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Irrigation of radish cultivars in the region of Viçosa, Minas Gerais, Brazil[1]

Irrigação de cultivares de rabanete na região de Viçosa-MG

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ABSTRACT - The region of Viçosa in Brazil stands out for vegetable production. For success in this activity, the correct choice of cultivar with the correctly applied irrigation are necessary. As such, the aim of this study was to evaluate the agronomic performance of radish cultivars submitted to different irrigation depths. The radish crop was grown in a protected environment over three cycles, for periods of 38 to 40 days. The experimental design was of randomised complete blocks in split plots with five replications, comprising five irrigation depths (50, 75, 100, 125 and 150% of crop evapotranspiration-ETc) in the plots, with three radish cultivars in the subplots. (Hybrid no 25 - Sakata, Crunchy Royale - Sakata and Vip Crimson - Feltrin). A drip irrigation system was used, with the ETc obtained by means of the GESAI method. The following parameters were evaluated: root depth, plant water potential, leaf temperature, leaf weight, root diameter and length, number and weight of commercial and non-commercial roots, and water use efficiency. Since the experimental soil presented high water retention and availability, greater than 1.8 mm cm^{-1}, an irrigation depth of 50% ETc is recommended, provided that the soil is at field capacity at the start of the cycle. When considering productivity and quality, the Crunchy Royale cultivar is recommended when cultivating the radish in Viçosa, Brazil.

Key words: Protected cultivation. Horticulture. Irrigation management. *Raphanus sativus*.

RESUMO - A região de Viçosa-MG se destaca na produção de hortaliças. Para alcançar sucesso nesta atividade, é necessária a escolha correta de cultivares e aplicação correta da irrigação. Diante disto objetivou-se avaliar o desempenho agronômico de cultivares de rabanete submetidas a diferentes lâminas de irrigação. A cultura do rabanete foi cultivada em ambiente protegido durante três ciclos, com períodos de 38 a 40 dias. O delineamento experimental foi em blocos ao acaso em esquema de parcelas subdivididas, com cinco repetições, tendo nas parcelas cinco lâminas de irrigação (50; 75; 100; 125 e 150% da evapotranspiração da cultura-ETc) e nas subparcelas três cultivares de rabanete (Híbrido nº 25 - Sakata, Crunchy Royale - Sakata e Vip Crimson - Feltrin). O sistema de irrigação foi o gotejamento e a ETc obtida por meio do método GESAI. Os parâmetros avaliados foram: profundidade de raízes, potencial de água da planta, temperatura foliar, massa de folhas, diâmetro e comprimento de raiz, número e massa de raízes comerciais e não-comerciais e eficiência do uso da água. Sendo o solo do presente experimento de alta disponibilidade de retenção de água, superior à 1,8 mm cm^{-1}, recomenda-se irrigar com lâmina de 50% da ETc, desde que, no início do ciclo o solo esteja na capacidade de campo. Considerando produtividade e qualidade, a cultivar Crunchy Royale deve ser recomendada no cultivo de rabanete na região de Viçosa-MG.

Palavras-chave: Cultivo protegido. Horticultura. Manejo da irrigação. *Raphanus sativus*.

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INTRODUCTION

The consumption of vegetables is currently on the increase due to greater awareness by the population in search of a healthy diet, rich in diversity. Among vegetables, the radish (*Raphanus sativus* L.) deserves highlighting for being a good source of vitamin A, complex B and C, calcium, phosphorus, potassium, magnesium, sodium and iron (VIDIGAL; PEDROSA, 2007). The crop has been cultivated for over three thousand years and is of European origin (SOUZA *et al*., 2016). The radish belongs to family Brassicaceae, and has roots of a reddish or white colour, which are globular or cylindrical, developing best in regions of mild climate with temperatures between 13 and 20 ºC.

The radish, despite being a minor crop in terms of planted area, has been cultivated in large numbers on small properties in the green belts of metropolitan regions (CUNHA *et al*., 2019). However, some problems need to be resolved, including a reduction in the seasonality of supply, the supply of better-quality products and an increase in the sustainability of the crop with the lowest impact on the environment. As such, more scientific research on the radish is necessary to reduce or even eliminate these shortcomings in the productive sector.

Choosing a variety of radish that is best suited to the climate and type of soil in a region allows for increases in crop productivity. Many farmers, unaware of this fact, insist on using the same cultivars used by their ancestors, making cultivation unproductive, and discouraging the activity. There is, therefore, a need to study the adaptation of cultivars to the climate of a region, considering its adaptation to the type of soil in the region, susceptibility to pests and diseases caused by fungi, bacteria, viruses and nematodes, and physiological disorders.

In addition to choosing the appropriate variety, success in vegetable production depends on the use of irrigation to fully supply or supplement the water requirements of the crop. The use of irrigation systems in horticulture is justified by the fact that irregularity in the rainfall regime can restrict agricultural development, since, even during the rainy season, periods of water deficit can be seen. Evapotranspiration in vegetables generally exceeds rainfall, so an adequate artificial distribution of water through irrigation is a way of guaranteeing planned production, without the lack of rainfall altering previously established indices of crop productivity or yield. (CUNHA *et al*., 2013).

In Brazil, irrigated agriculture is the largest consumer of water among the various human activities. In most irrigated areas, the lack of rational water management results in excessive application, wasting water and energy (SOUZA *et al*., 2013) and, in the radish, leading to reduced productivity and quality (LIMA *et al*., 2015; SILVA *et al*., 2012). Studies of the radish carried out in Botucatu, São Paulo, at different irrigation depths, indicate that replenishing 100% of the crop water requirement is unnecessary, and that the recommended value is from 60 to 80% (KLAR *et al*., 2015). Slomp *et al*. (2011) found in Erechim, Rio Grande do Sul, that an irrigation depth of 40% was enough to reach production levels in the radish equal to those at an irrigation depth of 100% evapotranspiration. On the other hand, Bregonci *et al*. (2008) found that water stress reduces bulb diameter and fresh root matter in the Vip Crimson radish, decreasing end production by 50%. Such different results justify studies on adjusting the parameters related to irrigation management in the radish.

Given the above, the aim of this study was to determine the optimal irrigation depth, and identify the best radish cultivars for the region of Viçosa, in the state of Minas Gerais.

MATERIAL AND METHODS

The present study was carried out in the Research Area of the Federal University of Viçosa (UFV), in Viçosa, MG. The experimental area is located at 20º45’ S and 42º52’ W, at an altitude of 648 m.

The soil of the area was classified as a Red-Yellow Latosol, with a sandy-clay loam texture at a depth of 0 to 15 cm and a sandy-clay texture from 15 to 30 cm, as per Empresa Brasileira de Pesquisa Agropecuária (2013). Before setting up the experiment, soil samples were collected from the 0-15 and 15-30 cm layers for a physical and water analysis of the soil (Table 1), carried out at the Soil Physics Laboratory of UFV. A particle-size analysis of the soil was made using the densimeter method (EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA, 2011). Soil densities were obtained as per the recommendations of Empresa Brasileira de Pesquisa Agropecuária (2011). The water content equal to field capacity was obtained using the basin method (BERNARDO *et al*., 2019), and the permanent wilting points obtained by means of the soil water retention curves using a Richards extractor, where a pressure of 15 bar was considered equal to the wilting point.

The chemical attributes of the soil were determined before planting the first crop, and carried out at the Soil Chemical Analysis Laboratory of UFV (Table 2). There were no fertiliser recommendations, as nutrient levels were already suitable for the crop (VIDIGAL; PEDROSA, 2007).

Table 1 - Physical and water parameters of the soil at the experimental site at different depths

Depth	FC^1	PWP^2	Ds^3	Clay	Silt	Sand	Textural Classification
cm	--------- $cm^3\ cm^{-3}$ ---------		$g\ cm^{-3}$	--------------------- % ---------------------			
0-15	0.4474	0.2656	1.24	32	5	63	Sandy-clay loam
15-30	0.4482	0.2739	1.27	37	12	51	Sandy clay

[1]Moisture at field capacity by the basin method; [2]Permanent wilting point; [3]Soil density

Table 2 - Chemical parameters of the soil at the experimental site

Depth	pH	P	K	Ca^{2+}	Mg^{2+}	Al^{3+}	H+Al	SB	t	T	V	m	Prem
cm	H_2O	-- $mg\ dm^{-3}$ ---		---------- $cmol_c\ dm^{-3}$ ----------				------------------- % --------------------					$mg\ L^{-1}$
0-15	6.2	555	216	6.5	1.6	0.0	3.0	8.7	8.7	11.7	74.2	0.0	42.9
15-30	6.3	422	295	6.3	1.5	0.1	1.0	8.5	8.6	9.5	89.5	1.2	42.4

Available P and K extracted with Mehlich I; Exchangeable Ca, Mg and Al extracted with KCl 1 mol L^{-1}; Potential acidity at pH 7.0 extracted with calcium acetate 0.5 mol L^{-1}

The radish crop was grown in a protected environment over three cycles for periods of 38 days (11 January 2016 to 17 February 2016), 40 days (1 March 2016 to 9 April 2016) and 38 days (12 April 2016 to 19 May2016). The protected environment was a fully enclosed, arched greenhouse, covered in clear plastic film, with a total area of 182.4 m² (7.6 m wide and 24.0 m long) and an indoor height of 2.2 m. The sides were lined with polyethylene screen (25 mesh and 25% shading).

The experiments were conducted in a randomised block design (RBD), in a split-plot scheme of five irrigation depths in the plots and three cultivars in the subplots, with five replications. The sample units consisted of plots, 0.8 m wide and 1.0 m long, as per Castro *et al*. (2016), with a total area of 0.8 m², comprising 40 plants per plot.

The radish cultivars used were Hybrid no 25 (marketed by the Sakata company); Crunchy Royale (Sakata) and Vip Crimson (Feltrin). Each of these cultivars has round, red roots, and are materials with a high resistance to splitting and isoporation.

The irrigation depths used were to replace 50, 75, 100, 125 and 150% of crop evapotranspiration (ETc). The irrigation system, operated by gravity, was by drip. The drip tapes (model Amandi, brand Petroisa) were 16 mm in diameter. Spacing between the drip tapes was 40 cm, which allowed for the irrigation of two rows of plants per lateral line. The emitters (drippers) operated at a working pressure of 100 kPa (~10.2 mH_2O), applying a mean flow rate of 1.2 L h^{-1}, and were spaced 20 cm apart.

Direct sowing was chosen, at a spacing of 0.2 m between rows and 0.05 m between plants. Thinning was carried out 15 days after sowing (DAS), keeping the spacing of 0.1 m between plants.

To control the weeds, manual weeding was carried out weekly. There was no incidence of pests during the first or second crop, however, during the third crop, the presence of green aphid (Myzus persicae) early in the crop required the use of insecticide. The insecticide used was Keshet 25 EC (Deltamethrin 25 g L^{-1}), from Milenia Agrociências S.A.

The irrigation frequency (IF) was fixed for each stage of the crop, with an IF for the first stage of two days and for the later stages of three days. The actual irrigation requirement in the treatment including water replacement at 100% ETc was defined to represent the actual water requirement of the crops as a function of the climate, the irrigation system, the plant and the soil (Equation 1).

$$AIR_{LOC} = \sum_{day1}^{i} ET_0\, K_C\, K_S\, K_L - P_E \quad (1)$$

where: AIR_{LOC} = actual irrigation requirement in localised systems (mm); ETo = reference evapotranspiration (mm d^{-1}); K_C = crop coefficient (dimensionless); K_S = soil moisture coefficient (dimensionless); K_L = localised coefficient (dimensionless); and P_E = effective precipitation during the period (mm).

Effective precipitation is that used directly by the crop (BERNARDO *et al*., 2019), and as the experiment was conducted in a greenhouse, was equal to zero throughout the experimental period.

The Penman-Monteith-FAO56 methodology (ALLEN *et al*., 1998) was used to estimate the reference evapotranspiration (ET_0) (Figure 1A). Daily weather data to estimate the ET_0 were collected from the E4000 automatic weather station installed inside the greenhouse. The following parameters were collected: air temperature (°C) (Figure 1B), relative humidity (%) (Figure 1B), global solar radiation (MJ m^{-2}) (Figure 1A), and wind speed at a height of 2 m (assumed value of 0.02 m s^{-1}).

The applied crop coefficients (K_C) were 0.7 and 1.0 for stages I and III respectively. For stage II, linear weighting was used between the end of stage I and the beginning of stage III. Stages I and II lasted 10 days each, and stage III from day 21 until harvesting. The soil moisture coefficient (K_S) and localised coefficient (K_L) were calculated as per Bernardo *et al*. (2019).

The value for AIR_{LOC} was corrected for irrigation efficiency, defining the total irrigation requirement for localised systems (TIR_{LOC}). In these systems, application efficiency is approximately 100%, with irrigation efficiency equal to the distribution efficiency. Distribution uniformity was obtained with the uniformity coefficient (UC), using the methodology proposed by Keller and Karmeli (1975).

The variables used to evaluate the treatments in the radish crop were:

- Root depth (cm): obtained by opening a trench at the side of the plants using a hoe. After removing the deepest roots possible, any soil adhered to the roots was removed, and the distance between the collar and the end of the roots measured using a 0.1-cm rule. This analysis was carried out on four plants, previously identified at the beginning of each cycle.

- Plant water potential (kPa): Scholander pump methodology was used (SCHOLANDER *et al*., 1965). The measurements were taken between 03:00 and 06:00, when the water potential in the plant was at maximum. However, when under water stress there is no replenishment of the potential, demonstrating a certain level of water stress caused by the lack of water in the soil. As nitrogen gas is dry, a moist paper placed inside the chamber was used to take the measurement. The analysis was carried out on two leaves, obtained from two different plants.

- Leaf temperature (°C): taken with a digital infrared thermometer. Four plants per plot were used. The evaluations were made between 11:30 and 13:30, i.e. during the hours of greatest insolation, so that any variations over time would have no effect. No measurements were taken if there were clouds present.

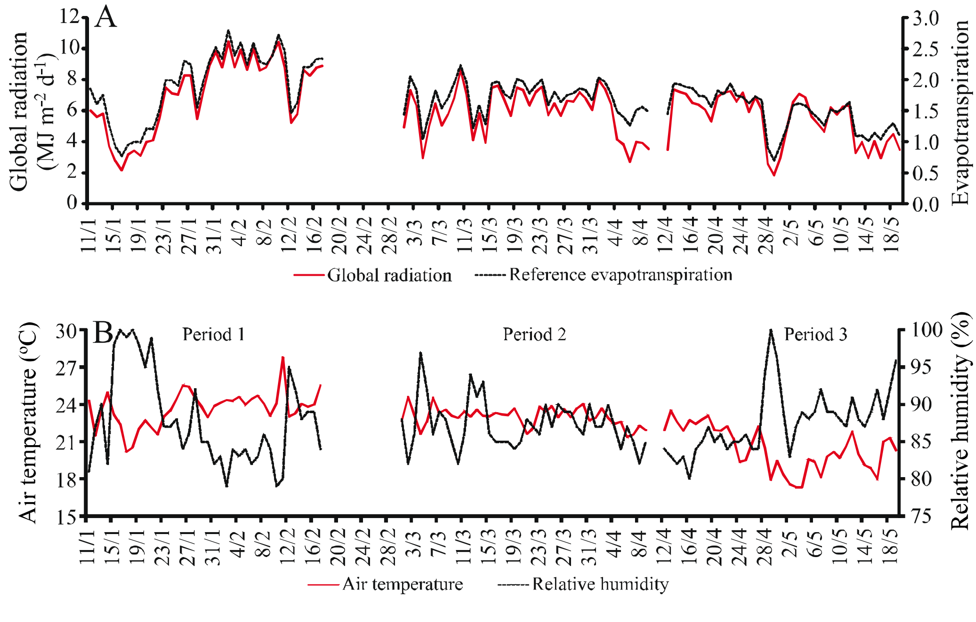
- Mean leaf weight for each plant (g): obtained by removing the shoots of the four previously identified plants and measuring their respective weights.

- Tuberous-root diameter (cm): obtained from the mean of two measurements taken perpendicular to the length of the tuberous root, i.e. the transverse root measurement. For this measurement a calliper was used.

- Tuberous-root length (cm): measured between the leaf insertion and the start of the root, i.e. the longitudinal root measurement. A 0.1-cm rule was used.

- Number of non-commercial roots (unit m^{-2}): a tuberous root was considered non-commercial if it presented

Figure 1 - Daily variation in (A) global radiation (MJ m-2 d-1), reference evapotranspiration (mm d-1) (B) temperature (ºC) and relative humidity (%) for the three growing periods of the radish



splits, surface defects, an irregular shape, or other defect that prevented its being marketed.

- Number of commercial roots (unit m^{-2}): roots that presented criteria favourable for marketing.

- Weight of non-commercial tuberous roots (Kg m^{-2}): the weight of all tuberous roots classified as non-commercial.

- Weight of commercial tuberous root (Kg m^{-2}): the weight of all tuberous roots classified as commercial.

- Water use efficiency (Kg m^{-3}): obtained from the ratio between the commercial productivity of the vegetables in a plot and the amount of water applied.

The data were subjected to analysis of variance and regression analysis. The mean values were compared by Tukey's test at 5% probability. For the quantitative factors, linear and quadratic models were tested. Model selection was based on the significance of the regression coefficients using the t-test at 5% probability, on the coefficient of determination (R^2) and on the biological phenomenon. To perform the statistical analysis, the Assistat 7.7 (SILVA; AZEVEDO, 2016) and SigmaPlot 11.0 (SYSTAT SOFTWARE, 2011) statistical software was used.

RESULTS AND DISCUSSION

It was found that the radish presented a greater irrigation requirement during the first crop, followed by the second and third crops (Table 3). This result is due to the higher evapotranspirative demand that occurred during the first crops (Figure 1). According to the uniformity coefficient, the irrigation system showed an efficiency of 88.3, 89.9 and 97.0% during cycles 1, 2 and 3 respectively.

There was interaction between cultivar and irrigation depth for root depth in cycle 3 (Table 4). It can also be seen from Table 4, that in the treatment with an irrigation depth of 125% ETc, the Vip Crimson cultivar had the greatest root depth; for all other irrigation depths, however, there was no difference. In cycles 1 and 2, an isolated effect from the cultivars was found, where Hybrid 25 from Sakata achieved greater root depths than Crunchy Royale (Table 4). The irrigation depth did not affect root length (Figure 2), agreeing with Bregonci *et al*. (2008). Those authors applied water stress at different stages of the radish cycle in Alegre, Espírito Santo, and found a reduction in the weight and diameter of the tuberous roots, especially when stress was applied during stage II; however, root system depth was not affected by water stress.

There was an interaction between cultivar and irrigation depth for water potential in the radish in cycle 2. The cultivars did not differ at the greatest irrigation depths for this parameter (Table 4). In cycle 2, it was found (Figure 2) that irrigation depth had a positive linear effect on water potential in each of the radish varieties. In cycles 1 and 3, the same effect was obtained (Figure 3). This increase in the modulus of the plant water potential shows that the radish suffered greater water stress in treatments that received smaller irrigation depths. There is a high correlation between plant water potential and photosynthesis, since, in stressed plants, a reduction in potential causes a reduction in the enzyme activity required for the process of CO_2 fixation (VIEIRA *et al*., 2014).

An isolated effect from irrigation was seen on leaf temperature in the radish in cycles 1 and 2, with the reduction in irrigation depth causing an increase in leaf temperature (Figure 3). When the plant water potential was reduced in the treatments that received a smaller irrigation depth (Figures 2 and 3), the water content of the plant was also reduced, explaining the increase in leaf temperature caused by stomatal closure, and the latent-heat loss caused by vaporisation of the water.

According to Vieira *et al*. (2014), in order to use leaf temperature in irrigation management as an indicator

Table 3 - Actual and total irrigation requirement applied in each treatment and growing period

Period	Parameter	Irrigation depth (% ETc)				
		50	75	100	125	150
1	Actual irrigation requirement (mm)	29.17	43.75	58.33	72.92	87.50
	Total irrigation requirement (mm)	33.03	49.55	66.06	82.58	99.10
2	Actual irrigation requirement (mm)	18.95	28.42	37.89	47.37	56.84
	Total irrigation requirement (mm)	21.08	31.61	42.15	52.69	63.23
3	Actual irrigation requirement (mm)	19.13	28.70	38.26	47.83	57.39
	Total irrigation requirement (mm)	19.72	29.58	39.44	49.31	59.17

Table 4 - Mean values for root depth (cm), plant water potential (kPa), leaf temperature (°C), leaf weight per plant (g), tuberous root diameter (cm) and length (cm), number (unit m^{-2}) and weight (Kg m^{-2}) of non-commercial tuberous roots, number (unit m^{-2}) and weight (Kg m^{-2}) of commercial tuberous roots, and water use efficiency (Kg m^{-3}) as a function of different cultivars (CR) and irrigation depths (ID) in three radish crops

Factor	Cycle	F-Test			Irrigation depth	Hybrid 25 Sakata	Crunchy Royale	Vip Crimson
		ID	CR	ID*CR				
Root depth (cm)	1	2.236^{ns}	18.73**	1.14^{ns}		19.48 a	17.24 b	19.74 a
	2	1.240^{ns}	9.989**	1.066^{ns}		11.83 a	10.19 b	10.85 b
					50% ETc	11.32 a	11.61 a	11.42 a
					75% ETc	11.49 a	11.35 a	11.26 a
	3	0.404^{ns}	6.576**	2.423*	100% ETc	11.73 a	11.65 a	9.93 a
					125% ETc	12.07 a	12.62 a	9.10 b
					150% ETc	12.68 a	11.33 a	11.66 a
Plant water potential (kPa)	1	31.01**	0.143^{ns}	0.557^{ns}			ŷ = -273	
					50% ETc	-210 b	-225 b	-265 a
					75% ETc	-175 b	-250 a	-180 b
	2	10.54**	6.535**	6.844**	100% ETc	-200 a	-190 a	-155 b
					125% ETc	-190 a	-205 a	-205 a
					150% ETc	-115 a	-135 a	-145 a
	3	46.81**	0.394^{ns}	1.767^{ns}			ŷ = -212	
Leaf temperature (°C)	1	4.040*	0.737^{ns}	0.494^{ns}			ŷ = 27.92	
	2	9.267**	0.214^{ns}	1.095^{ns}			ŷ = 24.30	
	3	1.379^{ns}	0.876^{ns}	0.891^{ns}			ŷ = 24.75	
Leaf weight per plant (g)	1	1.047^{ns}	44.17**	0.518^{ns}		68.21 a	26.17 c	56.86 b
	2	7.282**	107.2**	1.427^{ns}		57.77 a	23.15 c	46.14 b
					50% ETc	47.71 a	23.25 b	39.28 a
					75% ETc	46.42 a	22.70 b	32.59 b
	3	0.682^{ns}	46.80**	4.086**	100% ETc	55.04 a	23.37 b	26.06 b
					125% ETc	47.44 a	20.56 b	30.73 b
					150% ETc	31.61 a	28.38 a	39.00 a
Tuberous root diameter (cm)	1	0.326^{ns}	1.914^{ns}	1.057^{ns}			ŷ = 4.38	
	2	4.775**	28.04**	1.477^{ns}		2.84 b	3.98 a	3.73 a
	3	3.590*	2.953^{ns}	1.780^{ns}			ŷ = 4.23	
Tuberous length (cm)	1	0.823^{ns}	21.25**	0.708^{ns}		9.26 b	8.27 c	10.07 a
	2	5.550**	22.08**	0.831^{ns}		5.07 b	6.29 a	6.41 a
	3	0.815^{ns}	0.342^{ns}	0.579^{ns}			ŷ = 6.28	
Number of non-commercial tuberous roots (unit m^{-2})	1	1.122^{ns}	45.75**	0.564^{ns}		17.30 a	11.05 b	4.05 c
	2	1.033^{ns}	89.33**	0.832^{ns}		26.10 a	11.10 b	3.85 c
	3	1.434^{ns}	119.9**	1.097^{ns}		17.45 a	7.50 b	2.30 c
Weight of non-commercial tuberous roots (Kg m^{-2})	1	0.811^{ns}	37.73**	1.190^{ns}		0.883 a	0.814 a	0.176 b
	2	0.716^{ns}	27.04**	0.483^{ns}		0.379 a	0.466 a	0.103 b
	3	1.067^{ns}	102.6**	0.498^{ns}		0.633 a	0.262 b	0.051 c
Number of commercial tuberous roots (unit m^{-2})	1	1.353^{ns}	136.4**	0.548^{ns}		20.55 b	33.85 a	11.00 c
	2	1.887^{ns}	140.0**	0.936^{ns}		18.25 b	35.65 a	7.80 c
	3	0.930^{ns}	213.8**	1.034^{ns}		23.00 b	37.75 a	9.35 c
Weight of commercial tuberous roots (Kg m^{-2})	1	0.240^{ns}	96.39**	1.397^{ns}		1.598 b	2.506 a	0.946 c
	2	3.282*	189.7**	1.048^{ns}		0.790 b	1.955 a	0.412 c
	3	1.530^{ns}	116.7**	0.989^{ns}		1.188 b	1.972 a	0.441 c

Continuation Table 4

					50% ETc	57.56 b	79.22 a	29.29 c
					75% ETc	31.09 b	59.39 a	26.68 b
	1	26.08**	90.39**	4.036**	100% ETc	27.97 b	44.56 a	17.99 b
					125% ETc	23.56 b	36.95 a	8.38 c
					150% ETc	18.30 ab	26.62 a	11.99 b
					50% ETc	34.25 b	90.59 a	18.35 c
					75% ETc	22.75 b	59.50 a	8.52 c
Water use efficiency (Kg m^{-3})	2	13.41**	198.9**	6.459**	100% ETc	25.30 b	60.35 a	8.76 c
					125% ETc	17.44 b	39.63 a	11.07 b
					150% ETc	15.29 b	38.72 a	10.81 b
					50% ETc	67.70 b	113.84 a	25.12 c
					75% ETc	40.33 b	82.25 a	17.12 c
	3	45.72**	85.87**	5.015**	100% ETc	29.17 ab	48.84 a	8.87 b
					125% ETc	24.18 ab	44.05 a	11.87 b
					150% ETc	26.89 ab	32.89 a	7.84b

*p<0.05; **p<0.01; ^{ns}p>0.05. Mean values followed by the same letter on a line do not differ by Tukey's test (p<0.05)

of the water conditions of the crop, it is necessary to establish indices of crop water stress that would determine when and which irrigation depths to apply. However, there are several drawbacks to using this method, as different climate conditions to those during the experimental period may generate a different crop response to water availability. Since in the present research readings were taken on sunny days, and always under similar conditions, the established indices would be reliable. As such, it would not be possible to estimate irrigation depths on cloudy days, unless methods of correction were employed.

There was an interaction between cultivar and irrigation depth for leaf weight per radish plant in cycle 3, where the Hybrid 25 Sakata presented greater values than the other cultivars (Table 4). Cycles 1 and 2 showed an isolated effect from the cultivars, in which Hybrid 25 Sakata presented greater mean values than the Vip Crimson cultivar, which in turn had a greater leaf weight per plant than the Crunchy Royale cultivar (Table 4).

No isolated effect from irrigation was seen on leaf weight per radish plant in cycle 1. It was also not possible to fit any regression equation for leaf weight per plant as a function of irrigation depth (Figure 2). This result agrees with that of Bregonci *et al*. (2008), who used different values for soil water pressure in the irrigation management of the Vip Crimson radish in the city of Alegre, Espírito Santo. In cycle 2, there was an isolated effect from irrigation depth on leaf weight per radish plant. It can be seen from Figure 3 that irrigation depth caused an increasing linear effect on leaf weight per plant in cycle 2. Carmichael *et al*. (2012), evaluating the radish in Swaziland, also found an increase in the shoots in treatments with a greater soil water content.

There was an isolated effect from the cultivars on tuberous root diameter in the radish in cycle 2. The Crunchy Royale and Vip Crimson cultivars did not differ from each other, and showed higher values than the Hybrid 25 Sakata (Table 4). There was also an isolated effect from irrigation depth on root diameter in cycles 2 and 3. It can be seen from Figure 3 that irrigation depth had an increasing linear effect on tuberous-root diameter in cycle 2, corroborating the results of Abdel (2015) in Germany, working with different radish cultivars submitted to different levels of irrigation.

In cycles 1 and 2, there was an isolated effect from the cultivars on root length in the radish. It can be seen in Table 4, cycle 1, that the Vip Crimson cultivar presented a greater root length than Hybrid 25 Sakata, which in turn had a greater value compared to the Crunchy Royale cultivar. In cycle 2, the Crunchy Royale and Vip Crimson cultivars did not differ from each other, and showed higher mean values than Hybrid 25 Sakata. In the analysis of variance, there was an isolated effect from irrigation depth on tuberous-root length in cycle 2, which had an increasing linear effect (Figure 3).

The number and weight of non-commercial tuberous roots in the radish in all the cycles under evaluation were affected by the individual cultivars. For the number of non-commercial tuberous roots, Table 4 shows the same behaviour in all cycles, where Hybrid 25 Sakata had higher values than Crunchy Royale, which in turn had higher values than VIP Crimson. For the weight of non-commercial tuberous roots, in cycles 1 and 2, Hybrid 25 Sakata did not differ from Crunchy Royale, and both showed higher values than Vip Crimson. In cycle 3, Hybrid 25 Sakata showed higher values compared to Crunchy Royale, which in turn showed higher values than Vip Crimson. The results suggest that in the Vip Crimson cultivar, the loss of commercial tuberous roots is smaller.

Irrigation did not affect the number or weight of non-commercial tuberous roots in the radish. It is possible that this result is based on Sanders (1997) and Silva *et al*. (2017), who report that one cause of non-commercial radishes is splitting; however, the best way of preventing the roots from splitting is to maintain a uniform supply of water, which can be achieved when they are grown in a protected environment, exactly as in the present research. Silva *et al*. (2012), testing radish tolerance to saturated soil in Mossoró, Rio Grande do Norte, found that radish was sensitive to water saturation, especially when stress occurred during the early stages of plant development, and concluded that the root system of the radish crop is more sensitive to saturation than are the shoots.

There was an isolated effect from the cultivars on the number and weight of commercial tuberous roots in the radish in each cycle under evaluation. For each parameter, the Crunchy Royale radish presented higher values compared to Hybrid 25 Sakata, which in turn presented higher values than Vip Crimson (Table 4). Among the cultivars evaluated in the present research, Crunchy

Figure 2 - Estimated root depth (RD) in cycle 3, plant water potential (PWP) in cycle 2, leaf weight per plant (LWP) in cycle 3, and water use efficiency (WUE) in cycles 1, 2 and 3 as a function of irrigation depth, in radish cultivars

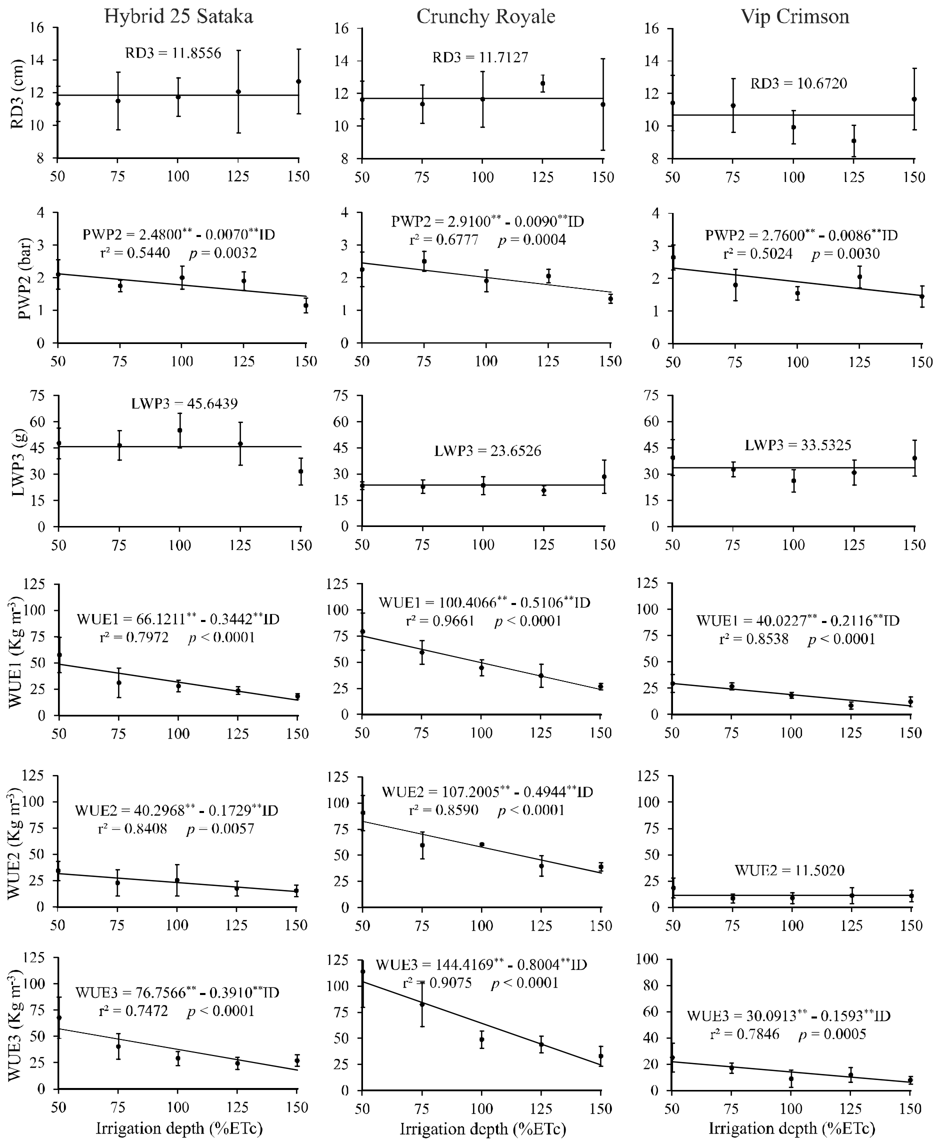
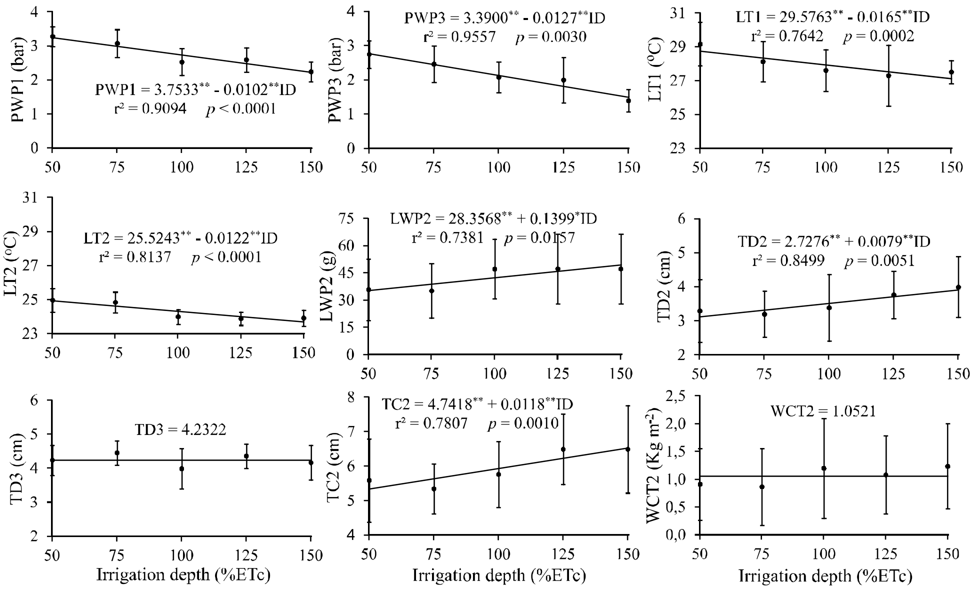


Figure 3 - Estimated plant water potential (PWP) in cycles 1 and 3, leaf temperature (LT) in cycles 1 and 2, leaf weight per plant (LWP) in cycle 2, tuberous-root diameter (TD) in cycles 2 and 3, tuberous root length (TL) in cycle 2, and weight of commercial tuberous roots (WCT) in cycle 2, in the radish as a function of irrigation depth. Viçosa, MG. DEA-UFV, 2016



Royale should be the preferred radish for cultivation in Viçosa, MG, due to greater productivity and better-quality tuberous roots. Mean productivity for Crunchy Royale in the three cycles was 2,144 kg m^{-2} commercial tuberous roots, similar to the 1,943 kg m^{-2} obtained by Lima *et al.* (2015), who produced the same radish cultivar in a protected environment under irrigation, in Lavras, MG.

There was an isolated effect from irrigation on the weight of commercial tuberous roots in the radish in cycle 2, however, it was not possible to fit a regression equation (Figure 3). No effect from irrigation depth was found in cycle 2 for the number of commercial tuberous roots or in cycles 1 and 3 for the number or weight of commercial tuberous roots. This result can possibly be explained by the irrigations carried out at the start of the experimental period, which left the soil with a water content equal to field capacity in all treatments. Analysing the values for field capacity, permanent wilting point of the plant (Table 1) and mean depth of the root system (Table 4), the total soil water capacity in cycles 1, 2 and 3 was 33.9 19.9 and 20.8 mm respectively. Whereas, the difference in net irrigation depth applied in the treatments of 50 and 100% ETc in cycles 1, 2 and 3 (Table 3) was 29.2, 18.9 and 19.1 mm respectively. It can therefore be seen that, in treatments with smaller irrigation depths, the radish possibly took up the water that was retained in the soil from the irrigations performed at the start of the cycle, minimising the effect from the smaller irrigation depth, to the point that no response to this factor was found in the production parameters of the crop.

The “buffering” effect occurred due to the short cycle of the radish crop, together with the clay soil in the experimental area presenting a high level of water retention (Table 1). Lima *et al*. (2015), working with radish under protected cultivation in Lavras, MG, found that the levels of soil water pressure had no influence on radish production. Klar *et al*. (2015), in Botucatu, São Paulo, found similar behaviour for the radish in two cycles, with a quadratic response to increases in irrigation depth, where the optimal point was obtained in the range of 60 to 80% ETc. Slomp *et al*. (2011), growing the radish under protected cultivation in Erechim, Rio Grande do Sul, and testing irrigation depths corresponding to 40, 60, 80, 100 and 120% of a Class A evaporation tank, found that when applying a depth of 40%, the production of tuberous-root fresh matter was as efficient as at the other irrigation depths.

For water use efficiency (WUE), interaction was seen between the cultivars and irrigation depths for all radish cycles. Overall, the Crunchy Royale radish had higher values for WUE than the other cultivars (Table 4). This result is due to the greater productivity achieved by Crunchy Royale.

Except for Vip Crimson in cycle 2, it can be seen from Figure 2 that irrigation depth had a negative linear effect on WUE in the radish. This result was expected, as the factors are inversely proportional. Slomp *et al*. (2011) growing radish in a protected environment in Erechim, Rio Grande do Sul, also found a linear reduction in WUE when applying irrigation depths to meet the demand of 40 to 120% of a Class A evaporation tank.

CONCLUSIONS

1. Considering productivity and quality, the Crunchy Royale cultivar is recommended for radish cultivation in the region of Viçosa, in the state of Minas Gerais;
2. For soils with high water availability, greater than 1.8 mm cm^{-1}, irrigation at 50% of crop evapotranspiration is recommended, provided that at the start of the cycle the soil is at field capacity.

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