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Economic and operational analysis of tomato mechanized harvesting systems for industrial processing

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The determination of the cost of agricultural production is an important tool for controlling and managing productive activities and generating information to support decision-making. The objective of this work was to make technical and economic evaluations of three mechanized tomato harvesting systems for industrial processing through the study of times, movements and the determination of operational costs. The research was conducted during the year 2018 in the municipality of Morrinhos-GO. The productive and unproductive times were collected, and subsequently, an economic analysis of each one as well as the calculation of the internal rate of return according to the useful life of each system were performed. After the data collection and analysis, it was concluded that the productive and unproductive times were similar for the evaluated systems. Only the system formed by the harvester, tractor, hauling and bucket was different from the others in relation to the values in US\$ h^{-1} and US\$ ha^{-1}. From the fourth year, the internal rate of return was positive for all systems evaluated.

Key words: Costs of production, times and motion study, *Solanum lycopersicum*.

INTRODUCTION

Brazil is the 5th largest producer of tomato for industrial processing in South America and she leads the production, being the largest consumer market for its industrialized derivatives. Among the Brazilian states with the highest production of this variety, the state of Goiás stands out, with a transplanted area of 12,670 ha and an average yield of 75,000 kg ha^{-1} (Camargo et al., 2016).

Mechanization has been developing more and more in the different stages of the productive cycle, making possible the substitution of manual labor through the mechanization of crops (Fernandes et al., 2012).

Harvest aid machines can be a valuable alternative for improving labor conditions in the field and increasing harvest yield (Sarig, 2012; Elkins, 2012). Mechanization that replaces hired labor focuses on replacing labor in high-valued crops such as fruits and vegetables. At the beginning of the 20th century, this replacement led to debates about labor-push or labor-pull, where agricultural labor was used in the growing industrial sector (Schmitz and Moss, 2015).

Mechanized harvest of industrial tomato in Brazil has shown greater technical/economic reliability due to better

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cost-benefit ratio, making it attractive for most producers who practice it (Machado et al., 2014).

In this context, the mechanized harvesting of industrial tomatoes becomes important, because if the losses resulting from this operation reduces, there will be an increase in productivity per area; consequently, reflecting in the highest total production in the country (Casa and Evangelista, 2009).

Thus, the maximum utilization of machine functions with the improvement of harvesting techniques; resulting in the maximization of the use of the functions of the factors of production and increased of yield continuously (Pereira et al., 2015).

Regarding the costs of harvesting, the first harvester reduced harvest costs to 33% of total costs. After the electronic sorter was introduced in 1975, harvester costs dropped to 16% of total costs by 1979. Harvest costs have slowly declined since then (Huffman, 2010).

The systematic monitoring of the performance of agricultural machinery and calculations of their operating costs are fundamental factors for rational use. In this way, the operational performance of a machine refers to a complex set of information, which define their attributes, when operations are performed under certain conditions (Piacetini et al., 2012).

Knowledge of operational performance of an agricultural machine has become a growing concern and of utmost importance, because with the advent of mechanization the production costs were directly influenced by the efficiency of the machine in the field (Simões and Silva, 2012).

In this context, the objective of this work was to make technical and economic evaluations of three mechanized tomato harvesting systems for industrial processing; using combinations of equipment formed by the harvester, truck, hauling, bucket, and tractor.

MATERIALS AND METHODS

The study was conducted at Fazenda Santa Rosa, located in the municipality of Morrinhos, Goiás, with the longitude and the latitude of 17°44'31.7"S and 49°03'12.6"W, respectively and an average altitude of 770 m. The research was conducted in the year 2018. The experimental area was restricted to 300 ha for each evaluated system with slightly wavy relief (10%). At harvest time, the predominant soil of the type Dark Red Latosol was with the average water content of 20% (Embrapa, 2013).

The plant material used in this work was tomato cultivar Heinz 9553, which was transplanted in the area using the no-tillage system, with the harvesting process being fulfill approximately 125 days after culture introduction.

The soil corrections and irrigation for the crop were implemented according to the recommendations used for commercial cultivation. The material was transplanted in double rows and at the end of the harvest; it obtained an average yield of 105 tons ha^{-1}.

The equipment used were a self-propelled harvester of the brand Guaresi, model G-89/93 MS 40", with FIAT-Iveco engine of 128.7 kW, with floating collection platform; a truck of the Volkswagen brand, model 31.330, with Cummins ISL engine of 242.7 kW of power and traction 6×4 with body to transport rollon/off buckets of

40 m³; a hauling with 2-axle double wheels with chassis and shock absorber itself of the Imavi brand; and a tractor of the John Deere brand, model 6.130J, with 95.6 kW of nominal power in the engine. Each harvester evaluated, harvested a double row at a time.

To measure the times, a digital chronometer and an extra chronometer were used for case of failures. The collected measures were applied in the scale of seconds, being composed by the time spent in the conduct of harvesting operations, as well as stops of the maneuvers and the displacements, during an eight-hour day's work. For the measurement of the operational velocity, each experimental plot had an area of 60 m² (50 m × 1.2 m) where the harvesters already entered the plot in full working regime.

The times measured were classified as productive and unproductive. The productive times were spent during the action of the machined sets in the field, being determined from the displacements to the execution of harvesting operations.

For the unproductive times, it was considered: auxiliary time (composed of the cleaning time of the harvester and the time for coupling and uncoupling of the hauling), time for maneuvers (sum of maneuver times of each harvesting system) and time for repair and maintenance. The productive and unproductive times of three harvesting systems, that were treated as experimental units and formed by the equipment: system 1, a harvester, a truck, a hauling and two buckets; system 2, a harvester, a tractor, a hauling and a bucket; and system 3, a harvester, a truck and a bucket.

A randomized complete block design was used where 10 repetitions were considered for each time measured in each harvesting system, and the mean of the observed times was used for the determination of field yields and effective field capacity of each harvesting system in the evaluated areas.

The mechanical availability, according to Simões et al. (2010), is defined as the percentage of working time, associated with the machine mechanically able to develop its operations, which comprises disregarding the time spent to perform repairs or maintenance (Equation 1).

$$D_m = \left(\frac{T_{pro}}{T_{pro} + T_{rep}}\right) 100 \qquad (1)$$

where D_m: degree of mechanical availability, %; T_{pro}: productive time, h; and T_{rep}: interruption time for repairs or maintenance, h.

The efficiency of use presents equivalence in relation to the hours used and the total hours; consequently, it comes from the unproductive time of the agricultural machine (Equation 2).

$$E_u = \left(\frac{T_{pro} + T_{aux}}{T_{pro} + T_{imp}}\right) 100 \qquad (2)$$

where E_u: utilization efficiency,%; T_{pro}: productive time, h; T_{aux}: auxiliary time, h; and T_{imp}: unproductive time, h.

To determine the percentage of time effectively worked, the operational efficiency was calculated according to the methodology proposed by Leite et al. (2012), as presented in Equation 3.

$$E_O = \left(\frac{T_{pro}}{T_{pro} + T_{imp}}\right) 100 \qquad (3)$$

where E_o: operating efficiency, %; T_{pro}: productive time, h; and T_{imp}: unproductive time, h.

After the data acquisition, a variance analysis was performed for these values, and subsequently subjected to the Tukey test at 5% probability.

The initial values of the acquisition of the machines and

Table 1. Initial values of acquisition, useful life and working hours per year of machines and implements used in tomato harvesting for industrial processing.

Used equipment	Initial value (US$)	Hours worked/year (h)	Useful life (years)
Truck	84,541.06	873	10
Hauling	16,908.21	873	10
Bucket	2,898.55	873	10
Tractor of 95.6 kW	47,111.44	873	10
Harvester	314,009.66	873	8

Table 2. Mechanical availability, utilization efficiency and operational efficiency of the evaluated systems.

System	Mechanical availability (%)	Utilization efficiency (%)	Operational efficiency (%)
System 1	89.73[a]	87.51[a]	85.91[a]
System 2	90.29[a]	88.39[a]	87.28[a]
System 3	89.40[a]	87.62[a]	85.95[a]

Averages followed by the same letter in column, do not differ statistically among themselves, by Tukey test at 5% probability.

implements were acquired through consultations in resales of the region and are shown in Table 1, where the descriptions of the useful life and the number of hours worked per year are also arranged. Initial values were considered after consulting the machine dealers in the region. The useful life values were the same as those obtained by the CONAB methodology (2010).

After determining the hourly cost of each machine set, the operating costs were expressed in American commercial dollars, official of the Central Bank of Brazil (PTAX 800), at the selling price, per hour of work (US$ h^{-1}). It was considered as exchange rate the price of foreign currency, measured in units and fractions of the national currency, in the amount of R$ 4,14 (30/08/2018).

Operating costs were estimated using the same methodology proposed by Machado et al. (2017). Operating costs were composed by fixed costs and variable costs. Fixed costs composed of depreciation, interest on invested capital and expenses with shelter, insurance and taxes. The variable costs composed of labor, fuels, lubricants, and repair and maintenance costs.

Subsequently, the operational costs in productive and unproductive times of each system were compared by the Tukey test at 5% probability. Statistical analyses were performed using the Minitab 17.0 software.

The annual revenue of each system was calculated considering the total production in each area by the value of the ton of tomato harvested (harvester) or by the value of the ton of tomato transported to industry (transport). The values were separated according to each evaluated system. The average productivity in the area was 100 t ha^{-1}, the value of the ton harvested of R$ 23.00 and the value of the transported ton of R$ 25.00. These values are the values consulted in agroindustries and were practiced in the region during the harvest period.

In determining the cost of production, only the fraction of the total time was considered, during which the harvesting system was programmed to perform productive work, that is, the time actually spent at work.

The annual cost of each system was calculated from the sum of operating costs and the acquisition value of each equipment. For the subsequent years, only the operational cost was considered, and in the last year of the useful life, the residual value of each equipment was added to the operational cost.

To evaluate the attractiveness of the evaluated systems, the Internal Rate of Return (IRR) was calculated, which represents the real profitability of the investment, and for that reason is considered the internal rate of the enterprise. According to Lanna and Reis (2012), it was obtained with the support of Equation 4, expressed as a percentage.

$$\sum_{j=1}^{n} R_j (1 + TIR)^{-j} - \sum_{j=1}^{n} C_j (1 + TIR)^{-j} = 0$$

where IRR: internal rate of return, %; R_j: revenue from the period of time j considered, US$; C_j: costs from the period of time j considered, US$; and N: duration of the project, years.

For the comparison of IRR, the minimum rate of attractiveness of the investment used for the present study was the selic rate that on 30/08/2018 was 7% per year.

RESULTS AND DISCUSSION

The mechanical availability, efficiency of use and operational efficiency were studied using analysis of variance. The means of the variables evaluated did not differ among the harvesting systems used (Table 2). The average speed of the harvesters during the operation was 3.93 km h^{-1}.

It can be observed that the mechanical availability in the different harvest systems was around 89%, that can be explained by the greater proportional time spent to perform corrective maintenance, predicted in the unproductive times, during the operation that consequently generated a decrease in efficiency of use, justified mainly for the loss or impediment of work due to unproductive time. Time spent with repair and maintenance were the same in all three systems, because as there is dependence between the harvester and the transport system, when the equipment is stopped the operation of the other is compromised.

Table 3. Productive, auxiliary, maneuvers and repairs time for the different evaluated systems.

System	Productive time (h)	Auxiliary Time(h)	Maneuvers Time(h)	Repairs time(h)	Unproductive time (h)
System 1	514.25 a	9.55 a	15.88 a	58.88 a	84.31 a
System 2	524.45 a	6.67 a	13.32 a	56.42 a	76.41 a
System 3	519.35 a	10.10 a	13.49 a	61.32 a	84.91 a

Using Tukey test at 5% probability, averages followed by the same letter in column do not differ statistically among themselves.

Table 4. Production costs in US$ h^{-1} (%) for the evaluated systems.

Parameter	System 1 (%)	System 2 (%)	System 3 (%)
Depreciation	34.32 (44.26)	33.34 (48.17)	32.52 (44.77)
Interest	7.77 (10.02)	7.46 (10.78)	7.20 (9.91)
Shelter, insurance and taxes	2.69 (3.47)	1.76 (2.54)	2.58 (3.55)
Fuel	18.92 (24.40)	14.13 (20.41)	16.86 (23.21)
Lubricants	3.42 (4.41)	2.87 (4.15)	3.37 (4.64)
Repair and maintenance	8.70 (11.22)	7.89 (11.40)	8.38 (11.54)
Labor	1.72 (2.22)	1.77 (2.55)	1.72 (2.38)
Total	77.56 (100)	69.22 (100)	72.64 (100)

As there is no similar research in tomato harvesting, the comparison with other crops is necessary. In this context, the objective is to evaluate technically and economically the performance of a harvester at harvest of eucalyptus in forest of first cut. Simões et al. (2010) observed all the experimental plots, for an average mechanical availability of 92.04% that resulted in an average operating efficiency of 91.53% by effective working hours. These values show that the operational efficiency in the eucalyptus harvest in the situation described by the authors is greater than that found in the present study.

The values of operational efficiency were around 86% and are due to less time spent with unproductive times, characterized by a longer productive time spent during the harvesting operation. Evaluating self-propelled harvesters in irrigated rice harvesting, Araldi et al. (2013), concluded that the average operating efficiency in different types of systematization of the soil was 65% with minimum values of 50.8% and maximum values of 77.6%. This shows that the values found in the present work show high efficiency during harvesting in the three evaluated systems.

Table 3 shows the productive and unproductive times for each harvesting system, where the values did not differ from each other. The values were obtained for the harvest of 300 ha in each evaluated system.

In relation to the highest value of productive time, the results are explained by the fact that the harvesting operation was performed at a slower speed and with few stops during the activity; consequently, there was less unproductive time spent with stops, maintenance and maneuvering.

The values of auxiliary times of the machines did not influence the systems, characterized as fast operations, which adjusts well to the harvesting systems that use it. These systems presented a greater facility for performing the maneuvers in relation to system 1. However, this condition did not result in differences in relation to the harvesting system regarding the time spent on this issue.

Harvesting systems presented the same behavior, where the productive times were greater than the unproductive times, which is explained by the values of mechanical availability, efficiency of use and operational efficiency. The values presented indicate a longer time of mechanized sets in operation during the harvesting process.

In Table 4, hourly production costs of each system were separated in fixed costs and variable costs.

The total hourly cost of system 1 was the highest value among the analyzed systems. The sum of fixed and variable costs made this operation cost 77.56 US$ h^{-1}. The fact can be explained by a greater initial value for the truck used in the execution of the operation. In reverse of system 2, the tractor had a lower acquisition cost, which reduced the operating costs. In the three systems analyzed, the highest value for fixed costs was found for the depreciation and for variable costs; while the highest value was spent on fuel.

In this same context and corroborating with the present work, Cunha et al. (2015) evaluated different types of coffee harvesting and concluded that the factors of depreciation, fuel, repairs and maintenance were the elements of the costs that had greater participation in the

Table 5. Costs in productive, unproductive and total times per hectare in each system.

System	Productive (US$ ha^{-1})	Unproductive (US$ ha^{-1})	Total (US$ ha^{-1})
System 1	$108.67 (87.17%)[a]	$15.65 (12,83%)[a]	$124.32 (100%)[a]
System 2	$98.92 (86.90%)[b]	$14.91 (13.10%)[b]	$113.83 (100%)[b]
System 3	$102.80 (86.77%)[a]	$15.67 (13.23%)[a]	$118.47 (100%)[a]

Using Tukey test at 5% probability, averages followed by the same letter in column do not differ statistically among themselves.
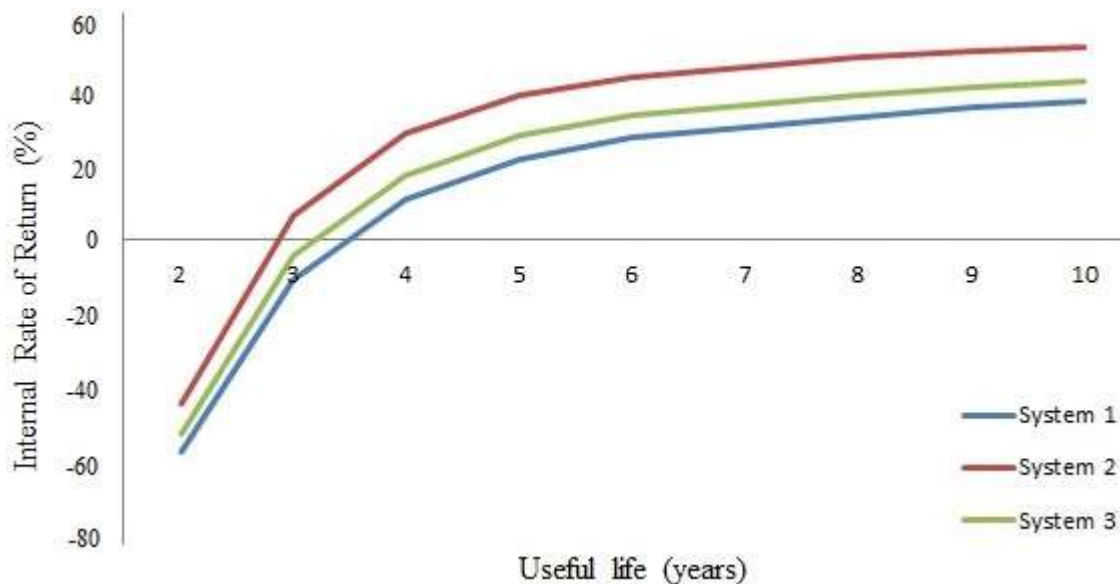
Figure 1. Internal rate of return for the three systems evaluated.

operating costs of the studied mechanized systems.

Oliveira et al. (2009) who analyzed the forest harvest of a forwarder in the extraction of pine logs concluded that fixed costs accounted for 42.8% of total operating costs explained this behavior, and the depreciation obtained 34.1%, which was the factor that mostly influenced the result.

In this context, Simões et al. (2011) analyzed in a subsoiling operation implantation of a commercial forest that the fuel item is the main component among others, which composed of the operating cost of agricultural machinery, directly affecting the final costs of production.

Table 5 shows the results of costs for the realization of different harvesting systems per hectare, considering the costs associated with productive times and unproductive times.

System 2, in addition to differentiating itself from the other harvesting systems, was the one that presented the smallest difference between productive and unproductive times. The total cost of operation in system 2 was lower than systems 1 and 3, because of the lower value of acquisition for tractor, while the others used a truck. These results corroborate with Janini (2008), evaluating

mechanized and semi-mechanized transplantation of sugarcane. Oliveira et al. (2009) and Santos et al. (2016) evaluated different forest harvesting systems and concluded that the greater the operational efficiency of a system, the lower the cost of your operation.

The IRR was calculated for different harvesting systems, as shown in Figure 1. In system 2 it was - 43.07% in the second year. In the third year, the value started positively (8.97%), and it obtained increasing values until the end of the useful life (52.88%). This system obtained the highest initial IRR value because the acquisition value of the tractor is lower than the truck, and this directly influenced the result of the useful life.

System 1 obtained lower value at the end of the useful life of your equipment and it took longer time to obtain positive values over the years. The fourth year of use presented positive value, indicating that the system is paid only from that year. In the other years, until the end of the useful life, the value of IRR increased continuosly. At the end of its useful life, system 1 was paid and it generated a gain of 38.48% on services provided. System 2 obtained a positive IRR value in the third year, having a return to a shorter term.

In this context, from the detailing of the costs of production in the forest harvest, Santos et al. (2016) evaluated that the maximum value of the IRR on the investment of a harvester and a forwarder was obtained in the fifth year. This is useful for two evaluations, with depreciation up to the sixth year of useful life and with depreciation until the fourth year of useful life being the percentage of the order with 34 and 21%, respectively.

All the systems presented superior results in relation to attractiveness rate, considering the selic rate of 12.25% per year, and it demonstrated that the activity is profitable until the end of the useful life of the equipments studied.

Knowledge of economic values, which are part of the culture cycle of industrial tomato, are important to determine the amounts paid to producers. Therefore, new techniques are necessary to reduce production costs and to make the business more attractive within the agribusiness chain.

Conclusions

There was no difference between the factors of mechanical availability, efficiency of use and operational efficiency among the evaluated harvesting systems.

For all harvesting systems, the fixed costs were higher than the variable costs, for values in US$ h^{-1} and for the values in US$ ha^{-1}.

Only the system formed by the harvester, tractor, hauling and bucket (system 2) obtained a lower cost than the others in relation to the values in US$ h^{-1} and US$ ha^{-1}. System 1 presented higher values for costs per hectare when compared with others. System 2 obtained a positive value for Internal Rate of Return after the third year of harvest, while systems 1 and 3 had a positive value after the fourth year of the equipment's useful life.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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