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LETTUCE AND RADISH GROWN IN SINGLE CROP AND INTERCROPPING SYSTEMS UNDER DIFFERENT IRRIGATION WATER DEPTHS IN A PROTECTED ENVIRONMENT[1]

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ABSTRACT - Vegetables intercropping of results in a better use of natural resources, water, light, and nutrients, when properly managed. The objective of this work was to evaluate the performance of lettuce and radish in single crop and intercropping systems under different irrigation water depths. The experiment was conducted in a protected environment at the State University of Maringá, in Maringá, Paraná, Brazil. A randomized block experimental design was used in a 4×2 factorial arrangement, with four replications. The first factor consisted of four irrigation water depths (60%, 80%, 100%, and 120% ETc), and the second factor consisted of two crop systems (single crop and intercrop). A drip irrigation system was used, consisting of constant water table lysimeters. The variables evaluated were: shoot fresh weight, root dry weight, and leaf area for the lettuce crop; total fresh weight, root fresh weight, and root diameter for the radish crop; and yield, water use efficiency, and land use efficiency index for both crops. Shoot fresh weight, leaf area, and yield of lettuce, and total fresh weight, root fresh weight, and yield of radish increased as the irrigation water depth applied was increased. Total fresh weight, root fresh weight, root diameter, and yield of the radish crop were higher in the intercropping system. The water use efficiency of both crops was higher in the single crop, and the land use efficiency index was higher in the intercropping system.

Keywords: Drip. Lysimeter. Irrigation management. Olericulture Crop systems

ALFACE E RABANETE EM MONOCULTIVO E CONSÓRCIO SOB DIFERENTES LÂMINAS DE ÁGUA EM AMBIENTE PROTEGIDO

RESUMO - O consórcio de hortaliças apresenta melhor aproveitamento dos recursos naturais, água, luz e nutrientes quando manejados corretamente. Objetivou-se avaliar o desempenho das culturas de alface e rabanete em sistema de monocultivo e consórcio submetidas a lâminas de água. O experimento foi conduzido em ambiente protegido na Universidade Estadual de Maringá em Maringá – PR. O delineamento experimental foi em blocos ao acaso, fatorial 4 x 2, com quatro repetições. O primeiro fator consistiu de quatro lâminas de água (60; 80; 100 e 120% da ETc) e o segundo fator de dois sistemas de cultivo (monocultivo e consórcio). O sistema de irrigação utilizado foi gotejamento e o manejo efetuado por lisímetros de lençol freático constante. As variáveis avaliadas da cultura de alface foram: massa fresca da parte aérea, massa seca da raiz e área foliar. Para cultura do rabanete avaliou-se: massa fresca total, massa fresca da raiz e diâmetro da raiz. E para ambas as culturas: produtividade, eficiência na utilização da água e índice de uso eficiente da superfície da terra. A massa fresca da parte aérea, área foliar e produtividade da alface, bem como, a massa fresca total, massa fresca da raiz e produtividade do rabanete aumentaram conforme incremento das lâminas de água aplicadas. A massa fresca total, massa fresca da raiz, diâmetro da raiz e produtividade do rabanete foram superiores no consórcio. A eficiência da utilização da água de ambas as culturas foi superior no monocultivo e o índice de uso eficiente da superfície da terra foi superior no consórcio.

Palavras-chave: Gotejamento. Lisímetro. Manejo de irrigação. Olericultura. Sistema de cultivo.

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INTRODUCTION

Lettuce (*Lactuca sativa* L.) is the most consumed leafy vegetable in the world. In Brazil, it is among the main vegetables in terms of production, marketing, and nutritional value. In addition, lettuce is increasingly accepted by consumers for being healthy and easy to prepare (RUSU; MORARU; MINTAS, 2021; TENG; LIAO; WANG, 2021). Radish (*Raphanus sativus* L.) is a small plant whose crop has a fast economic return due to its short cycle; however, despite its little importance in terms of planted area, it has been gaining attention among olericulturists and can be used as an intermediate crop (PELLOSO et al., 2012; ZOMERFELD et al., 2021).

There is a growing trend towards vegetable consumption due to an increasing social awareness regarding healthy eating, thus emerging a need to develop crop systems that ensure the balance between the environment and its natural resources and generate sustainable solutions and cultural practices (SILVA et al., 2020).

Intercrops is widely used as an important means to provide food security, diversify crop systems, promote sustainable agricultural development, and promote efficient use of the limited labor in small farms. It is widely used for vegetable crops and in areas that undergo intense soil turning and exposure, intensive use of pesticides, fertilizers, and irrigation, and have difficult control of invasive plants and use other practices that result in considerable environmental impact (YIN et al., 2020).

The intercropping system consists of simultaneous growing of two or more species with different cycles and vegetative architectures in the same field and period, which are not necessarily sown and harvested together (PINTO et al., 2011; ALBUQUERQUE et al., 2012). The interaction between crops in an intercropping system can result in increases in yield; better use of labor; greater efficiency in the use of available resources (soil, water, light, and nutrients); and reduction of invasive plants, pests, and diseases (YIN et al., 2020). Intercropping systems contribute to the stability of rural activities, ensuring more harvests and providing additional income to the producer (CUSTÓDIO et al., 2015).

Researches have evaluated vegetable intercrops, such as lettuce and arugula (ALMEIDA et al., 2015), broccoli and lettuce (OHSE et al., 2012), beetroot and Chinese cabbage (MELO et al., 2015), radish and lettuce (CUSTÓDIO et al., 2015), and radish and cabbage (SILVA et al., 2020). However, no record on the agronomic performance of crops in intercrops are found regarding water consumption.

Irrigation is necessary for growing of vegetables in protected environments, consequently, water and crop management techniques that optimize the use of this resource, which is increasingly scarce and discussed in society, are necessary. Intercropped plants can complement each other spatially or temporally and provide a better combined water use than single crops; thus, it can be an alternative to obtain high yields and reduce water consumption (MAGALHÃES et al., 2015). The objective of this work was to evaluate the performance of two lettuce and radish crop systems, single crop and intercrop, under different irrigation water depths in a protected environment.

MATERIAL AND METHODS

The experiment was conducted from September to November 2019, in a protected environment at the Technical Center for Irrigation (CTI) of the State University of Maringá (UEM), in Maringá, Paraná (PR), Brazil (23º25'S; 51º57'W; 542 m). The climate in the region is Cfa, subtropical mesothermic, without a defined dry season, according to the Koppen classification (ALVARES et al., 2014).

The protected environment used was 25 m long, 7 m wide, and 3.5 m high, built in a north-south direction with an arched roof, and covered with 150 µm thick polyethylene film and a white anti -aphid screen on the sides. A randomized block experimental design was used, with a 4×2 factorial arrangement and four replications. The first factor consisted of four irrigation water depths (60%, 80%, 100%, and 120% of the crop evapotranspiration - ETc), and the second factor consisted of two crop systems for lettuce and radish (single crop and intercrop).

The soil of the experimental area was classified as Typic Hapludox (Nitossolo Vermelho distroferrico; EMBRAPA, 2018). The chemical analysis of the soil 0-0.2 cm layer presented the following results: base saturation = 80; cation exchange capacity (CEC) = 10.12 $cmol_c dm^{-3}$; pH in water = 6; organic matter = 15.00 g dm^{-3}; P = 75.47 mg dm^{-3}; K = 0.42 $cmol_c dm^{-3}$; Ca^{2+} = 7.43 $cmol_c dm^{-3}$; Mg^{2+} = 2.27 mg dm^{-3}; Cu = 16.80 mg dm^{-3}; Zn = 11.88 mg dm^{-3}; Mn = 124.86 mg dm^{-3}; Fe = 102.42 mg dm^{-3}, and B = 0.32 mg dm^{-3}.

The area was prepared with soil turning with a rotary hoe and 48 beds were raised. Planting and topdressing fertilizer applications were performed based on the interpretation of the soil chemical analysis and recommendations for lettuce and radish crops (TRANI, 2014).

The fertilizer application at planting consisted of 32 g m^2 of nitrogen (N), 200 g m^2 of phosphorus (P_2O_5), 18 g m^2 of potassium chloride (K_2O) and 0.36 g m^2 of boron (B) for the lettuce crop, and 24 g m^2 of N, 200 g m^2 of P_2O_5, 18 g m^2 of K_2O and

0.72 g m^2 of B for the radish crop. In the intercropping system, fertilizers were applied based on the requirements of the main crop (lettuce).

Topdressing was carried out at 9 and 21 days after transplanting (DAT) for the lettuce crop; 23 g m^2 of N were applied in each of time. Topdressing for the radish crop consisted of application of 10 g m^2 of N at 14 days after sowing (DAS). The Vanda lettuce cultivar (Sakata company) was used; it is characterized by adapting to tropical environments. The seedlings were produced in 200-cell expanded polystyrene trays containing coconut fiber substrate; the trays were kept in a greenhouse until transplanting, when the plants had four definitive leaves. The radish hybrid 19 (Sakata company) was sowed on the same day as the lettuce transplant, a thinning was carried out when the plants reached 0.05 m in height.

The spacing used was 0.30 × 0.25 m for the lettuce crop and 0.15 × 0.05 m for the radish crop. The experimental plot in the intercropped system consisted of a 0.6 m wide and 3.0 m long bed, with two rows with 12 lettuce plants each in the sides and a central row with 60 radish plants. In the single crop system, the bed consisted of two lines with 12 plants for the lettuce, and two lines with 60 plants for the radish (Figure 1).

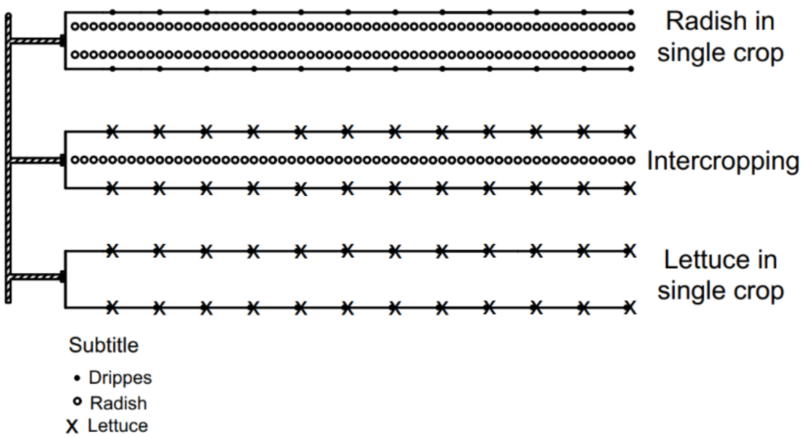

Figure 1. Sketch of the experimental plots with lettuce and radish in intercropping and single crop systems.

A drip irrigation system was used in each bed; it consisted of a double outlet with two lateral lines of 16 mm in diameter, and 12 pressure-compensating drippers spaced 0.25 m apart, with a flow rate of 2.1 L h^{-1} and operation pressure of 10 mca.

The ETc were determined by constant water table lysimeters installed inside the protected environment, with an area of 0.86 m^2 and a volume of 0.38 m^3. The crops were arranged in the lysimeters, similarly reproducing the conditions of intercropping and single crop systems of lettuce and radish in the beds. ETc readings and replenishment of water were performed daily at 08:00 a.m., followed by irrigation.

Phytosanitary measures related to control of diseases and insects were not needed; manual weeding was carried out to control weeds.

Lettuce was harvested at 35 days after transplanting and radish was harvested at 28 days after sowing; then, the following characteristics were evaluated: shoot fresh weight (SFW; g), root dry weight (SDW; g), leaf area (LA; cm^2 $plant^{-1}$), and crop yield (CY; kg m^{-2}). In addition, root diameter (RD; mm), root fresh weight (RFW; g), and total fresh weight (TFW; g) were evaluated for the radish crop.

The water use efficiency (WUE; kg m^{-3}) was obtained using the ratio between crop yield (kg m^{-2}) and applied irrigation water depth (mm). The equation proposed by Willey (1979) was used to calculate the land use efficiency (LUE).

SFW, SDW, RFW, and TFW were determined using a precision digital balance (0.01 g), RD was determined using a digital caliper, and LA was determined using an area meter (LI-3100). The plant parts were placed in a forced air circulation oven at 65 °C until constant weight to obtain the dry matter.

The data were subjected to analysis of variance, evaluating the individual effects of the treatments, and the interactions were compared by the Tukey's test and regression analysis at 5% significance level, using the SISVAR statistical program (FERREIRA, 2014).

RESULTS AND DISCUSSION

According to the analysis of variance, the interaction between the factors (irrigation water depth and crop system) was not significant for any of the variables evaluated in the lettuce crop. The effect of the irrigation water depth factor was significant for SFW, SDW, LA, CY, and WUE, and the effect of the crop system factor was significant for SFW and CY.

The variables SFW, LA, and CY of lettuce in single crop were affected by the applied irrigation water depths (114, 152, 190, and 228 mm), fitting to increasing linear regression models (Figures 2 A, C, and D). SDW and WUE were also affected by the irrigation water depths, fitting to decreasing linear regression models (Figure 2 B and E).

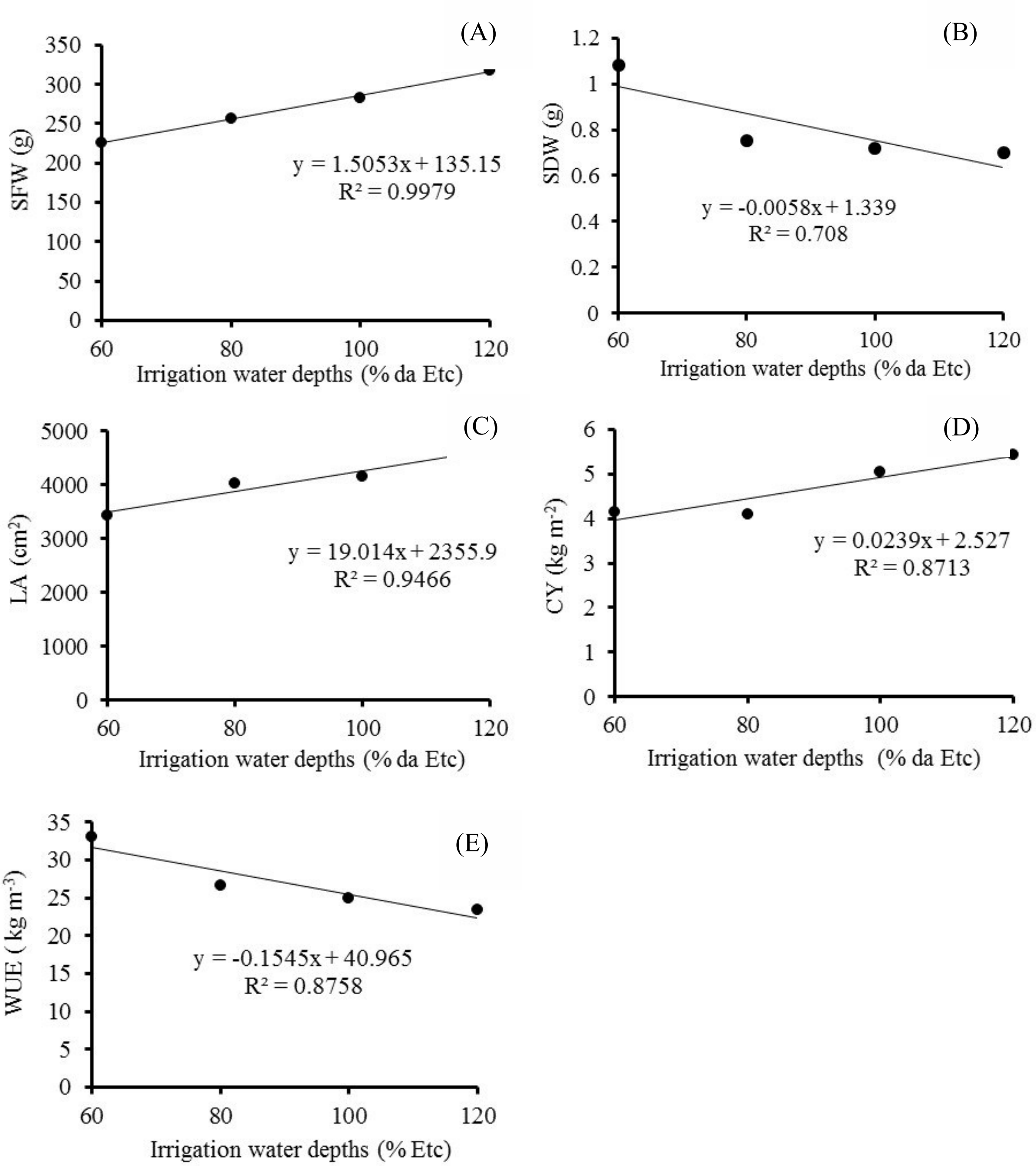

Figure 2. Shoot fresh weight (A), root dry weight (B), leaf area (C), crop yield (D), and water use efficiency (E) of lettuce plants in single crop system as a function of irrigation water depths. Maringá, PR, Brazil.

The increase in irrigation water depth resulted in a linear increase in SFW (Figure 2A). The irrigation water depth of 120% ETc resulted in the highest SFW accumulation, with a mean of 317.28 g, representing an increase of 70% when compared to the lowest irrigation water depth applied. Magalhães et al. (2015) found similar results when applying irrigation depths to lettuce crops. Maintenance of turgor is the main defense mechanism of plants when exposed to water deficit. However, although some mechanisms, such as decreases in stomatal conductance, assist in maintaining turgor, they lead to reductions in plant gas exchanges, resulting in decreases in photosynthetic rates and, consequently, in fresh and dry matter accumulations (NAWAZ et al., 2015).

The crop system also significantly affected lettuce SFW. The single crop resulted in a mean SFW of 292.84 g, which was higher than that found in the intercrop (248.91 g). The single crop probably provided a better development for the lettuce crop by the lower competition between plants.

The increases in irrigation water depths resulted in decreases in SDW; the highest SDW was found for the irrigation water depth of 60% ETc (Figure 2B). The treatments with less water probably stimulated the expansion of the root system to deeper and moister regions of the soil profile.

The most affected process by water deficit is cell expansion; reductions in water supply inhibit stem growth and leaf expansion in many plants, but stimulate root elongation. A relative increase in roots relative to leaves is an adequate response to reductions in water availability; thus, the sensitivity of shoot growth to decreases in water availability can be seen as an adaptation to drought rather than a physiological restriction (TAIZ et al., 2017).

The level of abscisic acid increases in plants stressed by lack of water, resulting in stimulation of root growth, increased ethylene synthesis, and increased leaf abscission (SHARP, 2002). However, the plant can develop a mechanism of tolerance to water stress, in which the root growth is prioritized, providing greater capacity to absorb water (CORREIA; NOGUEIRA, 2004).

The lettuce leaf area increased as the irrigation water depth was increased (Figure 2 C). According to Taiz et al. (2017), the limitation in leaf area may be a first reaction of plants to water deficit, since it affects cell elongation, causing the secondary cell wall to be formed, determining the definitive size.

The increases in irrigation water depths resulted in increases in CY (Figure 2 D). The highest CY was 5.43 kg m^{-2}, obtained when applying the irrigation water depth of 120% ETc, representing an increase of 75% when compared to the lowest irrigation water depth.

The crop system also affected the lettuce CY, the mean CY found in the single crop was 4.68 kg m^{-2}, which was higher than that found in the intercropping system (3.98 kg m^{-2}). Bezerra Neto et al. (2003) evaluated the performance of carrot and lettuce in an intercropping system and found higher CY in the single crop system; they reported that the lower CY in the intercropping system was probably because of a greater intraspecific competition caused by a greater plant density, and a greater interspecific competition caused by shading.

The WUE decreased linearly as the irrigation water depth was increased, with values ranging from 33.12 to 23.38 kg m^{-3} (Figure 2 E). This denotes that a water volume of 30 to 43 liters was needed to produce 1 kg of fresh lettuce leaves. Similar results were found by Magalhães et al. (2015), who used irrigation water depths between 50% and 125% ETc for lettuce crops and found a linear decrease in WUE, from 12.5 to 8.9 kg m^{-3}. Lima Junior et al. (2012) found a linear decrease in WUE, from 96.29 to 13.12 kg m^{-3} when using different irrigation water depths (30 to 150% ETc) for iceberg lettuce grown in a protected environment.

The land use efficiency (LUE) in the intercropping system with lettuce and radish was 2.56, which was higher than 1, indicating a better use of environmental resources in the intercropping system, compared to the lettuce in single crop. This result represents a 156% increase in lettuce and radish production per square meter in the intercropping system when compared to the same area in the single crop system.

The interaction between the factors (irrigation water depths and crop system) was significant for the radish TFW and RD. In addition, the effect of the irrigation water depth factor was significant for TFW, RFW, RD, CY, and WUE, and the effect of the crop system factor was significant for TFW, RFW, RD, CY, and WUE. The radish TFW, RFW, and CY in the single crop were affected by the irrigation water depths applied, fitting to increasing linear regression models (Figures 3 A, B and D, respectively). The irrigation water depths also affected the RD, fitting to a quadratic regression model, and the WUE, fitting to a decreasing linear regression model (Figure 3 C and E).

The increases in irrigation water depths increased radish TFW (Figure 3 A). The crop system also affected radish TFW, with the intercrop presenting a mean of 54.53 g, which was higher than that in the single crop (45.85 g), indicating that the radish plants were well adapted to the intercrop, presenting good water, nutrient, and CO_2 absorptions.

The interaction between factors was significant for radish TFW only in the intercropping system, fitting to a linear regression model (Figure 4).

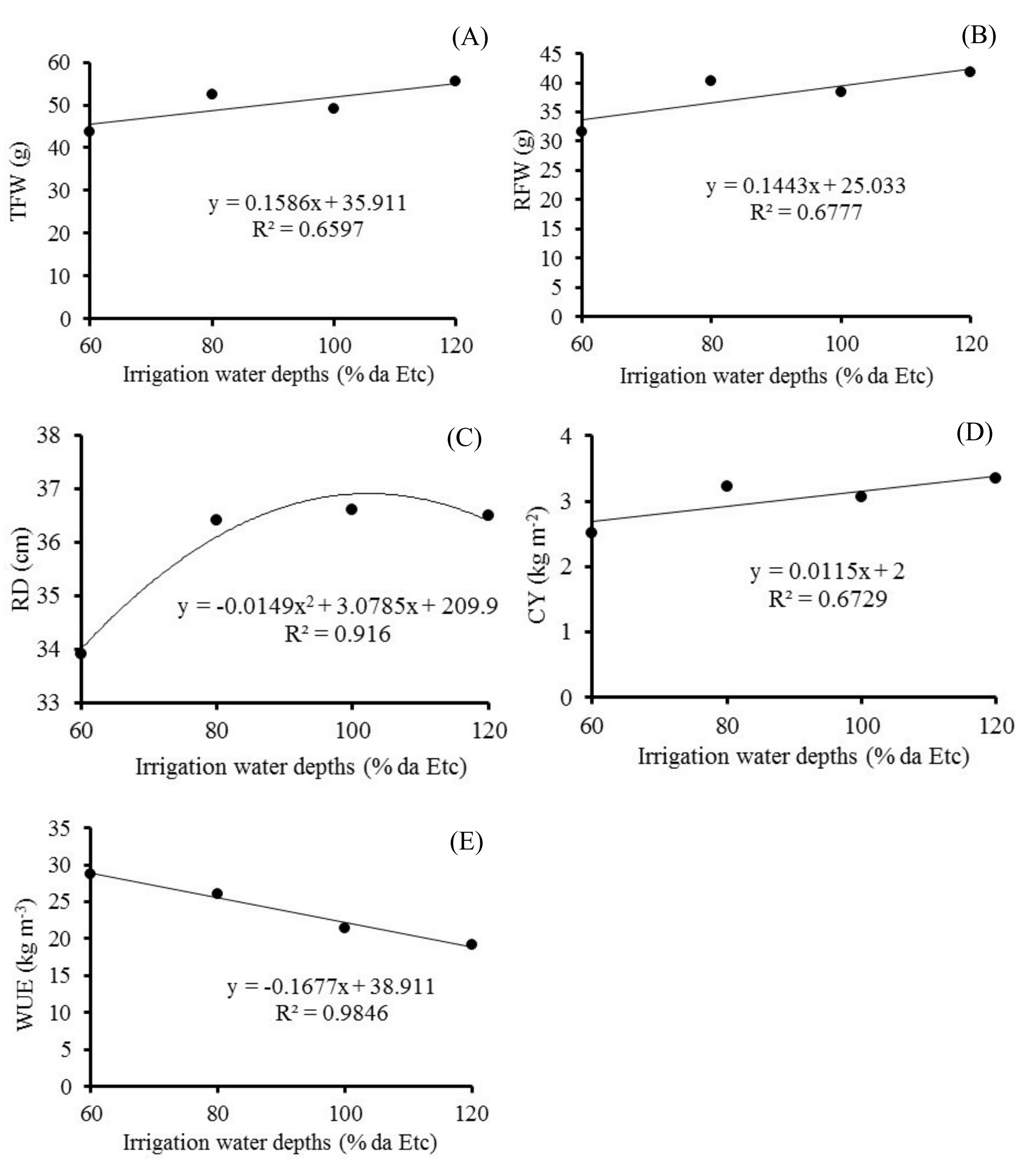

Figure 3. Total fresh weight (A), root fresh weight (B), root diameter (C), crop yield (D), and water use efficiency (E) of radish in single crop system as a function of irrigation water depths. Maringá, PR, Brazil.

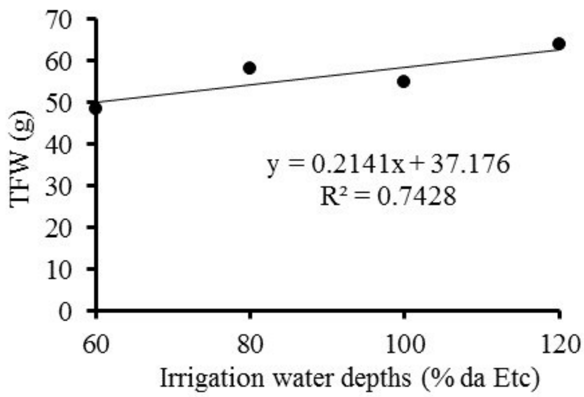

Figure 4. Total fresh weight of radish plants in intercropping system as a function of irrigation water depths. Maringá, PR, Brazil.

In the intercropping system, the water deficit conditions resulted in decreases in radish TFW (Figure 4), indicating that reductions in water availability in these intercrops may result in competition for water resources. Competition occurs when there is more than one species searching for the same resource in the same area; competition for water may affect the production of biomass, photosynthesis, and transpiration rate (RAJCAN; SWANTON, 2001).

Considering the crop systems within each irrigation water depth, the crop systems had significant effects when using 80% and 120% ETc, and the intercropping system presented higher TFW than the single crop. This indicates that the radish crop has a better development in intercropping systems under water stress, as well as under high water availability conditions.

Radish RFW increased as the irrigation water depth was increased (Figure 3B). The irrigation water depth of 120% ETc resulted in a mean RFW of 41.85 g, corresponding to a relative increase of 75% when compared to the lowest irrigation water depth applied. Similar results were found by Lacerda et al. (2017) when evaluating production characteristics of radish plants under irrigation water depths varying from 50% to 125% ETc.

The crop system also affected radish RFW; the intercropping system resulted in a mean RFW of 41.57 g, which was higher than that found in the single crop (34.48 g). Similar results were found by Salgado et al. (2006), who reported higher RFW in radish and carrot intercropped with leaf lettuce or butterhead lettuce, compared to the single crop system. The mean radish RFW found in the present study were close to that found by Salgado et al. (2006), who reported RFW of 43.8 g for the lettuce and radish intercropping system and 35.2 g for the single crop.

Radish SFW was affected only by the crop system; the intercropping system resulted in higher SFW (13.05 g) than the single crop system (10.78 g). These results of RFW and SFW indicate that intercropping systems have greater potential for weight accumulation than single crop systems. This is probably due to the greater efficiency in use of light and nutrient resources by the shoot and root systems (RADOSEVICH; HOLT; GHERSA, 1997).

The largest radish RD was found for an irrigation water depth close to 100% ETc (Figure 3 C). RD was also affected by the crop system; the intercrop resulted in a mean RD of 36.53 mm, which was higher than that found in the single crop (35.17 mm).

Intercropping systems with lettuce, which is the species that has dominant architecture, present lower variations in soil moisture and temperature than those in single crop systems, because the shading of the soil increases in the critical phase of the radish crop, which presents a smaller architecture, thus altering the water vapor concentration, osmotic regulation, and consequently, reducing the stress of radish plants, improving their performance when compared to those in single crop systems (SUGASTI; JUNQUEIRA; SABOYA, 2013).

The interaction between irrigation water depth and crop system was significant for RD. A significant effect of the irrigation water depth was observed only for the single crop, fitting to a quadratic regression model (Figure 5).

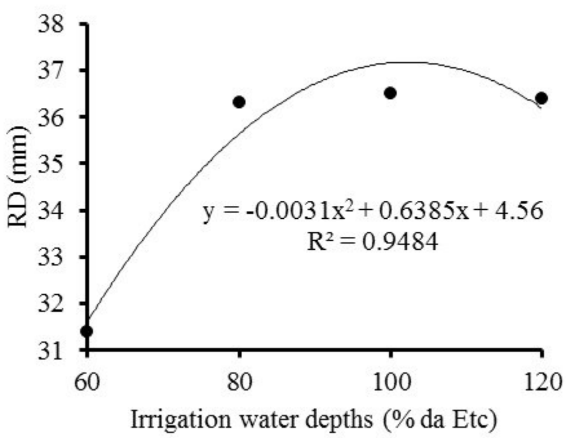

Figure 5. Radish root diameter as a function of irrigation water depth for the single crop system. Maringá, PR, Brazil.

The smallest RD in the single crop was found for the irrigation water depth of 60% ETc, indicating that the most severe reduction in water availability affected the radish diameter in this crop system (Figure 5). A significant effect of the crop system was observed only for the irrigation water depth of 60% ETc, with the intercropping system presenting a mean of 36.43 mm, which was higher than that found in the single crop (31.44 mm). According to Moreira, Silva and Stone (2007), intercropping systems have greater potential to remove water from the soil than single crop systems, considering that two species are grown in the same space.

Radish CY increased as the irrigation water depth was increased (Figure 3 D). CY was also affected by the crop system; the intercropping system showed a mean CY of 3.32 kg m^{-2}, which was higher than that found in the single crop system (2.75 kg m^{-2}). This can be explained by a possible benefit for the radish plants due to the soil cover by the lettuce plants, which reduced the thermal and water oscillations between rows (CECÍLIO FILHO; REZENDE; CANATO, 2007).

WUE decreased from 28.75 to 19.10 kg m^{-3} as the irrigation water depth was increased (Figure 3 E). Slomp et al. (2011) evaluated the effect of different irrigation depths on radish yield and found that WUE decreased as the irrigation water depth was increased.

The crop systems evaluated also affected WUE, which was higher in the single crop (25.26 kg m^{-3}) than in the intercropping system (22.38 kg m^{-3}), i.e., the radish plants in the intercropping system presented a good performance, but required higher water consumption.

The best use of available environmental resources was found in the lettuce and radish intercropping system, which presented a LUE of 1.68, indicating that 68% more area is needed for the single crop to reach the equivalent crop yield of the intercropping system in one square meter. This is important because, when dealing with protected environments that require high investments, the use of an intercropping system is an alternative for vegetable growers, as it results in a better use of the area and increases the diversity of products that can be offered, thus increasing the profitability.

CONCLUSION

The lettuce crops showed higher shoot fresh weight and yield when grown in the single crop system, while the radish crops showed higher root fresh weight, root diameter, and yield in the intercropping system. The land use efficiency was greater in the intercropping system, but it presented a lower water use efficiency by the lettuce and radish crops.

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