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Efficiency and economic viability of water management in the production of table tomatoes

Carlos Luiz Vieira[1]*, Franciely da Silva Ponce[1], Renê Arnoux da Silva Campos[2], Tadeu Miranda de Queiroz[3], Rivanildo Dallacort[1], Santino Seabra Júnior[3]

[1]Universidade do Estado de Mato Grosso, Tangará da Serra-MT, Brasil
[2]Universidade do Estado de Mato Grosso, Cáceres-MT, Brasil
[3]Universidade do Estado de Mato Grosso, Nova Mutum-MT, Brazil
*Corresponding author, e-mail: carlos.luiz_12@hotmail.com

Abstract

Tomato (*Solanum lycopersicum* L.) cultivation can be expensive, with costs exceeding BRL 100,000 per hectare, which drives the search for tactics that reduce costs. Consequently, strategies have been developed to make it viable in tropical regions and areas with water scarcity. The objective was to evaluate the cost and profitability of water management in table tomato cultivation under different irrigation schedules. This study was carried out using the Fascínio tomato hybrid and four irrigation management approaches (no cutting, 100, 105, and 110 days after sowing, DAS). Harvesting was conducted four times, and the averages were summed toCOE estimate the total and commercial production, as well as the losses, for each irrigation schedule. To calculate the cost, both the effective and total operational costs were considered, referring to the establishment of the crop and to each irrigation cut used. Several economic indicators were calculated, including gross income ($), operating profit ($), profitability index (%), gross margin ($), break-even point (kg), and price break-even point ($/kg).The cost of water for irrigation had little impact on Effective Operating Cost (EOC) and Total Operating Cost (TOC); however, the treatment without cutting irrigation provided greater total and commercial production, which reflected the profitability parameters (OP, PI, GM, break-even point, and price break-even point). The treatment without cutting irrigation was 0.13%, 0.19%, and 0.024% more profitable than the treatments with irrigation cuts at 110, 105, and 100 DAS, respectively. This increase in profitability was justified due to the higher productivity, justifying the maintenance of irrigation in tomato cultivation. The treatment without cutting irrigation provided the highest total and commercial productivity of tomato fruits, with 8099.58 and 7927.36 units, respectively, generating a higher gross revenue of $32,398.32.

Keywords: Economic analysis, economic efficiency, Protected environment, *Solanum lycopersicum*

Introduction

Tomato (*Solanum lycopersicum* L.) is a significant vegetable cultivated in various regions worldwide, contributing significantly to employment generation and income. Brazil stands as one of the largest global producers, ranking 10th with a harvested area of 55,597 hectares, experiencing a 22% decrease over the past decade (FAOSTAT, 2021).

The primary limiting factor for agricultural production in several regions of Brazil is water availability, which directly impacts tomato cultivation. Over the years, climatic conditions have made irrigation an essential technical requirement with considerable economic and social implications (Elame et al., 2016).

Agriculture is highly dependent on climate conditions, making water management a crucial aspect of economic and social development. Climate uncertainties not only contribute to global food insecurity but also significantly affect the living conditions of rural communities, thereby impacting other economic activities (Parween et al., 2021).

The efficiency and valuation of water usage have become central topics of debate. Water assessment has often been viewed from the perspective of farmers, with profitability sometimes mistaken for water efficiency. Various studies have attempted to estimate the value of water based on the net margin per cubic meter (m³) (Parween et al., 2021).

Agriculture is the largest consumer of water resources globally, accounting for approximately 70% to 87% of total freshwater use. Therefore, it is imperative to adopt tools that manage and monitor actual water consumption in food production, as the cost of water is not always factored into the price of products from a business management perspective (Viol et al., 2015).

With the aim of optimizing tomato production,

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analyzing production costs while considering water pricing helps evaluate the economic conditions of the production process. This assessment focuses on critical aspects such as resource profitability and the potential for resource recovery, thereby facilitating informed decision-making to improve production activities and achieve greater satisfaction (Reis & Guimarães, 1986).

The objective of this study was to evaluate the cost and profitability of water management in table tomato cultivation under different irrigation strategies.

Material and Methods

This study was conducted at the University of the State of Mato Grosso (UNEMAT) on the Nova Mutum - MT campus. The municipality is situated at the following coordinates: latitude 13°49'44" south and longitude 56°04'56" west, with an altitude of 460 meters. The climate in the region is classified as type Aw (Köppen), tropical, with concentrated rainfall during the summer (October to April) and dry winter (May to October). The average annual precipitation is 1900 mm, and the average temperature is 26°C (Alvares et al., 2013). The soil in the area is classified as Dystrophic Red-Yellow Latosol (EMBRAPA, 2013).

The experiment was carried out between August and December 2021, and it involved studying the productivity of the Fascínio tomato hybrid (Feltrin®) cultivated under different irrigation schedules (no cut, 100, 105, and 110 days after sowing, DAS).

Tomato cultivation took place in a protected arch-type environment with a height of 3 meters, width of 7 meters, and length of 21 meters. The sides had windows covered with black Sombrite® screen with 50% shading and agricultural film made of transparent polyethylene of 150 µm.

Seedlings were grown in expanded polypropylene trays (162 cells) filled with the Vivato® commercial substrate. The seedlings remained in the nursery for 19 days before transplantation.

Fertilization at planting was based on the chemical analysis of the soil, with the following characteristics: pH (water) = 7.2; P = 106 mg/dm^3; K = 245 cmg/dm^3; Al = 0.0 cmol/dm^3; Ca = 5.2 cmol/dm^3; Mg = 1.9 cmol/dm^3; H + Al = 1.3 cmol/dm^3; B = 1.3 mg.dm^3; Zn = 24.4 mg/dm^3; SB (Sum of Bases) = 7.7 cmol/dm^3; t (effective CTC/CTC at pH 7.0) = 7.7 cmol/dm^3; T = 9.0 cmol/dm^3; V = 86%; m (Al sat.) = 0%, and organic matter - MO (Walkley-Black) = 22.82 g/dm^3. Planting fertilizer was incorporated into the furrow using urea (200 kg ha^{-1} of N), potassium chloride (400 kg ha^{-1} of K_2O), and simple superphosphate (300 kg ha^{-1} of P_2O_5). Top dressing was carried out via fertirrigation, with applications every 3 days, using ammonium sulfate and potassium nitrate (Ribeiro et al., 1999).

Staking was performed using the "Florida weave" technique, where plants were vertically conducted between ribbons arranged horizontally on both sides of the lines and raised as the stems grew.

Harvests began 112 DAS and continued for 133 days, totaling four harvests. The fruits were harvested at stage VI of maturation when they were ripe and red.

The total and commercial productivity and losses due to physiological disturbances were obtained and extrapolated to the greenhouse area (147 m²). The costs of materials required for the structure, conduction, and irrigation systems were also calculated using values obtained from local businesses. The price of tomatoes per kilogram (BRL 4.00 per kg^{-1}.) was obtained according to the CEASA/MT quotation for the growing season.

As Mato Grosso state does not charge for water resources (ANA, 2018), the pricing of the Water Footprint used the average of the amounts charged for the use of Water Resources under the Domain of the Union, fiscal year 2019 - Resolution n. 91, of November 26, 2018 (ANA, 2018). The average value was R$ 0.01795, calculated based on raw water collection from the basins.

The production cost calculation methodology was defined by Matsunaga et al. (1976) regarding the total operating cost (TOC), as described by Martin et al. (1998). The structure of the total operating cost of production comprises the following components:

a) Costs with Manual Operation: These are all costs arising from tasks such as area preparation, bed preparation, sowing, setting up the irrigation system, hole preparation, transplanting seedlings, plant maintenance, fertilization, insecticide application, and harvesting, expressed in reais (R$) per man/day (HD).

b) Costs with Consumed Materials: These are costs associated with the materials consumed, multiplied by their purchase price, including seeds, fertilizers, insecticides, ribbons, and substrates.

c) Effective Operating Cost (EOC): This constitutes the sum of inputs and manual operations.

d) Other Operating Costs: This corresponds to 5% of (EOC).

e) Total Operating Cost (TOC): This is the sum of EOC and operating costs, representing the cost that the producer incurs in the short term to produce and cover other expenses, per hectare, and continue producing.

For the economic analysis of tomato production, the following economic indicators were determined, as described by Martin et al. (1998):

a) Gross Revenue (GR): This is the projected revenue for the activity based on a predetermined sales price (tomato productivity in kg × sale price per kg set by the producer).

b) Operating Profit (OP): This is composed of the difference between the gross revenue (GR)values and the TOC per cultivated area.

c) Profitability Index (PI): This is the ratio between OP and GR, expressed as a percentage (PI = (OP / GR) × 100), indicating the available rate of activity revenue after deducting operating costs.

d) Gross Margin (GM): This is the ratio between GR and TOC (GM = (GR - TOC) / TOC × 100), representing the availability (%) to cover other fixed costs

e) Break-even Point (Production): This allows visualization of how much product needs to be produced to pay the total operating costs (Production = TOC / PV) based on the tomato production costs and the product's selling price (PV).

f) Break-even Point (Price): This determines the minimum selling price per kilogram of tomatoes needed to cover production costs (Price = TOC / p).

Results and Discussion

The total operating cost of cultivating table tomatoes with different irrigation cuts had minimal influence on the applied treatments concerning water costs (**Table 1**). The highest values of EOC and TOC were observed in the cultivation without irrigation cut, with the TOC for this treatment being 0.13%, 0.19%, and 0.24% greater than the TOC obtained in the cultivation with irrigation cut at 110, 105, and 100 days, respectively.

The current water charges are very low, resulting in a maximum difference of R$ 11.00 between EOC and TOC for the various irrigation cuts (no cut x 100 DAS cut). However, this cost is calculated for an area of 147 m² and will increase when extrapolated to a larger area. Additionally, it is crucial to consider that the current low water price may change in the future with a decline in water resources.

Tomato cultivation is known to have a high production cost due to the occurrence of numerous pests, diseases, and nutritional requirements (Nascimento et al., 2021). The estimated costs per hectare exceed 100 thousand reais, equivalent to R$ 25.00 to R$ 30.00 per 23 kg box (HortiBrasil, 2022). Furthermore, during the rainy season, the use of a protected environment is necessary to ensure production quality (Seabra Júnior et al., 2022).

The TOC obtained in this study was higher than that observed by Nascimento et al. (2021) for tomato cultivation in a protected environment, which was R$ 1,477.35. This increase can be attributed to rising input prices, resulting in tripled costs for the same cultivation area, highlighting the need to reduce costs in cultivation and manage water resources responsibly.

Table 1 - Estimation of effective operating cost (EOC) and total operating cost (TOC) of tomato cultivation in a protected environment under different irrigation cuts (m²)

Description	Unit	Quantity	Unit Value (R$)	Área (147 m²)
Protected environment*	unit	1	15,998.00	388.63
Fertigation system*	unit	1	2,500.00	151.83
Seedling trays	unit	0.17	0.32	0.02
Water tank*	unit	1	1,200.00	43.73
Drip hose	m	160	0,5	10.60
Wooden beams	unit	16	11.36	22.08
Bamboo	unit	24	0.5	1.46
Ratchet	unit	16	3	1.17
Wire	kg	190	0,95	13.15
Supplies				
Seeds	unit	324.00	0.39	126.36
Substrate	kg	2.50	75	18.75
P2O5	kg	24.5	12	294
Planting urea	kg	7.35	8.36	61.44
Potassium chloride	Kg	9.8	19.7	193.06
Fertilizer urea	kg	46	8.36	384.56
Potassium nitrate	Kg	17.71	6.12	108.44
Insecticide	g		0.53	136.25
Fungicides	g		0.37	102.90
Tying string	kg	2	13.05	26.10
Total supplies				2,084.51
Services				
Soil preparation	Dh	1	100	100.00
Furrow opening	Hm	1	100	100.00
Furrow fertilization	Dh	1	50	50.00
Seedling transplanting	Dh	1	50	50.00
Fertigation	Dh	44	6.25	275.00
Tying	Dh	17	50	850.00
Spraying	Dh	6	12.5	75.00
Weeding	Dh	7	100	700.00
Harvesting	Dh	4	50	200.00
				2,400.00
Water cost/price				
no cut	m³	107.00	5.35	19.21
110 DAS	m³	66.88	5.35	12.00
105 DAS	m³	53.50	5.35	9.60
100 DAS	m³	40.13	5.35	7.20
Total services				**4,484.51**
Total EOC (No cut)				4,503.72
Total EOC (110 DAS)				4,496.51
Total EOC (105 DAS)				4,494.11
Total EOC (100 DAS)				4,491.71
Total TOC (No cut)				4,727.94
Total TOC (110 DAS)				4,721.70
Total TOC (105 DAS)				4,718.94
Total TOC (100 DAS)				4,716.42

* Lifespan: Environment: 15 years; irrigation system: 10 years; plastic tray: 6 years

The highest total production was achieved in the treatment without an irrigation cut, with a yield of 8.09 tons (**Table 2**). Treatments with an irrigation cut at 110,

Table 2: Total productivity, commercial productivity, losses, and gross income of tomato hybrids produced in protected cultivation under irrigation cuts

Irrigation Cuts	Total Production	Commercial Production	Losses (kg)	Losses (R$)	Gross Revenue (R$)
No cut	8,099.58	7,927.36	172.22	688.87	32,398.32
110	6,176.31	5,668.06	508.25	2,033.00	24,705.23
105	6,820.93	6,490.30	330.63	1,322.52	27,283.72
100	6,927.45	6,656.20	271.25	1,084.98	27,709.79

105, and 100 DAS produced 23.74%, 15.78%, and 14.47% less, respectively, than treatment without an irrigation cut.

Similarly, the highest commercial production was achieved under cultivation without irrigation cuts (7.92 tons). Treatments with an irrigation cut at 110, 105, and 100 DAS resulted in a reduction in commercial production of 28.5%, 18.12%, and 16.03%, respectively. However, the difference observed could not be solely attributed to the irrigation cut, as the most severe cuts at 105 and 110 DAS had a less significant impact on production compared to the cut performed at a later stage, 110 DAS.

The losses obtained were greater in the irrigation cut carried out at 110 DAS, highlighting that this treatment negatively influenced the productive aspects of tomato plants (Table 2). The losses in this treatment exceeded half a ton, being 66.11%, 34.94%, and 46.63% higher than those obtained in the treatment without an irrigation cut and cuts at 105 and 100 DAS, respectively. This resulted in a lost value of BRL 2033.00 when the cut was applied at 110 DAS.

The gross revenue was affected by the irrigation cuts applied, with the treatment without an irrigation cut generating a gross revenue of BRL 32,398.32 (Table 2). Treatments with an irrigation cut at 110, 105, and 100 DAS resulted in a reduction in GR of 28.5%, 18.12%, and 16.03%, respectively. Treatment with irrigation cut at 110 DAS was the most detrimental to production, losses, and gross revenue generation.

Losses in agricultural cultivation may be attributed to various factors, such as pests, weather conditions, and diseases (Ponce et al., 2022; Secretariat et al., 2021). However, water restriction can lead to a reduction in production by causing less fruit filling, flower abortion, and maturation of leaves and fruits (Taiz & Zeiger, 2017). The late irrigation cut may have induced greater stress on the plants due to climatic conditions during that period or even due to imbalances in the water supply, resulting in fruit cracking and scalding.

Regarding profitability indicators, the highest operating profit was obtained in the treatment without an irrigation cut, while cuts at 105 and 110 DAS were still relatively profitable (**Table 3**). Due to lower commercial production and higher losses, the irrigation cut performed at 110 DAS resulted in the lowest OP, being 33.47%, 21.27%, and 18.80% lower than the treatment without irrigation cut and cuts at 105 and 100 DAS, respectively.

Table 3: Profitability indicators of tomato in protected cultivation under irrigation cuts (m²).

Variables	Unit.	No cut	110 DAS	105 DAS	100 DAS
Operating Profit (OP)	R$	26,981.51	17,950.53	21,242.26	21,908.39
Profitability Index (PI)	%	85.09	79.17	81.82	82.29
Gross Margin (GM)	%	570.68	380.17	450.15	464.51
Break-even Point (TOC)	kg	1,181.99	1,180.42	1,179.73	1,179.10
Break-even Point in R$	R$/kg	0.60	0.83	0.73	0.71

The profitability index indicates how profitable the activity can be. All treatments used in the present study showed a high PI of above 80%. The treatment without cutting irrigation had the highest PI, and the treatment with cutting irrigation at 110 DAS provided the lowest PI. The PI obtained in the present study was more than 30% higher than that obtained by Nascimento et al. (2022) who worked with tomato in protected environments and open fields. Ponce et al. (2022), working with cabbage (*Brassica oleracea*var, acephala), observed an PI value above 85%, which demonstrates the profitability of the activity.

The gross margin followed the trend observed throughout the work, in which the treatment without cutting irrigation amounted to 570.68%, which is quite high for the activity. The treatment with irrigation cut at 110 DAS obtained an GM of 380.17%, which was 190.51% lower than the treatment without cutting. The gross margin represents the profit margin for the payment of any costs that may arise, which is important to estimate how safe the activity can be.

Treatments with irrigation cutoffs at 105 and 100 DAS provided an GM of 450.15 and 464.51%, respectively, values close to those obtained by the treatment without cutting irrigation (Table 3). The higher the GM, the safer the activity.

The break-even point is formed by the amount of product that will need to be sold to pay the TOC. As the TOC values were very close, the break-even point followed the difference between treatments. The highest leveling point was obtained in the treatment without cutting irrigation and the lowest when the cut was performed at 100 DAS, with a difference of 2.89 kg (Table 3).

The leveling point/price refers to the minimum value for the sale of kg of tomato to guarantee the payment of the TOC based on production. It was observed that the treatment without cutting irrigation allows the sale of kg of tomato at R$ 0.61, being the lowest price obtained. The treatment with cut irrigation at 110 DAS promoted the highest commercial value of R$ 83.

The irrigation cutoffs at 105 and 100 DAS have minimum commercialization values of R$ 0.73 and R$ 0.71, respectively. These values are quite competitive, making a high profit margin possible for the producer.

Irrigation cutting is a management strategy that is constantly used to concentrate the maturation of industrial tomato fruits; in addition, it allows the concentration of sugars and the elevation of Brix. This allows for better remuneration for the fruits. In table tomatoes, there is still no remuneration for these quality aspects; however, it would be interesting to add value to these quality aspects, which would make it possible to pay for technology or even cutting irrigation.

The insertion of technologies provides guarantees of production in tomato cultivation; however, it is necessary that the costs are added to the final price of the product to guarantee the profitability of the activity (Testa et al., 2014). Otherwise, the producer runs the risk of incurring costs that are impossible to pay for production.

The cost of tomato cultivation in Barcelona, Spain are represented by labor (24.7%), cultivation environment (15%), pest control (12.6%), and irrigation water consumption (9.5%). This is because the cost of rainwater used for irrigation is € 8.7 (m^3), much higher than treated water, which is € 2.5 (m^3) (Peña et al., 2022). In Brazil, the cost of water is not added to other production costs, which makes it difficult to determine how much the value of water represents for the TOC of crops.

Irrigation management in table tomato is still a recent initiative; however, due to the reduction of water resources in the coming years, studies on the application of this technique should be encouraged. This is mainly because agriculture consumes the most water, and it is necessary to reduce this consumption.

Despite the irrigation cut at 110 DAS having provided lower production, which affected the other economic aspects, the irrigation cuts applied at 105 and 100 DAS showed very promising results, and could be management strategies adopted without major damage, mainly in places with water deficits.

All applied irrigation cuts were economically viable, providing profitability, and could be used in tomato cultivation. The cost of irrigating crops in Brazil has little influence on the total operating cost of tomato production. However, the highest total and commercial production was obtained without cutting irrigation, which influenced the profitability parameters.

All treatments used in the present study provided profitability for tomato cultivation, although the treatment without cutting irrigation was the most profitable. However, the cuts at 105 and 100 DAS have productive and economic advantages, providing lower costs and greater profitability in relation to the irrigation cut performed at 110 DAS.

Conclusion

The treatment without cutting irrigation was 0.13%, 0.19%, and 0.24% higher than the cutting treatment at 110, 105, and 100 DAS, respectively; however, due to higher productivity, greater profitability was obtained, justifying the maintenance of irrigation in tomato.

The treatment without cutting irrigation provided the highest total and commercial productivity of tomato fruits at 8099.58 and 7927.36, respectively, generating a higher gross revenue of R$ 32,398.32.

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