

Economic viability and development of radish (*Raphanus sativus* L.) under different soil water tensions and mulching types

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The authors declare no competing interests.

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Abstract: There is a lack of information on the production of irrigated radish associated with the use of mulching and on the economic viability of these production technologies. The objective of this study was to evaluate the growth, yield, and economic viability of the radish crop under different soil water tensions (SWT) and mulching types. The experiment was conducted in a greenhouse. During the experiment, the following variables were evaluated: growth parameters, yield and economic viability. SWT at 7 kPa in the treatments without mulching and at 12 kPa in the treatments with black plastic and black non-woven resulted in higher growth parameters and yield. The leaf area index and the root diameter were the parameters that had a high and positive correlation with yield. Expenses with variable resources represent on average 75% of the total production cost. Therefore, the investment pays all resources applied in the activity and provides an economic profit. In this context, the higher radish yield with 37.5 t ha⁻¹ provided the highest profitability of the evaluated treatments, thus, for radish production, the recommendation is to use 12 kPa as an indicator of the moment for irrigation, associated with the use of black plastic.

1. Introduction

Radish crop (*Raphanus sativus* L.) is a vegetable belonging to the Brassicaceae family grown worldwide, consumed mainly in salads, cooked, and even pickled (Chihoub *et al.*, 2019). The radish has been gaining prominence among vegetables due to its rusticity and its short cycle (Kim *et al.*, 2014; Zhang *et al.*, 2021), ideal for small and medium producers. However, in Brazil, its production and consumption are still small, and it can be better exploited by horticulturists, creating a market niche. In Brazil, according to the agricultural census (2006), around 10,500 tons of

radishes were produced, generating revenue of R\$ 9 million (CONAB, 2010). The South and Southeast regions are the regions with more radish production, with 4,587 and 4,456 tons, respectively. In general, radish productivity in Brazil is between 11 and 30 t ha⁻¹.

Despite its rusticity, the high yield and profitability of the radish crop will only be achieved under optimal conditions of soil moisture, air temperature, and fertilization (Gruver *et al.*, 2016). Therefore, adequate management techniques are necessary to achieve this optimal cultivation condition. Proper irrigation management is one of the ways to achieve maximum yield. The timing and amount of water applied are critical to the irrigation effectiveness. Excessive irrigation increases pumping costs, water waste, and crop disease susceptibility; nevertheless, deficit irrigation generally causes losses and reduces production quality (Contreras *et al.*, 2017). Soil water tension (SWT) is one of the ways to determine the timing of irrigation and the volume of water to be applied. SWT is a fundamental variable to describe the water availability in the soil and the capacity for that water to be used by plants (Meyer and Green, 1981). According to Masseroni *et al.* (2016), the local measurement of SWT is one of the most effective options for irrigation management.

In addition to adequate irrigation, mulching is also a technique used in the search for high yield. Soil mulch can decrease the evaporation rate, maintain the soil moisture, moderate the temperature, and form a barrier to weed growth, which can significantly affect yield and water consumption (An *et al.*, 2015; Gao *et al.*, 2019). According to Carmichael *et al.* (2012), mulching significantly increased the radish yield. However, the acquisition, installation, and maintenance of the irrigation and mulching require a high investment, which represent important additional costs to production.

Based on agricultural production costs, it is possible to evaluate the profitability and efficiency of the production system adopted by the rural producer and makes it possible to obtain information for decision-making on agricultural activities (Artuzo *et al.*, 2018). The production cost is grouped into fixed costs, variable costs, operating costs, and total cost. Economic analysis compares the production cost with the gross revenue obtained from the sale of the product produced. Therefore, the success of the enterprise is related not only to the production cost, but also to the final product price and, mainly, to

crop yield (Schwerz *et al.*, 2017).

Radish yield can be influenced by numerous factors, including the plant's response to the production environment. Therefore, it is necessary to understand the crop traits that contribute to high yield and their interrelationships. Knowledge of the relationship between yield and crop growth variables obtained through correlation analysis helps in plant selection and develop high yielding varieties (Carmichael *et al.*, 2012; Schwerz *et al.*, 2017). Correlation coefficient (r) measures the degree (intensity) and nature (direction) of association between characters (Abd El-Mohsen *et al.*, 2013).

Given the above, the present study suggests that the combined use of water tension in the ideal soil with mulching can increase development, yield, and profitability. Besides, the gain in profitability with the use of these techniques can exceed the costs of implementation and generate high profits. Therefore, the aims of this study were to evaluate the growth variables and economic viability of radish production under different water tensions in the soil associated with types of mulching, under unheated plastic greenhouse. Also, to determine the relationship between morphological variables and the radish yield to help radish producers how to determine what growth parameters could be efficiently used to raises yield.

2. Materials and Methods

Experimental site characteristics and cultural practices

The experiment was conducted during September and October of 2018, in greenhouses covered by low-density polyethylene, at the experiment area of the Department of Water Resources and Sanitation of the Federal University of Lavras (UFLA). The experiment area is located in the southern region of the state of Minas Gerais (21°14' S, 45°00' W and 918,84m altitude). The climate in the region is classified as Cwa, according to the methodology proposed by Köppen (Dantas *et al.*, 2007).

Soil characteristics of the study area

The soil used in this study was classified as a dystroferic red latosol (oxisol) with a clayey texture according (Santos *et al.*, 2006). The chemical characteristics of the soil were: pH = 7.0; K = 106.7 mg dm⁻³; P = 0.7 mg dm⁻³; Ca = 3.53 cmol_c dm⁻³; Mg = 0.39

$\text{cmol}_c \text{ dm}^{-3}$; $\text{Al} = 0.04 \text{ cmol}_c \text{ dm}^{-3}$; $\text{H+Al} = 1.54 \text{ cmol}_c \text{ dm}^{-3}$; $\text{M.O.} = 2.11 \text{ dag/kg}$ e $V = 73.12$. It was applied in the planting fertilization 1500 kg ha^{-1} de P_2O_5 in the form of single superphosphate, 145 kg ha^{-1} of urea (N), 320 kg ha^{-1} of potassium chloride (K), 620 kg ha^{-1} of limestone and $12,5 \text{ kg ha}^{-1}$ of commercial product Solubor (17.5% boron - B).

Irrigation management and experimental design

The drip irrigation system was used, with self-compensating emitters, spaced 0.3 m apart, and operating with a discharge of 4.3 L h^{-1} . The SWT was determined utilizing tensiometers at two depths (0.15m and 0.25m) in each treatment. The soil water-retention curve was adjusted according to the model proposed by Van Genuchten (1980). The soil moisture of $0.453 \text{ L}^3 \text{ L}^{-3}$ (5 kPa) was the corresponding to the field capacity (θ_{cc}), according to the model proposed by Mello *et al.* (2002).

$$\theta = 0.235 + \frac{(0.614 - 0.235)}{[1 + (0.269 \times \frac{1}{2} \Psi^m)^{2.064}]^{0.515}} \quad R^2 = 0.93$$

Where: θ is the soil moisture content ($\text{cm}^3 \text{ cm}^{-3}$) and Ψ_m is the soil water tension (kPa). The functioning of the irrigation system was calculated based on the gross water depth, according to (Pizarro Cabello, 1996), considering a 0.2 m effective root. A 90% water-application efficiency of the irrigation system was adopted and a water distribution-uniformity coefficient (DUC) of 98% was obtained.

The experimental design was randomized complete in a 4×3 factorial, replicated four times, totaling 12 treatments. The four SWT used were 7, 12, 20, and 50 kPa. The mulching materials used were black polyethylene film (black plastic); black polypropylene (black non-woven film); and no mulch (control) (Table 1).

Table 1 - Treatments of soil water tension and mulching in the radish crop

Treatment code	SWT (kPa)	Mulch material
NM7	7	Control (no mulch)
BP7	7	Black Plastic
BNW7	7	Black non-woven film
NM12	12	Control (no mulch)
BP12	12	Black Plastic
BNW12	12	Black non-woven film
NM20	20	Control (no mulch)
BP20	20	Black Plastic
BNW20	20	Black non-woven film
NM50	50	Control (no mulch)
BP50	50	Black Plastic
BNW50	50	Black non-woven film

Experimental plots, data collection and analysis

The transplant of Comet Radish seedlings occurred 6 days after the planting of the seeds in the experimental plots prepared, fertilized, and with mulching fixed. The plots were kept with moisture close to the field capacity (θ_{cc}) for 3 days, after that period, the irrigation differentiation level started. The plot received 24 plants with 0.2m between rows and 0.05m between plants.

At harvest time, eight central plants were used for the analysis of leaf weight (LW), leaf number (LN), plant height (PH), root diameter (RD), root length (RL) and root weight (RW). The total yield (TY) was estimated considering the total weight of the roots within the useful area. Commercial Yield (CY) was estimated by subtracting the percentage of cracked and defective roots from TY. Also, the soil cover fraction (SCF) and leaf area index (LAI) were measured. The SCF was estimated using the following equation:

$$\text{SCF} = \text{PPA}/\text{UA}$$

Where: SCF is the soil cover fraction, PPA is the plant projection area (PPA), and UA is the useful area of the plot. For the leaf area index the following equation was used:

$$\text{LAI} = \text{TLA}/\text{UA}$$

Where: LAI is the leaf area index, TLA is total leaf area of the plants, and UA is the useful area of the plants. Moments before harvest, photos of the plots were taken using a camera 1m away to obtain the PPA (Fig. 1B). After harvesting, the plant leaves were placed on a platform and were photographed at 0.6m away to obtain the TLA (Fig. 1D). PPA and LA were calculated using ImageJ Software (Fig. 1C, 1E), which is free to use.

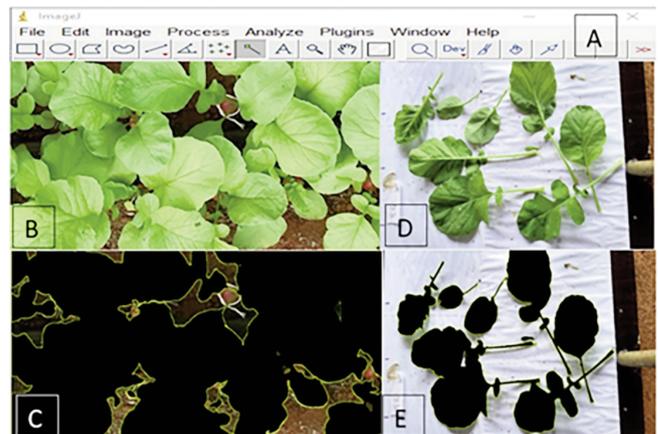


Fig. 1 - (A) ImageJ Software Interface; (B) Image of the useful area of the experimental plot; (C) Projection area calculation; (D) images of plant leaves and (E) Calculation of leaf area.

Fixed and variable cost

The radish yield ($t\ ha^{-1}$) and the costs per cultivated hectare were used for the cost analysis, in approximate values of Brazilian Real (R\$). In the estimate of commercial yield in the greenhouse, the useful planting area index of 57% was used (Araújo Neto *et al.*, 2012) in addition to subtracting the percentage of defective roots.

In this study, the methodology proposed by Reis (2002) was used to estimate production costs. The production cost is the integration of all inputs, labor, depreciation, and operational values in the production process, including the alternative cost. Production cost were grouped into: fixed costs, variable costs, and total cost. Fixed cost refers to depreciation and alternative costs. The variable costs are those related to the crop costs during the cycle of the production process. The sum of fixed and variable costs represents the total cost.

Depreciation is defined as the cost necessary to replace capital goods when rendered useless by physical or economic wear and tear. The linear method was used, considering 6 cycles per year, which corresponds to the average cultivation cycle of the radish cultivar used in addition to the rest and soil preparation period. The Depreciation (D) was calculated by the following equation:

$$D = (V_p - V_r) / Lu \times P$$

Where: D is depreciation (R\$), V_p is the present value of the asset (R\$), V_r is the residual or resale value (R\$), Lu is the useful life or period of activity of the asset (years), and P is the period of analysis or productive cycle (years).

The interest rate of 7% per annum (p.a) was considered for the analysis of the alternative cost of fixed and variable resources allocated to production, Above the recommended by the Companhia Nacional de Abastecimento - CONAB (2010). The alternative fixed cost allocated to the radish cultivation was calculated using the following equation:

$$AC_{fixed} = [(Lu - A) / Lu] \times V_p \times Ir \times P$$

Where: AC_{fixed} is the alternative fixed cost (R\$); A is the average duration of the asset use (years), considered 50% of Lu, and Ir is the interest rate (decimal). The alternative cost of the variable assets (AC_{var}) allocated to the radish cultivation was calculated according to equation:

$$AC_{var} = V_{exp} / 2 \times Ir$$

Where: AC_{var} is the alternative variable cost (R\$), and V_{exp} is the financial investment for the acquisition of

inputs and services for the crop production (R\$).

The fixed cost corresponding to the sum of the contributions of fixed factors in total product in each production cycle. The alternative cost of the production factor was added to the depreciation in calculating the fixed cost. The following items were considered in this calculation.

Land and Rural Land Tax: The value of the Rural Land Tax (RLT) was not considered, due to the exemption for properties below 30 ha. The land is not depreciated when proper soil management is adopted, and all chemical elements extracted by the plant are replaced through the practice of soil fertilization. The value considered was the alternative cost, based on the land rental value. The rental value was R\$ 131.35 per hectare and per month, as mentioned in the on the agricultural price indexes of the Department of Business Administration and Economics of UFLA (DAE/UFLA) and corrected by the General Price Index - Internal Availability (GPI - IA), for November 2018 amounts (R\$).

Mulching: The value of black polyethylene film (BP) and black non-woven film (BNW) were R\$ 0.41 m^{-2} and R\$ 0.67 m^{-2} . Based on the area of mulching required in the experiment, approximately 72% of the greenhouse area. Expenditures on BP and BNW were R\$ 3,028.1 ha^{-1} and R\$ 4,834.2 ha^{-1} , respectively. A useful life of 1 years was considered.

Seedling tray and greenhouse: The expenses with 2860 seedling tray were R\$ 6,292.0 ha^{-1} (20% more to guarantee the quantity of seedlings necessary for transplantation) and the useful life of 3 years. Expenses for greenhouse structure and low-density polyethylene film coverage were R\$ 380,000.00 ha^{-1} and R\$ 25,525 ha^{-1} , respectively, considering the useful life of 20 years and the change of greenhouse cover every 2 years.

Irrigation system: The quantities of material and the irrigation system cost is influenced by the unevenness degree of land, the water collection distance, and the equipment used. A project with the following characteristics was considered: 5 hp motor-pump set, system automation set with starter switch, contactor and relay, programmable irrigation controller with nine outlets, relief valve, air valves and vacuum, electric control valves (solenoids), underground irrigation pipes DN 150 for main irrigation system, PVC piping (50 mm in diameter) connecting the main system to sectors, DN 16 mm low density polyethylene (LDPE) tube, tube connection fittings DN 16 mm, self-compensating dripper with a nominal

flow of 4.3 L h⁻¹ and 2 disc filters with automatic backwash. The useful life considered was 20 years, except for LDPE pipes and connection fittings, which useful life considered was 3 years. The residual value was estimated at 20% of the acquisition value. The maintenance and operation of the system is equivalent to 2% of the acquisition value.

The expenses for the services and products acquisition in each crop cycle, added to the alternative cost, was used in the variable cost calculation. The following items were considered in this calculation.

Inputs: related to investment in the acquisition of substrate, seeds, chemical fertilizers, and pesticides. The value of each input was based on the report on agricultural inputs (CONAB, 2018) and the values provided by companies producing seeds and substrates. The amount of inputs needed were based on the quantity used in the experiment, according to the soil analysis and the recommendations for the crop.

Labor: Expenses with labor refer to the implementation, conduction and harvesting of the crop, operation of machines and irrigation system, and post-harvest processing (cleaning, bagging, and transportation within the property). The unit value practiced was R\$ 954.00 (minimum wage practiced in 2018) plus 51.56% as social charges, according to the methodology proposed by CONAB (2010).

Energy: The energy cost was calculated according to the following equation:

$$EC = V_{\text{kWh}} \times T \times (736 \times \text{Pwr}) / 1000 \times h$$

Where: EC is the energy cost (R\$); T is the total operating time of the irrigation system in each treatment (h); V_{kWh} is the kWh price (R\$); Pwr is the motor pump power (hp), and h is the motor pump efficiency (decimal). R\$ 0.49 is the price per kWh charged by Minas Gerais Electric Power Company (MINISTÉRIO DE MINAS E ENERGIA, 2018). The cost for the volume of water used was not considered, the collection being considered public or for use by the producer.

Administration and Post-harvest cost: Expenses with administrative labor and technical assistance were 6% of the variable costs (CONAB, 2010). Post-harvest cost refers to expenses with product improvement, wooden boxes for packaging and transportation to the destination. The quantities used changed depending on the average yield of each treatment.

Machines and implements: Referring to the investment in renting machines and implements in the preparation of the soil. The unit values consid-

ered were those mentioned in the Department of Business Administration and Economics of UFLA (DAE/UFLA) agricultural price indices. The quantities used for each resource were estimated according to the quantity used in conducting the experiment.

Alternative cost: The real interest rate of 7% p.a. was considered for calculating the alternative cost of each item of the fixed and variable cost.

Economic analysis

The radish price adopted was R\$ 1.20 kg⁻¹, which is equivalent to the average price paid by the Food Acquisition Program (Programa de Aquisição de Alimentos - PAA), operated by the National Supply Company, and the prices practiced in the Supply Centers of Minas Gerais (Centrais de Abastecimento de Minas Gerais S.A. - CEASAMINAS) in October 2018.

The operating cost considers the depreciation and inputs used, equivalent to the analysis period, without the alternative cost. Average total operating cost (TOC) and average total cost (ATC) were calculated in unit terms in the economic analysis. The TOC, in R\$ kg⁻¹ of radish, is divided into average fixed operating cost (FOC), which is composed of the depreciation, and the average variable operating cost (VOC), which is composed of the disbursements during the analysis period (Reis, 2002).

The economic analysis evaluates the TOC and the ATC in relation to the practiced price. This analysis can result in different conditions, and each result suggests an interpretation. To carry out this interpretation of the economic analysis, the situations of economic and operational analysis of the productive activity, described by Reis (2002), were considered. Thus, this study presents a diagnosis of the economic-financial behavior of irrigated radish cultivation, with information about the remuneration obtained and the allocated resources in comparison with the remuneration provided by investment alternatives (alternative cost).

Statistical analysis

Data were statistically analyzed using the Statistical Analysis System Learning Edition 8.0 (SAS, 2003) computer program. Data were initially examined for homogeneity of variance and then subjected to analysis of variance. Tukey test ($p > 0.05$) was used to compare the difference between the treatments for the growth variables, root variables and radish yield. In order to analyze the correlation of plant growth, root growth, and yield variables, Pearson

correlation was conducted, which was qualitatively evaluated for intensity using the following criteria, proposed by Callegari-Jacques (2003): null (0), low (0 to 0.3), regular (0.3 to 0.6), strong (0.6 to 0.9), very strong (0.9 to 1.0) and full (1.0) .

3. Results and Discussion

Growth and yield of radish

The results related to radish growth and yield can be seen in Table 2. For the variables leaf weight and plant height was possible to observe a similar behavior, were mulched system resulted in higher values of leaf weight and plant height than those without mulch (Table 2). The variables leaf weight and plant height were significantly higher with black plastic mulching at 12 kPa, and treatment without mulching at 50 kPa resulted in the lowest growth of these parameters. The water quantity applied had a direct influence on leaf weight and plant height and increase in the water quantity resulted in plants with heavier leaves and taller plants. The BP7 and BP12 resulted in a higher leaf number, however there was no significant difference between treatments.

The leaf area index and soil coverage fraction grew with the increase in the water quantity used and mulching treatments resulted in higher values (Table 2). The highest leaf area index and soil coverage fraction values were observed with BP7 and BP12, respectively. The lowest leaf area index and

soil coverage fraction observed were with the NM50 treatment, and the NM50 differed significantly from the BP7 treatment. These results agree with previous findings by Carmichael *et al.* (2012), who reported an increase in radish growth parameters with increasing irrigation depth. These authors also demonstrated that the use of mulching can significantly influence the growth of the radish. Other authors have also observed similar results. Kang and Wan (2005) reported a maximum leaf area index at 15 kPa in the radish crop in 2002. Yaghi *et al.* (2013) reported that different types of mulching created a positive effect on the growth of cucumber plants.

There was a significant difference between the treatments applied in the root diameter and root length parameters, however, in the root weight parameter, there was no significant difference between treatments. The highest values of root diameter, root length, and root weight were obtained with treatments BP12, NM7 and BNW12, respectively (Table 3). The lowest values of root diameter, root length, and root weight were obtained from the NM20, NM50, and NM50 treatments in decreasing order. The increase in SWT resulted in a decrease in root growth parameters in treatments without mulching; however, a higher growth was observed at 12 kPa in treatments with black plastic and black non-woven.

For the total yield and commercial yield (Table 3) was possible to observe that treatments without mulching, maximum total yield and commercial yield were obtained at 7 kPa and the increase in SWT

Table 2 - Effect of irrigation and mulching on growth variables of radish

Treatment	Growth variables				
	Leaf weight (g)	Leaf number	Plant height (cm)	Leaf area index	Soil coverage fraction
NM7	25.3 abc	6.6 a	32.7 abc	5.78 ab	2.32 abc
BP7	30.3 ab	7.2 a	35.5 ab	6.46 a	2.73 a
BNW7	22.8 bc	7.0 a	33.2 ab	5.02 abc	2.40 abc
NM12	22.4 bc	7.0 a	30.7 bc	4.49 abc	2.32 abc
BP12	34.1 a	7.2 a	37.3 a	6.30 ab	2.55 ab
BNW12	24.8 abc	6.8 a	33.5 ab	5.15 abc	2.19 abc
NM20	22.4 bc	6.6 a	30.1 bc	4.11 bc	1.86 bc
BP20	25.8 abc	6.8 a	34.4 ab	4.81 abc	2.34 abc
BNW20	23.2 abc	6.4 a	32.9 ab	4.46 abc	2.28 abc
NM50	14.9 c	6.1 a	27.0 c	3.13 c	1.74 c
BP50	21.8 bc	6.8 a	32.0 abc	4.45 abc	2.12 abc
BNW50	23.5 abc	6.4 a	33.9 ab	4.48 abc	1.93 bc
CV	15.52	6.62	5.97	15.51	10.63

* Different letters within columns indicate significant difference by Tukey test at 5% probability level.

decreased these variables. However, the behavior of total yield and commercial yield was different between treatments with black plastic and black non-woven. The maximum total yield and commercial yield were reached at 12 kPa in these treatments. Therefore, keeping soil moisture close to the field capacity associated with mulching resulted in water stress suffered by the plant, due to the mulch's characteristics of maintaining high soil moisture. However, with the proper SWT, the use of mulching increased yield when compared to treatments without mulching. Gao *et al.* (2019) and Li *et al.* (2018) also reported a significantly increase of yield of different crops with mulching.

The BP12 treatment resulted in the highest total yield and commercial yield, 41.8 t ha⁻¹, and 37.5 t ha⁻¹, respectively (Table 3). This result highlight the importance of the use of irrigation and water management in radish crop. Kang and Wan (2005) reported the total yield of 47.4 t ha⁻¹ under irrigation management system. These yield differences observed in the literature can be explained by the radish cultivars used, and the difference in cultivation techniques adopted. Yield values above those obtained in the present study indicate a potential for yield growth that can be achieved by new techniques.

Correlation and multiple linear regression analysis

The yield of the radish root is usually determined by some characters of a morphological nature.

Adequate knowledge of the relationship between yield and morphological characters is essential for the identification of selection criteria to be used to improve the yield of radish. Significant association was found between all the contributory characters studied and total and commercial yield (Table 4). The results of the person correlation presented in Table 4 showed that the leaf area index (plant growth parameter) and the root diameter (root growth parameter) that had a very strong and positive correlation with total and commercial yield. The other characters also showed a positive correlation, however with lower *r* values. Therefore, the increase in leaf area index and root diameter implies a greater increase in yield when compared to the other characters. These results indicate that concentrating efforts on the selection of plants with high leaf area index and higher root diameter would be accompanied by high yield capacity in these conditions.

The findings in this paper confirm previous studies by Ullah *et al.* (2010), which found a positive and significant correlation between radish yield with plant height, root length, and root diameter. Khatri *et al.* (2019) found a positive relationship between yield and plant height, root length and root diameter, however leaf number showed highest significant positive correlation with total yield of radish. However, these papers showed that different morphological characters can have a greater relationship with yield under different cultivation conditions.

Table 3 - Effect of irrigation and mulching on root growth variables and radish yield

Treatment	Root variables			Yield	
	Root diameter (cm)	Root length (cm)	Root weight (g)	Total yield (t ha ⁻¹)	Commercial yield (t ha ⁻¹)
NM7	42.9 ab	60.6 a	53.3 ab	37.6 ab	32.0 ab
BP7	41.0 abc	60.1 a	46.8 abcde	33.0 abcde	30.4 abcde
BNW7	39.0 abcde	63.6 a	47.7 abcde	33.7 abcde	30.8 abc
NM12	37.8 bcde	59.2 a	40.4 bcde	28.5 bcde	25.9 bcd
BP12	43.4 a	67.6 a	59.2 a	41.8 a	37.5 a
BNW12	42.9 ab	60.4 a	49.1 abc	34.6 abc	31.9 ab
NM20	35.1 de	56.5 a	31.2 de	22.0 de	20.0 cd
BP20	40.9 abc	68.4 a	48.4 abcd	34.2 abcd	31.4 ab
BNW20	40.3 abcd	64.8 a	40.3 bcde	28.5 bcde	25.6 bcd
NM50	33.7 e	55.1 a	30.4 e	21.4 e	19.3 d
BP50	37.1 cde	64.6 a	39.9 bcde	28.2 bcde	25.6 bcd
BNW50	36.7 cde	61.9 a	35.9 cde	25.3 cde	22.8 bcd
CV (%)	4.76	7.78	13.53	13.54	13.52

* Different letters within columns indicate significant difference by Tukey test at 5% probability level.

Table 4 - Pearson correlation coefficients among yield and its related characters in radish

	Plant growth					Root growth		Yield	
	LW	LN	PH	LAI	SCF	RD	RL	TY	CY
LW	1								
LN	0.69 **	1							
PH	0.87 **	0.63 **	1						
LAI	0.91 **	0.72 **	0.83 **	1					
SCF	0.61 **	0.48 **	0.66 **	0.67 **	1				
RD	0.70 **	0.44 *	0.66 **	0.77 **	0.56 **	1			
RL	0.56 **	0.51 **	0.69 **	0.55 **	0.35 *	0.51 **	1		
TY	0.74 **	0.56 **	0.71 **	0.83 **	0.62 **	0.90 **	0.66 **	1	
CY	0.75 **	0.59 **	0.73 **	0.82 **	0.64 **	0.89 **	0.68 **	0.99 **	1

LW= Leaf weight; LN= Leaf number; PH= Plant height; LAI= Leaf area index; SCF= Soil coverage fraction; RD= Root diameter; RL= Root length; TY= Total yield; CY= Commercial yield.

** , * = Significant at 1 and 5 % probability levels, respectively.

Production cost economic analysis

The percentage contribution of the fixed and variable cost items that make up the total cost are shown in Table 5. The total fixed cost and the total variable cost represent, on average, 25% and 75% of the total cost, respectively. Greenhouse (structure and cover) has the largest percentage contribution in total fixed cost, and input followed by labor has the largest percentage contribution in total variable cost. A similar result was observed by Silva *et al.* (2007) in the cultivation of sunflower, however Boas *et al.* (2011) and Lima Junior *et al.* (2014) in the onion and carrot crop, respectively, observed a percentage contribution of the total fixed cost in the total cost of less than 25%. These results can be explained by the

non-use of greenhouse and mulching in the cultivation of these vegetables, reducing fixed costs. These authors also observed a greater percentage contribution of input and labor in total variable cost.

Despite the depreciation of the greenhouse constituting a high percentage in the total fixed cost (Table 5), its use decreases the susceptibility to weather and allows the planting of the crop throughout the year. According to Araújo Neto *et al.* (2012), despite the high cost of greenhouses, its use generates higher yield, reduces the average total cost, and increases profitability. Inputs and Labor represent, on average, 47% of total production costs. Despite the inputs cost being difficult to reduce, family labor is recommended in the quest to reduce labor costs and

Table 5 - Percentages of fixed and variable costs of radish production in different mulching types and soil water tension

	% Total cost											
	NM7	BP7	NW7	NM12	BP12	NW12	NM20	BP20	NW20	NM50	BP50	NW50
Land	1.09	1.07	1.06	1.13	1.03	1.05	1.18	1.07	1.09	1.19	1.11	1.12
RLT	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mulching	0.00	2.15	3.38	0.00	2.07	3.36	0.00	2.14	3.49	0.00	2.22	3.56
Seedling tray	1.62	1.60	1.58	1.69	1.54	1.57	1.75	1.60	1.63	1.76	1.66	1.66
Greenhouse structure	15.77	15.58	15.34	16.36	14.95	15.25	17.00	15.51	15.84	17.10	16.07	16.13
Greenhouse cover	4.77	4.71	4.64	4.95	4.52	4.61	5.14	4.69	4.79	5.17	4.86	4.88
Irrigation System	0.24	0.24	0.24	0.25	0.23	0.24	0.26	0.24	0.25	0.27	0.25	0.25
Dripper and LDPE pipes	1.19	1.18	1.16	1.23	1.13	1.15	1.28	1.17	1.20	1.29	1.21	1.22
TFC	24.61	26.47	27.32	25.53	25.40	27.17	26.54	26.35	28.22	26.69	27.29	28.73
Inputs	23.65	23.42	23.06	24.68	22.33	22.91	25.82	23.29	23.94	25.99	24.26	24.44
Labor	23.10	22.87	22.52	24.11	21.81	22.37	25.22	22.75	23.38	25.38	23.70	23.87
Energy	0.54	0.53	0.53	0.53	0.48	0.49	0.42	0.38	0.39	0.33	0.31	0.31
Post-harvest expenses	20.02	18.83	18.83	16.97	22.20	19.33	13.71	19.37	16.25	13.29	16.48	14.76
Administration Costs	4.15	4.05	4.01	4.10	4.12	4.02	4.04	4.06	3.95	4.03	4.00	3.92

production costs.

The NM7 treatment had the lowest percentage contribution of the total fixed cost and the highest percentage contribution of the total variable cost in the total cost, among the treatments applied (Table 5). The lack of mulching in this treatment contributed to the decrease in total fixed cost, also, NM7 resulted in high yield, increasing expenses with post-harvest and administrative costs. The BNW50 treatment showed the highest percentage contribution of the total fixed cost due to expenses with non-woven film and low yield, which reduces the total variable cost. Post-harvest expenses and administrative costs were high in BP12 treatment, due to high yield, resulting in a low percentage participation of total fixed cost in the total cost, despite the use of plastic mulching.

In the simplified economic study, R\$ 1.20 kg⁻¹ was considered as the average price practiced in the period of October 2018, and the average total cost and total operating cost for radish crop varied according to the treatment applied (Table 6). The BP12 treatment resulted in the lowest average total cost (R\$ 0.71 kg⁻¹) and total operating cost (R\$ 0.60 kg⁻¹). Although black plastic increased production costs, the mulching characteristics helped to increase yield and profitability, offsetting the expenses with the mulching. The BNW12 treatment resulted in the lowest average total cost (R\$ 0.81) and total operating cost (R\$ 0.68) among black non-woven film treatments, however they were lower than the values observed with the BP12 and NM7 treatment.

Although the black non-woven film increased the yield, the expenses with mulching did not compensate for the application. Therefore, that its use is viable, the prices practiced in the commercialization of non-woven film must be below the prices presented in the present study. Between the treatments without mulching, keeping the humidity close to the field capacity (7 kPa) provided the lowest production cost. The NM50 and NM20 treatments resulted in the highest average total cost and total operating cost, due to low yield, therefore they are not recommended.

Although the application of plastic mulching results in an increase in yield and financial return, its use must be done in a correct and controlled manner, to decrease the negative impact on the environment of plastic film pollution. In addition, accumulation of plastic residue in soil over time may produce negative effects on crop production (Gao *et al.*, 2019). Therefore, an effective cleaning is necessary after the useful life of mulching or the acquisition of biodegradable mulching film in order to develop sustainable agriculture.

All treatments applied exhibited average returns higher than average total cost. Therefore, the investment pays all resources applied in the activity and provides an economic profit, even in treatments with low yield. In this situation, investment is higher than market alternatives, and the trend in the medium and long term is for expansion and entry of new companies into the activity, attracting competitive invest-

Table 6 - Average economic and operating costs of radish production, in R\$ kg⁻¹, at different types of mulching and soil water tension

	Average fixed cost	Average variable cost	Average total cost	Average fix operating cost	Average viarable operating cost	Average total operating cost
NM7	0.19	0.60	0.78	0.08	0.57	0.66
BP7	0.21	0.62	0.83	0.11	0.60	0.70
BNW7	0.22	0.61	0.83	0.11	0.59	0.70
NM12	0.23	0.69	0.92	0.10	0.67	0.77
BP12	0.17	0.53	0.71	0.09	0.51	0.60
BNW12	0.21	0.60	0.81	0.11	0.57	0.68
NM20	0.30	0.85	1.14	0.13	0.81	0.95
BP20	0.21	0.60	0.81	0.10	0.58	0.68
BNW20	0.26	0.70	0.96	0.14	0.67	0.81
NM50	0.31	0.87	1.18	0.14	0.84	0.98
BP50	0.25	0.70	0.95	0.13	0.67	0.80
BNW50	0.30	0.76	1.06	0.15	0.73	0.89

ments.

The analysis was carried out with the product price at R\$ 1.20 kg⁻¹, however the price may vary according to the market at the time of harvest. If the price is lower than practiced, a new analysis must be made. However, there are alternatives to increase sales such as the sale of deformed and cracked roots (difference between total yield and commercial yield), for companies specialized in purchasing these products and increasing yield with new techniques and with more productive cultivars.

4. Conclusions

The different SWT levels and the use of mulching resulted in different growth and yield responses. The BP7 treatment resulted in the highest leaf area index and soil cover fraction. The BP12 treatment resulted in the highest leaf weight, plant height, leaf number, root diameter, root length, total yield and commercial yield. In this context, this treatment was recommended for the radish producers. The plant variables leaf area index and root diameter were the parameters that presented the highest and positive correlation with the radish yield.

Expenses with variable resources increased the final cost in all treatments studied. In conditions similar to those observed experimentally, it is recommended to adopt a black plastic cover keeping the SWT close to 12 kPa, to obtain the highest profitability in the productive activity. However, if the practice of mulching is not feasible, the SWT should be kept close to 7 kPa.

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