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ORIGINAL ARTICLE

Economic viability of a drip irrigation system on carrot crop**

Viabilidade econômica do uso do sistema de irrigação por gotejamento na cultura da cenoura

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ABSTRACT: In Brazil, there is a lack of information on the production of carrots via drip irrigation, both from the perspective of appropriate irrigation management and in relation to the economic feasibility of the technology of production. This study aimed to assess the economic feasibility of drip-irrigating carrot crops based on appropriate irrigation management. The experiment was established in open field beds in the experimental area at the Agricultural Department/UFLA, from June to October 2008. The experimental design was randomized blocks in a 2 x 6 factorial scheme, with four replications. The treatment levels were two carrot cultivars, the hybrid Optima F1 and the non-hybrid Alfa Tropical, and six soil water-tension values, i.e., 15, 25, 35, 45, 60 and 75 kPa. The economic analysis of the irrigated farming was based on production costs theory. According to this analysis, for all the treatment levels, variable costs were the costs that most affected the final cost of the carrots harvested. Under the experimental conditions, we recommend irrigation upon reaching a soil water tension of 15 kPa when using the Nantes cultivar and a tension of 25 kPa for the Nayarit F1 hybrid to obtain higher profitability in the productive activity. The costs of the resource variables were the largest final costs of carrot production in all the treatments, emphasizing the required inputs.

RESUMO: *No Brasil, há uma carência de informações sobre a produção de cenoura irrigada por gotejamento tanto no aspecto do manejo adequado da irrigação quanto em relação ao estudo de viabilidade econômica dessa tecnologia de produção. Objetivou-se avaliar a viabilidade econômica da cenoura irrigada por gotejamento com base no manejo adequado da irrigação. O experimento foi conduzido em canteiros construídos a céu aberto, na área experimental do Departamento de Engenharia-UFLA, no período de julho a outubro de 2010. O delineamento experimental utilizado foi em blocos casualizados, em esquema fatorial 2 × 6, com quatro repetições. Os tratamentos constituíram-se de duas cultivares, cultivar híbrida Nayarit F1 e cultivar não híbrida Nantes, e de seis tensões da água no solo: 15, 25, 35, 45, 60 e 75 kPa. A análise econômica da lavoura irrigada foi fundamentada na teoria dos custos de produção e, considerando-se a metodologia aplicada, conclui-se que as despesas com os recursos variáveis foram as que mais oneraram o custo final da cenoura em todos os tratamentos estudados. Na condição do experimento, a recomendação é de que se adote, como momento de irrigar, a tensão da água no solo de 15 kPa, ao se utilizar a cultivar Nantes, e a tensão de 25 kPa, quanto à cultivar híbrida Nayarit F1, para que se obtenha maior rentabilidade na atividade produtiva. As despesas com os recursos variáveis foram as que mais oneraram o custo final da produção de cenoura em todos os tratamentos estudados, com destaque para a utilização de insumos.*

KEYWORDS
Daucus carota L.
Economic aspects
Trickle irrigation

PALAVRAS-CHAVE
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1 Introduction

Carrot is one of the most important vegetable crops due to its worldwide consumption, the extent of the planted area, and its importance for the socioeconomic development of rural producers (FREITAS et al., 2009). In 2009, 796,000 were produced in Brazil (AGRIANUAL, 2012), mainly in the southeast region, forming 23% of the total production (MENEGAZZO, 2010). This production volume makes Brazil the fifth largest producer of carrots worldwide.

The irrigation of carrots, as of most vegetables, increases yield and improves the product quality in addition to being an important factor determining production. In Brazil, almost all carrot crops are irrigated, except in the states of the southern region (MAROUELLI; SOUZA; OLIVEIRA, 2011). However, a deficit and/or excess of water as well as an inappropriate mode of application (sprinkler or localized irrigation) may result in unfavorable conditions for carrot development and in reduced yield. In addition, excess irrigation can increase the required water-pumping energy and fertilization costs due to low irrigation and fertigation efficiencies and can also result in contamination of water resources (by fertilizers and agrotoxics) due to superficial run-off resulting from sprinkler irrigation (LIMA JUNIOR et al., 2012).

The selection of an adequate irrigation system for this crop is therefore important for the correct management of irrigation aiming to achieve high efficiency levels and economic maximization of the agribusiness and environmental sustainability.

The soil water tension can be used to determine the moment of irrigation and to estimate the quantity of water to be applied for several crops (SÁ et al., 2005; SANTOS; PEREIRA, 2004; VILLAS BOAS et al., 2012).

Drip irrigation demands a large investment in the construction of infrastructures and the acquisition of equipment for water capture, conveyance, control and distribution. In addition, expenses of the energy and labor force for the operation and management of the system should also be considered because they represent additional production costs. Determining the economic viability when starting an undertaking is essential for its success (VILLAS BOAS et al., 2011; LIMA JUNIOR et al., 2011).

Irrigation requires significant investment and is associated with the intensive use of agricultural inputs, making the economic study of the components involved in the irrigation system important (SILVA et al., 2007). Studies that help technicians and farmers to make decisions regarding irrigated agriculture are increasingly needed (SOUZA; FRIZZONE, 2003). The cost of irrigation can be predicted by an economic evaluation where all expected annual expenses and returns are estimated.

The economic evaluation will indicate whether the implementation of an irrigation system is or is not of interest.

Crop water consumption varies depending on the place of cultivation, making it important to perform *in loco* experiments of irrigation management and economic studies, with the goal of increasing water use efficiency.

The goal of the present study was to evaluate the production and economic viability of a drip irrigation system for carrot crops.

2 Materials and Methods

This study was conducted at the experimental area of the Department of Engineering of the Federal University of Lavras (Universidade Federal de Lavras- UFLA), Lavras municipality, in the southern region of the state of Minas Gerais (21° 14' S, 5° 00' W and 918.8 m altitude), between July and October 2010.

The soil was classified as a distroferric red latosol (oxisol) with a very clayey texture according to EMBRAPA (1999). The soil water-retention curve was represented by Equation 1:

$$\theta = 0.223 + \frac{0.312}{\left[1+\left(0.2334.|\Psi|\right)^{1.7023}\right]^{0.4126}} \qquad (1)$$

where: θ is the soil moisture content ($cm^3\,cm^{-3}$), and Ψ is the soil water tension (kPa).

An experimental design of completely randomized blocks (CRB) was used, with a 2 × 6 factorial scheme with 12 treatments and four replicates per treatment. The factors tested were two carrot cultivars (non-hybrid Nantes [N] and F1 hybrid Nayarit [HN]) and six soil water-tension levels (15, 25, 35, 45, 60 and 75 kPa) as indicators of the time for required irrigation (critical tension), resulting in 12 treatments (N15, N25, N35, N45, N60, N75, HN15, HN25, HN35, HN45, HN60 and HN75). The total irrigation depth of each treatment was used for economic analysis.

To monitor the energy state of the soil water, a set of five tensiometers was used per plot (three at 0.15-m depth for irrigation monitoring and two at 0.30-m depth to monitor the occurrence of percolation). The sets of tensiometers were placed in two of the four replicates for each treatment. According to Marouelli, Souza and Oliveira (2011), the effective carrot root depth varies between 35 and 45 cm. The tensiometer readings were obtained using a puncture digital tensiometer.

The experimental plots were 1.20 m wide and 2.00 m long (2.40 m^2). Four rows of plants were used, with 0.30 m between rows and 0.05 m between plants, with a total of 160 plants per plot. Plants from the central rows were used, except for the five plants at the beginning and end of the row, which were discarded (0.90 m^2 useful plot with 60 plants).

Sowing was performed on 07/02/2010, and irrigation was performed by microsprinkler using SANTENO® irrigation tape until 29 days following the sowing, which is the period required for plant germination and survival uniformity in the field. The different irrigation treatments were then applied, using a drip irrigation system with in-line pressure compensating, non-draining emitters (model NAAN PC) with a 1.73 $L\,h^{-1}$ nominal flow rate and 0.30 m between emitters. The dripline was placed in the plot so that it reached two rows of plants, with 140 kPa working pressure. A water distribution-uniformity coefficient (DUC) of 98% was obtained. Crop irrigation was interrupted two days before each harvest.

Each irrigation was an attempt to increase the soil moisture content, indicated by the soil water tension at the moment of irrigation, to field capacity. Irrigation was performed when at least four of the five tensiometers (placed at 0.15 m depth) reached the critical tension established for each treatment. The operation time of the irrigation system was calculated based on the gross water depth, considering a 0.30 m effective root depth. A 95% water-application efficiency of the irrigation system was adopted.

The production costs were estimated using an economic procedure which considers depreciation and alternative costs (REIS, 2007).

Approximate values in Brazilian Reals (R$) were used to estimate the production cost based on the following information: 1.0 ha carrot cultivated area, one harvest period, and fixed and variable costs.

Depreciation was defined as the cost of replacement of capital goods when rendered useless, whether due to physical or economic wear. This parameter was calculated using a linear method, considering a time period of 110 days (0.30 years), corresponding to the average crop cycle in the field for the two carrot cultivars used in this experiment, according to Equation 2:

$$D = \left(\frac{Vp - Vr}{Lu}\right).P \tag{2}$$

where: D is depreciation (R$), Vp is the present value of the asset (R$), Vr is the residual value (the resale value or final value of the asset following its rational use) (R$), Lu is the useful life of the asset (the period of time during which the asset was used for the activity) (years), and P is the period of analysis (years).

The alternative cost of the fixed production resources allocated to the carrot cultivation (alternative fixed-cost) was calculated considering a 6% per annum (p.a.) real interest rate, using Equation 3:

$$AC_{fixed} = \left(\frac{Vu - D}{Lu}\right).Vp.Ir.P \tag{3}$$

where: AC_{fixed} is the alternative fixed-cost (R$); A is the average duration of asset use (years), and Ir is the interest rate (decimal).

To simplify the calculation of AC_{fixed}, the average duration of use of fixed assets was considered to be 50% of the useful life of the asset (Lu), resulting in half of the asset's present value (Vp), multiplied by the interest rate (Ir) and the period of analysis (P), according to Equation 4:

$$AC_{fixed} = \frac{Vp}{2}.Ir.P \tag{4}$$

The alternative cost of the variable assets allocated to the carrot cultivation (alternative variable-cost) was calculated considering a 6% p.a. real interest rate, according to Equation 5:

$$AC_{var} = \frac{V_{exp}}{2}.Ir \tag{5}$$

where: AC_{var} is the alternative variable cost (R$), and V_{exp} is the financial investment by the producer for the acquisition of inputs and services necessary for the crop production (R$).

For the calculation of each fixed resource, the alternative cost of the production factor was added to the depreciation. The following items were considered for the fixed costs and operationalization process:

- Land: land suffers no depreciation because it is assumed that the farmer adopts an adequate soil management system and replenishes the soil with all the chemical elements extracted by the plants, through fertilization and conservationist practices, which preserve the soil characteristics. The value considered was the alternative cost, based on the land rental value. The rental value was R$ 80.00 per hectare and per month, based on the agricultural price indexes of the Department of Business Administration and Economics of UFLA;
- Liming: the liming expenses were R$ 257.50 ha^{-1} every 2 years;
- Rural Land Tax (Imposto Territorial Rural – ITR): this resource does not change in the short turn because its value is annual. The value considered was R$ 0.11 per hectare and per year, based on the agricultural price indexes of the Department of Business Administration and Economics of UFLA;
- Irrigation system: the cost of an irrigation system varies greatly because it depends on the site conditions and the equipment used. A project with the following characteristics was considered for this study: 5 hp motor pump set, starter switch with contactor and relay, programmable logic controller, fertilizer-injection pump, air and vacuum valves, electric control valve (solenoids), relief valve, 100 m zinc-plated water main up to the control head, PVC tubing from the head to the sectors, pressure-compensating driplines (model NAAN PC) with 1.73 L h^{-1} nominal flow rate and 16 mm DN (with 0.30 m distance between them), 2 disk filters with automatic backwashing and 40 m land level difference. A useful life of 15 years was considered;
- Alternative cost: to calculate the alternative cost for each one of the fixed-cost resources, a 6% p.a. real interest rate was considered, which is similar to the minimum remuneration obtained in the financial market.

The investment for product and service acquisition, added to the alternative cost, served as a base for calculating the cost of each variable resource. The following variable resources and operationalization procedure were used:

- Inputs: expenses for the acquisition of seeds, chemical fertilizers, pesticides (fungicides, insecticides and herbicides) and spreader stickers. The unit value considered was the one mentioned in the agricultural price indexes of the Department of Business Administration and Economics of UFLA. The quantity of each input used was based on the quantities used during the experiment and according to the technical coefficients supplied by the Technical Assistance and Rural Extension Company of the State of Minas Gerais (SEBRAE, 2011);
- Labor: labor costs are associated with the operation of the irrigation system, crop establishment (sowing, plot

preparation, fertilization and plant thinning), conveyance (top-dressing fertilization and pesticide application), harvest (uprooting and bundling), cleaning, boxing and transportation within the property. The unit value considered was the one listed in the agricultural price indexes of the Department of Business Administration and Economics of UFLA, and the quantities used for each service were estimated according to the Brazilian Agriculture Year Book (AGRIANUAL, 2010);

- Machines and implements: costs of the rental of machines and implements used in the preparation of the land (plowing and harrowing) and transportation within the property were considered. The unit value considered was the one listed in the agricultural price indexes of the Department of Business Administration and Economics of UFLA, and the quantities used for each resource were estimated based on Agrianual (2010);
- Administration expenses: this factor included costs of the administration workforce, technical assistance and taxes (2.3% of the total revenue), considering unit values and quantities according to Agrianual (2010);

Overhead: costs of 20 kg cardboard boxes for carrot packaging and transportation, with the quantities used depending on the average yield obtained in each treatment tested;

- Energy: the energy cost was calculated using Equation 6, according to Mendonça (2001):

$$EC = V_{kWh}.T.\frac{736.Pwr}{1000.\eta} \qquad (6)$$

where: EC is the energy cost (R\$); V_{kWh} is the kWh price (R\$); T is the total operating time of the irrigation system (h), variable for each treatment; *Pwr* is the motor pump power (hp), and η is the motor pump efficiency (decimal).

A R\$ 0.28 price per kWh was considered, as suggested by the Minas Gerais Electric Power Company (BRASIL, 2012).

Alternative cost: alternative cost was calculated for each variable resource item used for the carrot production, considering a 6% p.a. real interest rate.

The economic cost was calculated as the sum of the operating and alternative costs. The operating cost was divided into the fixed operating cost (CopF), composed of the depreciations, and the variable operating cost (CopV), composed of the expenditures. The total operating cost (CopT) was calculated as the sum of the fixed operating cost and the variable operating cost.

The economic analysis of production can indicate several conditions depending on the price (or average revenue), in terms of costs, with each condition suggesting a particular interpretation. Situations of economic and operational analyses of the production were considered according to Reis (2007).

A single price was adopted as a criterion for the correction of values. For this purpose, the resources used during the carrot crop cycle were added, and the result was multiplied by the price in use during October 2010. As a result, the product price adopted for the analysis was R\$ 9.13 per 20 kg box, as suggested by the Center for Advanced Studies on Applied Economics (Centro de Estudos Avançados em Economia Aplicada- CEPEA) of the "Luiz de Queiroz" College of Agriculture (Escola Superior de Agricultura "Luiz de Queiroz" - ESALQ), University of São Paulo (Universidade de São Paulo) (USP, 2010).

3 Results and Discussion

The total water depth corresponds to the sum of all the irrigation depths applied in each of the different treatments, the 41.4 mm water depth applied during the period of seedling establishment, and the total rainfall of 109.3 mm that occurred during the experimental period (Table 1).

The carrot root yield increased with decreasing soil water tension. The 439.12 mm water depth, corresponding to 15 kPa water tension (Table 1), resulted in a yield of 3,008 boxes ha^{-1} for the Nantes cultivar. A maximum yield of 3,285 boxes ha^{-1} was obtained for the hybrid Nayarit with 25 kPa water tension and 463.32 mm total water depth. The average national yield is 1,400 boxes ha^{-1}, and a yield between 2,000 and 3,000 boxes ha^{-1} may be achieved with adequate irrigation management and fertilization (MAROUELLI; SOUZA; OLIVEIRA, 2011).

The carrot crop yield may be considered high because the drip irrigation-management criteria were adopted. Higher root yields were obtained by Silva, Vieira and Carrijo (1982) when the soil water content was maintained at a constant high level. The water depths used were less than the 365.03 mm water consumption found by Moura et al. (1994) during the vegetative cycle of carrot under the climate conditions of Piracicaba, state of São Paulo (SP). An average total water consumption of 811.84 mm was reported for the variety Brasília, growing in a fluvic neosol in a rural area of the state of Pernambuco (SANTOS et al., 2009).

For the Nante cultivar, the percentage of total fixed costs (TFC) decreased and the percentage of total variable costs (TVC) increased (Table 2) with decreasing water soil tension and, consequently, with increasing water depths applied. The average yields of commercial bulbs increased with decreasing water soil tension (Table 1). For the F1 Nayarit cultivar, the

Table 1. Total water depth and average marketable root yield of two carrot cultivars under different soil water tensions.

Treatments	Total water depth (mm)	Yield (boxes ha^{-1})
N15	439.12	3,008
N25	485.56	2,574
N35	509.88	2,318
N45	475.36	1,920
N60	425.84	1,290
N75	397.51	701
HN15	428.14	3,024
HN25	463.32	3,285
HN35	509.88	2,929
HN45	475.36	2,055
HN60	425.84	1,582
HN75	397.51	722

Table 2. Percentages of fixed and variable production costs of the two carrot cultivars tested under different soil water tensions.

Total fixed and variable costs[1]	% total cost											
	N15	N25	N35	N45	N60	N75	HN15	HN25	HN35	HN45	HN60	HN75
Soil	2.15	2.19	2.22	2.29	2.41	2.52	1.54	1.51	1.53	1.60	1.64	1.72
Liming	0.21	0.22	0.22	0.22	0.24	0.25	0.15	0.15	0.15	0.16	0.16	0.17
ITR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Irrigation system	1.26	1.28	1.30	1.34	1.41	1.48	0.90	0.89	0.90	0.93	0.96	1.00
TFC	3.62	3.69	3.74	3.85	4.06	4.25	2.59	2.55	2.58	2.69	2.76	2.89
Inputs	41.21	41.96	42.44	43.80	46.09	48.28	57.77	56.88	57.42	59.92	61.62	64.41
Labor	16.67	16.98	17.17	17.72	18.65	19.53	11.92	11.74	11.85	12.36	12.72	13.29
Machines and implements	12.01	12.23	12.37	12.76	13.43	14.07	8.59	8.45	8.53	8.90	9.16	9.57
Administration costs	6.27	5.89	5.66	5.36	4.85	4.30	4.50	4.64	4.40	3.85	3.56	2.94
Overhead	16.65	14.81	13.70	12.10	9.32	6.42	11.96	12.66	11.56	8.92	7.43	4.45
Energy	2.71	3.58	4.06	3.55	2.76	2.31	1.80	2.20	2.80	2.48	1.88	1.57
Alternative cost	0.86	0.86	0.86	0.86	0.86	0.86	0.87	0.87	0.87	0.87	0.87	0.87
TVC	96.38	96.31	96.26	96.15	95.95	95.77	97.41	97.44	97.43	97.30	97.24	97.10
TC	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

[1] TFC – total fixed cost (including alternative cost); TVC – total variable cost and TC – total cost.

HN25 treatment had the lowest TFC and highest TVC, relating to the fact that the highest yield was found in this treatment.

In all the treatments tested, the item that contributed the most to the fixed cost was land, whereas the expenses with inputs contributed the least to the variable cost (Table 2). In a study of the profitability of carrot cultivation in the province of Huambo, Angola, it was concluded that the greatest contributions to the variable costs were from the use of fertilizers (39%), seeds (27%) and labor (27%), whereas the greatest contributors to the fixed costs were equipment maintenance (51%) and draught animals (42%) (CHAVES et al., 2009).

For treatment N15, the contribution of the land to the total production cost was 2.15%, the lowest percentage contribution of this resource to the fixed costs for the Nantes cultivar in the tested treatments. For the F1 Nayarit cultivar, treatment HN25 exhibited the lowest value. The greatest percentage contribution of this resource to the fixed costs (2.52% total cost) was observed in treatment N75.

Energy expenses represented 4.06% of the average total cost of each carrot box produced in treatment N35. This treatment received a larger quantity of water and, therefore, required more hours of operation of the irrigation system.

For the Nantes cultivar, the greatest contribution of the variable costs to the total production cost was observed for treatment N15, especially inputs (41.21) and labor (16.67%) expenses. This treatment for this cultivar displayed the highest marketable carrot root yield, and therefore, the costs for the harvest, administration and taxes were higher. For the F1 hybrid cultivar, the HN25 treatment had the largest contributions of the variable costs to the total production cost, especially expenses due to inputs (58.88%) and overhead (12.66%). This treatment had the highest box per hectare yield.

The average total costs for the Nantes cultivar increased with increasing intervals between irrigations (increased soil water tension) (Table 3). For the F1 hybrid Nayarit cultivar, treatment HN25 exhibited the lowest economic and operating costs because this treatment had the highest box per hectare yield. However, this cultivar exhibited an average cost per box of carrots higher than that of the Nantes cultivar, therefore decreasing the profitability per hectare.

The average fixed and variable costs for the production of a box of Nantes cultivar carrots decreased with increasing yield, with the lowest values in treatment N15 (Table 3). The lowest values for the hybrid cultivar were observed for the treatment HN25.

The data shown in Table 3 were used for a simplified economic study, considering R$ 9.13 as the average price of a 20 kg box of carrots, corresponding to the period of October 2010.

The economic study showed different behaviors for the cultivars tested (Table 3). Treatments N15, N25 and N35 of the Nantes cultivar exhibited average returns (AR) higher than average total costs (ATC), indicating situations of supernormal profit (AR > ATC). In these cases, the investment pays for all the resources invested in the economic activity and results in an additional profit that is higher than that of other market alternatives. The medium- and long-term trend is for the carrot agribusiness to expand and for new companies to enter this activity, thus attracting competitive investments. Similar results were reported by Miguel et al. (2008), who calculated supernormal profits in a study of carrot crops, with a 17,874 kg break-even point, a value well below the yield obtained by producers of Bebedouros, SP (33,000 kg ha^{-1}), who therefore had a margin to cover risks of production drops.

The treatment N45 exhibited an ATC equal to the AR of the box of carrots, indicating normal profit (ATC = AR), i.e., re-payment of all the invested resources with compensation equal to other alternatives of capital investment. In this case, the carrot production system will remain without growth but also without decline, and the trend over the short and long term is of equilibrium. Treatments N60 and N75 had negative returns, not covering the variable resources or the working capital (AR < AVCop) spent during the carrot cultivation and making it necessary to subsidize the variable resources. The

Table 3. Average economic and operational production costs of two carrot cultivars, in R$ 20 kg box^{-1}, at different soil water tensions.

Treatments	AFC	AVC	ATC	AFCop	AVCop	ATCop
N15	0.22	5.96	6.18	0.07	5.90	5.97
N25	0.26	6.83	7.09	0.08	6.77	6.85
N35	0.29	7.50	7.79	0.09	7.43	7.52
N45	0.35	8.76	9.11	0.11	8.68	8.79
N60	0.52	12.37	12.89	0.17	12.25	12.42
N75	0.96	21.68	22.64	0.31	21.49	21.80
HN15	0.22	8.38	8.60	0.07	8.30	8.37
HN25	0.21	7.83	8.04	0.07	7.76	7.83
HN35	0.23	8.70	8.93	0.07	8.62	8.69
HN45	0.33	11.87	12.20	0.11	11.77	11.88
HN60	0.43	14.98	15.41	0.14	14.85	14.99
HN75	0.93	31.37	32.30	0.30	31.09	31.39
Average	0.41	12.19	12.60	0.13	12.08	12.21

[1] AFC – average fixed cost; AVC – average variable cost; ATC – average total cost; AFCop – average fixed operating cost; AVCop – average variable operating cost; ATCop – average total operating cost.

best alternative in these cases would be abandoning the activity to decrease the losses.

For the hybrid cultivar, treatments HN15, HN25 and HN35 resulted in a situation of supernormal profit for carrot production, whereas the remaining treatments exhibited negative returns for this cultivar.

4 Conclusions

The soil water tensions of 15 kPa for the Nantes cultivar and 25 kPa for the F1 hybrid Nayarit cultivar resulted in the highest production profitability.

Expenses with variable resources, and especially the cost of inputs, were the greatest contributors to the final carrot-production cost in all the tested treatments.

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