is a limited knowledge of the behavior of water and solutes in the soil profile (SOUZA; FOLEGATTI, 2010). In order to make precise measurements of soil water content and electric conductivity in laboratory and in the field there is a tendency to use the TDR technique (Time Domain Reflectometry), in which a calibration curve for each soil type is recommended, a minor inconvenience considering that this technique offers more advantage over the others.

Taking into consideration the potential of drip irrigation, the lack of studies performed in Brazilian soils for acquisition of information on the movement of nutrients in the soil, and the tendency for using the TDR in the field, it is reasonable to suppose that this technique can be used to get helpful information to determine technical criteria for drip fertigation management, especially when a quick decision making is required, aimed at increasing production and conserving water resources.

The objective was to study the solution distribution and storage in the soil profile and the uptake of nutrients from bell pepper plants roots through a drip fertigation system at two flow rates, 2 and 4 L h⁻¹. The experiment focused on uptake of nutrients through the roots of bell pepper plants (*Capsicum annum* L) in a cycle of 120 days, between July and November of 2010.

4 MATERIAL AND METHODS

The experiment was carried out in a greenhouse of 6.40 x 20 x 3 m at experimental area of the Department for Agricultural Sciences, University of Taubaté – UNITAU (23 ° 01' 55, 25" South, 43° 30' 39, 74" west and 571 meters) at Taubaté, São Paulo, Brazil.

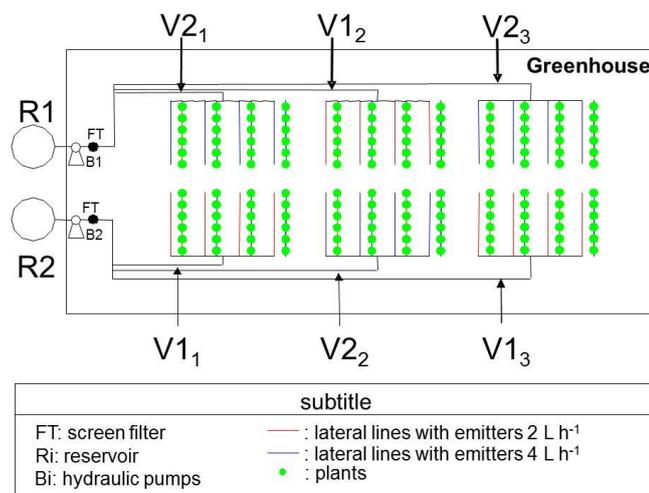
The physical and chemical characteristics of the medium texture Oxisol soil (Table 1) were determined in the Soil Analysis Laboratory at UNITAU. Based on the soil analysis fertilizers were applied according to Trani and Raij (1997) for bell pepper cultivation and 40 kg ha⁻¹ of N, 600 kg ha⁻¹ of P₂O₅, 120 kg ha⁻¹ of K₂O and 25 kg ha⁻¹ of manure were applied.

In order to provide water and nutrients through fertigation to bell pepper plants a drip irrigation system divided in two independent sectors was installed. Each system had three units that each one controlled in a panel. The units V2₁, V1₂ and V2₃ received water and nutrients from reservoir R1 and units V1₁, V2₂ and V1₃ from reservoir R2. Both reservoirs have 500 L of volume and the units V2 have 4 L h⁻¹ drippers while the units V1 have 2 L h⁻¹ drippers (Figure 1).

Table 1. Physical and chemical characteristics of soil layers up to 0.60 m depth

Physical characteristics										
Depth cm	FC	PWP	p	Sd	Pd	SSIR	Sand	Silt	Clay	
	m ³ m ⁻³			g cm ⁻³		mm h ⁻¹	(%)			
0 - 20	0.28	0.21	0.51	1.30	2.70	13.20	59	13	28	
20 - 40	0.28	0.21	0.50	1.35	2.70	9.40	57	13	30	
40 - 60	0.28	0.20	0.49	1.39	2.70	9.50	58	13	29	
Chemical characteristics										
Depth cm	pH	P	OM	H+Al	K	Ca	Mg	SB	CEC	Bs
	CaCl ₂	mg dm ⁻³	(%)			mmol dm ⁻³				%
0 - 20	5.00	12	7	23	1.40	23	12	36.40	59.40	61
20 - 40	4.30	2	6	34	0.70	7	4	11.70	45.70	26
40 - 60	4.50	3	5	22	1.30	10	7	18.30	40.30	45

FC - Field capacity, PWP - Permanent wilting point, p - Porosity, Sd - Soil density, Pd - Particle density, SSIR - Steady state infiltration rate, pH - Potential hydrogen, P - Phosphorus, OM - Organic matter, H + Al - Potential acidity, K - potassium, Ca - calcium, Mg - Magnesium, SB - Sum of bases, CEC - Cation exchange capacity, Bs - Percentage of Base saturation

Figure 1. Outline of the drip irrigation system

The lateral lines in each unit were 2.4 m long and distant 1.0 m from each other. In each sideline were installed six emitters 0.40 m apart each other totalizing 24 emitters per unit. The drip irrigation system still had, for each sector, pump, hydrometer to monitor water flow, pressure regulators 0.1 MPa and 120 mesh screen filter to remove impurities.

In the V1₂, V2₃, V2₂ and V1₃ experimental units were installed monitoring stations using TDR probes (TDR 100 – Campbell Scientific*) for estimating the soil water content and the electrical conductivity of the soil solution throughout the crop cycle. The sensors spaced 0.1 m apart formed an array of 48 probes. In each unit a lateral line was monitored.

The beds were built manually in each experimental unit and then the bell pepper seedlings, variety “Magda”, were transplanted. The fruits of this variety are produced in a period between 100 and 120 days and their shape is rectangular with pulp thickness of 6 to 8 mm. In each unit were transplanted 24 seedlings being each dripper responsible for supplying the demand for water and nutrients of a plant.

In order to monitor the distribution and storage of nutrients in the soil through drip fertigation the irrigation was managed as follows: the data of soil water content and electric conductivity from each TDR probe, acquired by each monitoring station and the behavior of the soil solution in each time was described.

The water volume applied was calculated using the average of soil water content from the layer of effective root zone (0.25 m) of the bell pepper plant. Irrigation was done whenever the mean values of soil water content were less than 15 % of field capacity. After the irrigation new data of electric conductivity and soil water content were collected and analyzed again. It was necessary about 180 minutes to verify all the stations after the irrigation.

Fertigation was performed according to the recommendations of Trani and Raij (1997) splitting the mineral fertilization coverage into five times with the application of 120 kg ha⁻¹ of N and 80 kg ha⁻¹ of K₂O in the form of potassium nitrate (KNO₃).

The control of pests and plant diseases was held weekly spraying the plants preventively with products registered for this crop (acaricide, fungicide) besides the manual weed control.

In order to obtain uniform distribution of water three tests of drippers flow were made: in the beginning, at 60 days after transplantation and at the end as specified in the, methodology by Barros et al. (2010) and using equation (1).

* Trademark references do not constitute an endorsement by the authors.

$$CUC = 100 \left[1 - \frac{\sum |X_i - \bar{X}|}{\bar{X}N} \right] \quad (1)$$

where:

CUC - Coefficient of Distribution Uniformity (%);

X_i - measured flow rate ($L h^{-1}$); \bar{X} = Average flow rate ($L h^{-1}$);

N - Number of estimated points.

The TDR technique is an indirect method to estimate the volumetric soil water content and electrical conductivity of the soil solution. Almeida, Cavalca and Souza (2007) proposed a calibration equation (2) for the same soil type and area for the conversion of the apparent dielectric constant (Ka) in water content:

$$\theta = 9.10^{-05} Ka^3 - 0.0038Ka^2 + 0.0577Ka - 0.0484 \quad (2)$$

where:

θ - volumetric soil moisture ($m^3 m^{-3}$);

Ka - apparent dielectric constant.

In order to find the relationship between EC_{TDR} and EC_S , it was used the equation (3), described below by Souza et al. (2006), where the concentration of soil solution should be estimated as a function of volumetric soil water content, which makes possible the relation between the measured electrical conductivity (EC_{TDR}) and the electrical conductivity of the soil solution (EC_S).

$$EC_S = \frac{EC_{TDR} - 0.04}{(2.608\theta - 0.165)\theta} \quad (3)$$

where:

EC_S - Electrical conductivity of soil solution ($dS m^{-1}$);

EC_{TDR} - Electrical conductivity measured by TDR ($dS m^{-1}$);

θ - Volumetric soil water content ($m^3 m^{-3}$).

Using the values obtained from the monitoring of soil water content and electrical conductivity of the soil moisture, it was possible to calculate the storage of soil solution. According to Souza et al. (2006), the equation (4) relates the concentration of KNO_3 and EC_S .

$$C = \left[\frac{EC_S}{0.173} \right]^{0.916} \quad (4)$$

where:

C - Concentration of soil solution ($mmol L^{-1}$).

In order to evaluate the macronutrient quantity in the plants leaf from different treatments leaves were sampled according to the Trani and Raij (1997) recommendations. Newly developed leaves were collected from the flowering to the half of the plant cycle totalizing 25 leaves per treatment. After the third harvest plants were chosen randomly for analysis of roots. The evaluation of the root system distribution was done by digital images generated by the program Spring, version 5.1.2. A grid with cells of $6.25 cm^2$ of area was used

to aid the conversion of the area occupied by the roots analyzed. The experiment ended with 120 days.

5 RESULTS AND DISCUSSION

5.1 Irrigation distribution uniformity

Tests of the irrigation distribution uniformity were performed for both emitters types. The results was higher than 92 %.

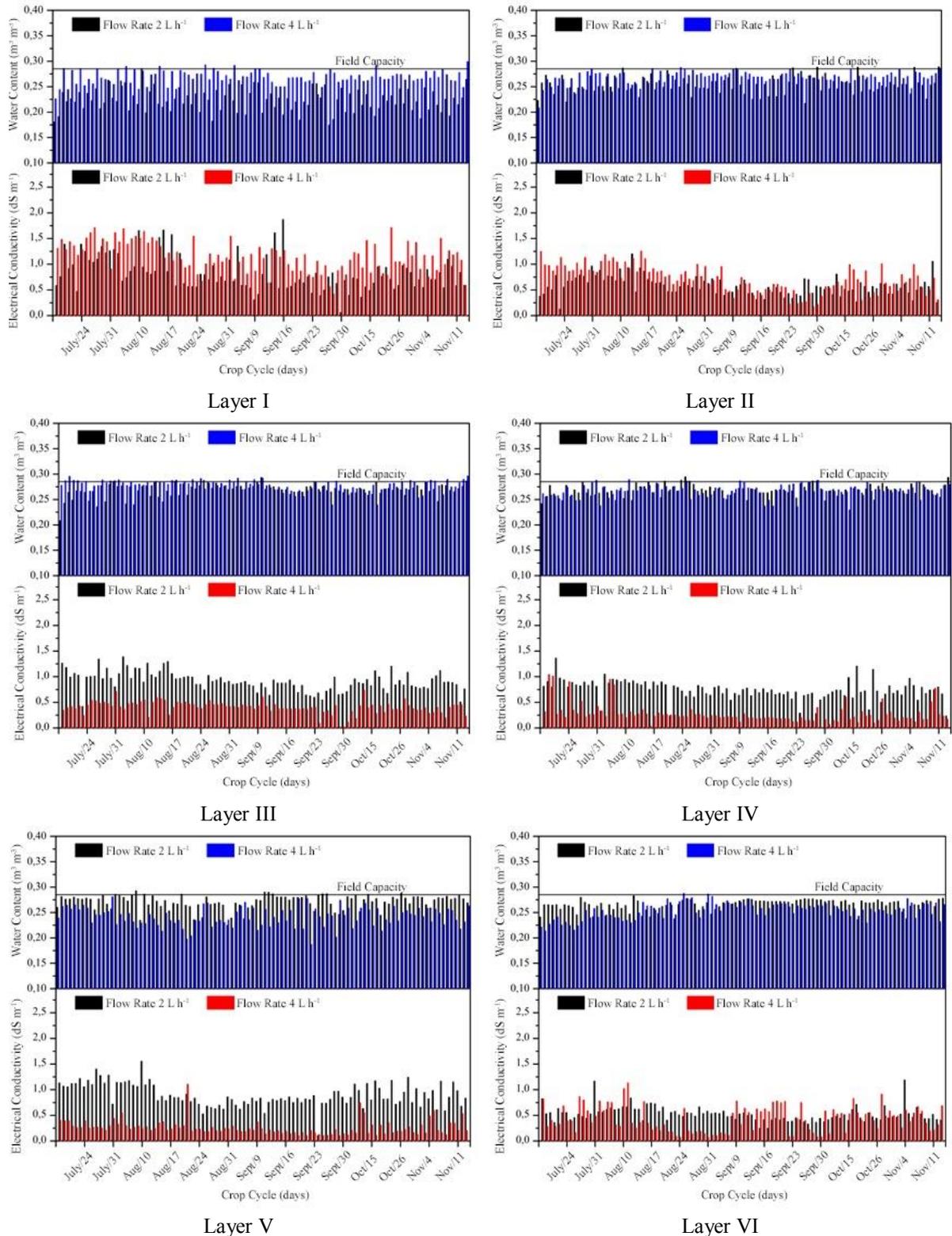
5.2 Distribution of soil solution

From the values measured by TDR probes it was possible to estimate the soil water content and the electrical conductivity of the soil solution. Thus, the distribution of the soil solution was monitored and accounted in layers of 0.1 m width. For the purpose of facilitate the results discussion, the soil profile was divided in six layers with 0.1 m depth each. Those layers were appointed from Layer I, which corresponded to the layer from soil surface to 0.1 m depth, to Layer VI, which corresponded to the layer from 0.5 to 0.6 m depth.

The values of volumetric soil water content and electrical conductivity of the soil solution in layers I, II, III, IV, V and VI measured during the crop cycle are shown in Figure 2, respectively, for treatments of 2 and 4 L h⁻¹.

The soil water content and electrical conductivity of the soil solution in the treatment with flow rate of 4 L h⁻¹ were greater compared to treatment with flow of 2 L h⁻¹ in the layers I and II. In the layers III and IV the values of electrical conductivity were the greatest in treatment with flow rate of 2 L h⁻¹, indicating the existence of leaching of nutrients, since the soil water content values for both treatments in these layers are similar. In the layers V and VI the values of volumetric soil water content from the treatment with 2 L h⁻¹ are greater than the values from the treatment with 4 L h⁻¹, which demonstrate the tendency of water applied through the dripper of 2 L h⁻¹ reach deeper soil layers. The electrical conductivity values for the treatment with 2 L h⁻¹ were also the highest.

Figure 2. Volumetric soil water content and electrical conductivity of the soil solution in different soil layers for flow rates of 2 and 4 L h⁻¹



In an experiment which aimed to study the distribution of water in the soil for drip irrigation, performed in the same area, Lopes, Souza and Santoro (2010) observed larger vertical evolution compared to horizontal one of the wetted bulb for a dripper with flow rate of

2 L h⁻¹ reaching 0.40 m depth. They also observed that the application of a flow rate twice times greater provides superior horizontal development of the wetted bulb, and decreases its vertical development.

The percentage of wetted area depends on factors related to the spacing, drippers flow and soil physical properties. For the latter, Souza et al. (2006) suggests the existence of a strong correlation between wet surface area and the saturated disk for sandy soils. From surface wet area in soil estimates the authors observed an expansion of the wet surface area correlated to the evolution of the saturated disk (small amount of water that accumulates on the soil surface during the process of infiltration) for the different flow rates studied, 2, 4 and 8 L h⁻¹.

The both flows affected the saturated disk which consequently modified the wetted bulb formation. This phenomenon occurs due to the soil infiltration capacity determined by its physical properties that regulates the saturated disk occupied area. In this way, by increase the application rate the infiltration surface area rises proportionally, reaching its apex at 0.0011 m² and 0.0025 m² for 2 and 4 L h⁻¹ flow rates, respectively.

Overall, it was observed that 4 L h⁻¹ treatment was more efficient in distributing the solute in the layer of higher root density. The highest values of electrical conductivity in layers III, IV, V and VI show that the 2 L h⁻¹ flow increases the potential of nutrients loss by leaching for this type of soil (Figure 2). This result supports the importance of knowing the distribution of the soil solution in the soil profile with different combinations of drippers at different flow rates.

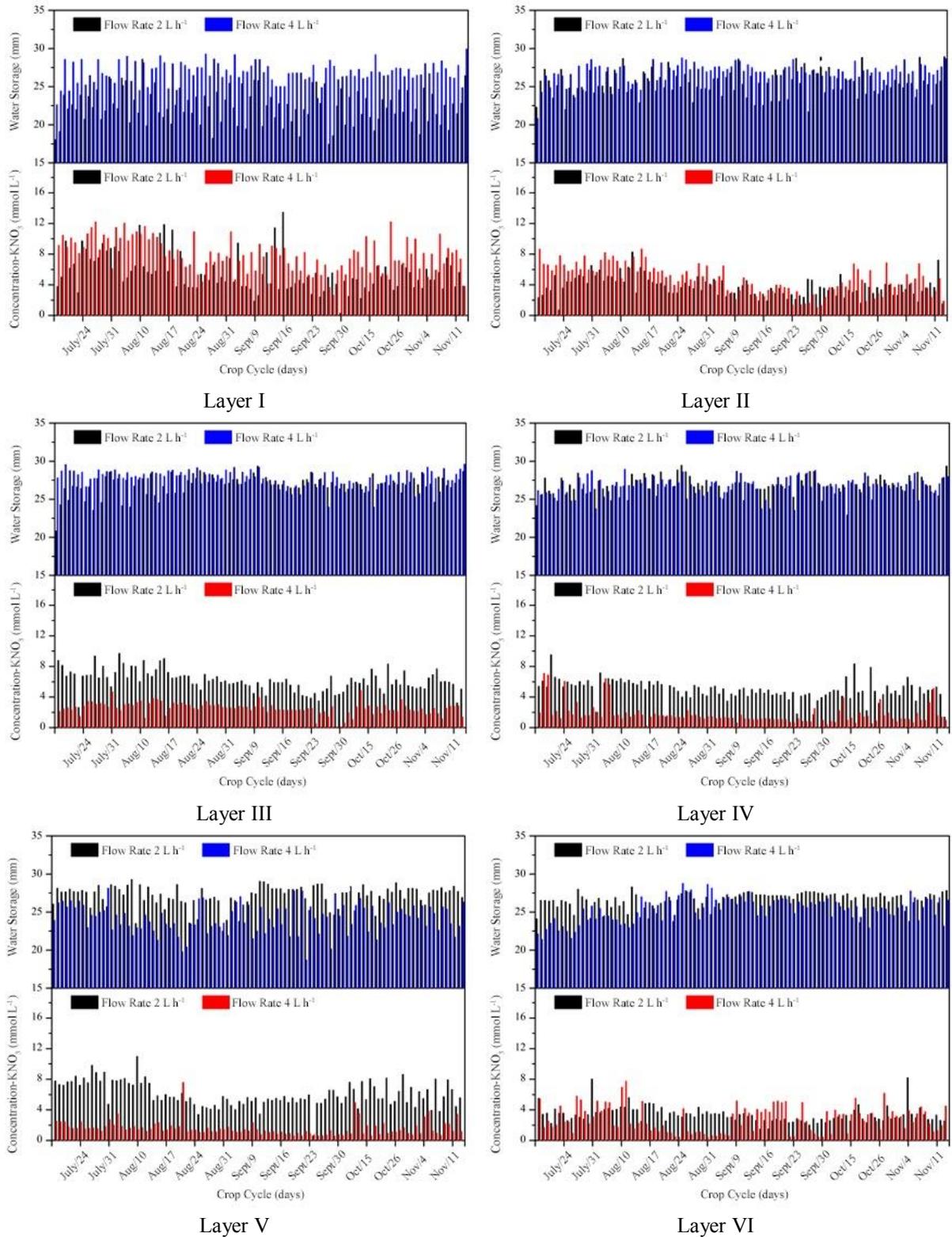
5.3 Soil solution storage

The values of water storage and concentration of soil solution in layers I, II, III, IV, V and VI are shown in Figure 3, respectively, for 2 and 4 L h⁻¹ treatments.

The oscillation of the solution concentration values occurred due to the cation exchange capacity (RIVERA et al., 2008), in other words, since the potassium in the soil solution interacted with the cation exchange complex and was retained in the soil closest to the applied point and the solution fraction which moved to the furthest extreme of wetted bulb had a lower concentration.

Additionally, greater solution storage in layers I and II for 4 L h⁻¹ treatment is observed. For layers III and IV the potassium nitrate solution storage was higher for 2 L h⁻¹ treatment showing that nutrients were available in a previous layer of the soil profile when compared to the results obtained from 4 L h⁻¹ treatment. The storage of water for these layers was similar. According to Blanco and Folegatti (2001), the movement of salts in the soil is slower than water movement and consequently their concentration is distributed more heterogeneously in the soil profile.

Figure 3. Storage of water and soil solution concentration in the different soil layers I for the flow of 2 and 4 L h⁻¹



Lopes, Souza and Santoro (2010) verified in the same type of soil that the solution applied at a flow rate of 4 L h⁻¹ did not reach the layer from 0.30 to 0.40 m depth, showing that the solution was stored in the upper layers of the soil profile. On the other hand, when

applied at flow rate of 2 L h^{-1} , the solution of potassium nitrate reached the layer from 0.4 to 0.5 m depth.

According to the values of storage for both treatments in layers V and VI, it is possible to note that there was more movement of nutrients (through the soil profile) when using the flow of 2 L h^{-1} . This flow rate combined with this type of soil can increase the contamination of water through leaching of nutrients and the cost and the impact of agricultural activity. Table 2 shows the mean values of water and nutrients stored in each soil layer for both treatments. The differences of water and nutrient storage in different layers for different treatments were obtained using linear regression analysis of the values measured throughout the crop cycle.

Table 2. Mean values of water and nutrients in the layers for different treatments

Layers	Storage in soil profile					
	Water (mm)			Nutrient (mmol)		
	2 L h^{-1}	4 L h^{-1}	Difference (%)	2 L h^{-1}	4 L h^{-1}	Difference (%)
I	22.2	26.6	19	98.1	168.9	51
II	25.2	26.5	4	75.9	100.3	25
III	26.5	27.5	3	130.1	55.9	58
IV	26.8	26.9	0	106.5	36.6	68
V	26.9	24.2	11	130.7	30.3	78
VI	26.5	25.3	5	71.2	56.6	23

The mean values of nutrients stored in each layer show for 2 L h^{-1} treatment the nutrients available is placed in layers below the plant roots, even for layers with no water storage difference concluding that application rate was the predominant variable for the nutrients leaching.

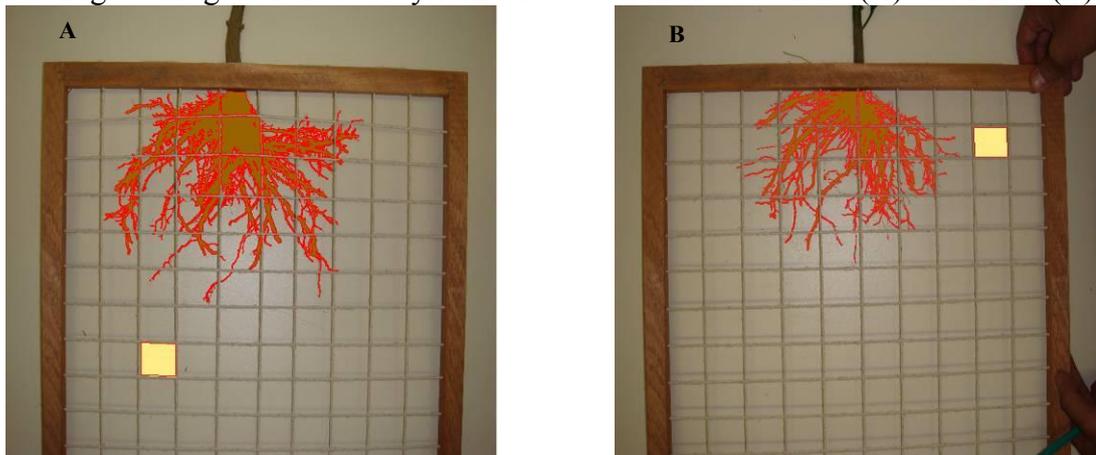
The leaf analysis was performed at the Laboratory of Soil and Plant Analysis, Department for Agricultural Sciences, UNITAU, and its results was compared with suitable levels of nutrients in bell pepper leaves recommended by Trani and Raji (1997) (Table 3).

Table 3. Leaf chemical analysis for treatments of 2 and 4 L h^{-1}

	N	P	K	Ca	Mg	S
	g kg ⁻¹					
Recommended	30-60	3-7	40-60	10-35	3-12	-
2 L h^{-1}	48.3	2.5	50.2	16.5	6.2	3.4
4 L h^{-1}	45.5	2.3	50.7	16.3	6.3	3.4

The nutrients amount of the leaves have appropriate range for both treatments. According to Table 3, there is no difference between the treatments, although, the counting of leaves during the experiment showed that 4 L h^{-1} treatment presented 50 leaves per plant more than 2 L h^{-1} treatment.

Figure 4 presents digital images of roots from plants randomly collected in each treatment at the end of plants cycle. The evaluation of the roots showed that for 4 L h^{-1} treatment the root system reached an area of 69.31 cm^2 while for 2 L h^{-1} treatment the observed area was 45.21 cm^2 . The 4 L h^{-1} treatment provided higher volume of water and nutrients in layer I, the depth where roots were effective, supporting greater development of plants.

Figure 4. Digital images of the root system for the treatments of 4 L h⁻¹ (A) and 2 L h⁻¹(B)

The average yield was 0.19 and 0.27 kg m⁻² for 2 and 4 L h⁻¹ treatments, respectively. These results are statistically different according to the Tukey test (Table 4), which supports the results of nutrients distribution, number of leaves and root development.

Table 4. Crop yield in different treatments in three harvests

Treatments	Beds	harvests (kg m ⁻²)			Mean (kg m ⁻²)
		1	2	3	
4 L h ⁻¹	A	0.18	0.20	0.32	0.27 a
	B	0.20	0.25	0.35	
	C	0.25	0.30	0.35	
2 L h ⁻¹	D	0.10	0.14	0.16	0.19 b
	E	0.15	0.19	0.21	
	F	0.19	0.26	0.30	

Note: same letters indicate that there is no difference between the means

Table 5 shows the values of water and nutrients consumption during the crop cycle, divided into five periods that correspond to subdivisions of fertigation. In order to account the nutrients uptake, the depths of 0.1 m and 0.15 m were used, respectively for the treatments with 2 L h⁻¹ and 4 L h⁻¹, according to the analysis of roots from digital images.

The values of water and nutrients consumption were greater for the treatment with 4 L h⁻¹, which supports the results of production of fruits and number of leaves per plant. This result is related to the development of plants roots in each treatment, since the availability of soil solution varied for the different flow rates tested. As previously demonstrated, it was observed a correlation between the distribution of soil solution and higher water consumption by plants in the treatment with 4 L h⁻¹, which allowed greater nutrient uptake. According to Souza et al. (2007) a hypothesis for this phenomenon may be based on the fact that the ions follow the advancing front of water and it moves slightly ahead of salts to the roots.

Table 5. Values of water and nutrient uptake

Days after transplanting*	Uptake of K ⁺ and NO ₃ ⁻ (mg plant ⁻¹ day ⁻¹)		Water consumption (L plant ⁻¹ day ⁻¹)	
	2 L h ⁻¹	4 L h ⁻¹	2 L h ⁻¹	4 L h ⁻¹
15-28	149	170	0.72	0.99
28-42	147	168	0.58	0.81
42-56	141	165	0.54	0.66
56-70	128	160	0.43	0.64
70-120	91	79	0.38	0.34

*Days after transplanting above correspond to the same period of fertigation

The results of distribution of soil solution in the soil profile allowed defining criteria for the management of irrigation and fertigation. For this type of soil, the drip of 4 L h⁻¹ was more efficient at distributing water and nutrients where there was a greater volume of roots, which increased the crop yield and decreased the time of operation of the irrigation system. The results can help the practice of fertigation, reducing the waste of fertilizers and the relation cost/benefit of this activity.

The monitoring of the soil solution concentration through its electrical conductivity in fertigation can lead to rapid decision making, which allows modifying the number of fertigation parcels and preventing the movement of nutrients to layers where there is no activity of roots

From the methodology used to study the characteristics of the storage of soil solution applied through fertigation, it was possible to verify that the dripper flow directly influences the availability of water and nutrients to plants. In that way, the knowledge of the water flow of emitters combined with the type of soil is important for the management of this practice, since it was noted a relationship of storage and culture production.

6 CONCLUSIONS

It is possible to conclude that for flow rate of 2 L h⁻¹ there was a tendency of nutrients loss by leaching, which increases the possibility of groundwater contamination, so this kind of dripper is not recommended for this soil type or it is necessary to adopt frequent irrigations.

The emitter with flow rate of 4 L h⁻¹ resulted greater storage and distribution of water and nutrients within the radicular zone of the plants, which improved the opportunity time to uptake and, consequently, the crop yield.

7 ACKNOWLEDGEMENT

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