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# Technical and economic analysis of an industrial tomato transplanting system

## Análise técnica e econômica de um sistema de transplantio para tomate industrial

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### Content



**ABSTRACT:**
The semi-mechanized transplanting of industrial tomato seedling has become a viable alternative for producers. With the aim to conduct a technical and economic analysis in industrial tomato transplanting, the work was done employing mechanized sets used to perform the implantation of seedlings. were analyzed times needed to carrying out the operations of these sets and also of their respective fixed and variable costs. The transplant operation had higher operating costs to be mechanized set of larger total time. The total operating cost for the entire area was U.S. $ 5.379.36.
**Keywords:** *Solanum Lycopersicum* L.,, production costs, time and movement, agricultural machinery, mechanized operations.

**RESUMO:**
O transplantio semi-mecanizado de mudas de tomate industrial tem se tornado uma alternativa viável para os produtores. Com o objetivo de se realizar uma análise técnica e econômica no transplantio de tomate industrial, o trabalho foi realizado empregando-se conjuntos mecanizados utilizados para a realização do transplantio de mudas. Foram analisados tempos necessários para a realização das operações desses conjuntos e também os seus respectivos custos fixos e variáveis. A operação de transplantio obteve maior custo operacional por ser o conjunto mecanizado de maior tempo total. O custo operacional total para toda a área foi de U.S.$ 5,379.36.
**Palavras-chave**: *Solanum Lycopersicum* L., custos de produção, tempos e movimento, máquinas agrícolas, operações mecanizadas.

## 1. Introduction

Currently, Brazil is the 5th largest world producer of tomatoes for industrial processing. In South America, leads the production, still being in this region, the largest consumer market its industrialized products. In 2015 the transplanted area was 56,690 ha, of which total production was 3.672 million tons, with an average yield of 64785 kg ha-1. Among the Brazilian states with the highest production, it stands out the state of Goiás, with a total production of 882,800 tons, totaling approximately 24% of national production (IBGE, 2015).

Sites grown with tomato plants intended for industrial processing are planted with seedlings that are grown in trays and then machine-transplanted and even manually transplanted, eliminating the use of beds. The mechanized system relies on fertilizer-dispensing equipment with evenly spaced plows corresponding to the desired seedling distribution for mechanized transplanting. This method of dispersing fertilizer promotes open furrows and applies the fertilizer immediately behind the plow. The entire transplanting process consists of the following steps: fertilizing, harrowing, applying pre-transplant pesticides, and depositing the seedlings by transplanting.

The attainment of good quality seedlings requires the use of substrate that provides the nutrients necessary for the full development of the plant (Ceconi et al., 2007). When this does not occur, fertilization becomes an essential activity, being considered one of the most important factors to ensure a good development of seedlings (Assenheimer, 2009).

Due to the high cost of manual processing, which is hard work and has low operational capacity, transplanting only became viable with the introduction of transplanting machines. Thus, optimization of this production process has become an object of study and technological development.

Molin et al. (2006) note that information on the performance and work capacity of agricultural machinery is greatly important in managing mechanized agricultural systems, assisting in decision-making. Information on performance is usually obtained manually using analyses of time and movement. Information about the operational capability is of great importance for managing mechanized agricultural systems, assisting in administrative decisions aimed at efficiency.

Nagahama et al. (2013) evaluated the performance of an agricultural tractor in terms of soil tillage systems and displacement speeds and concluded that the increased speed provided increment the effective and operational field capacity, in the speed variation, as in the traction force and estimated power, but reduced the yield of the theoretical field.

Cunha et al. (2016) determined the operational capacity and the field efficiency of mechanized sets, used in different mechanized operations in coffee production, since its implementation until the harvest and concluded that operating performance parameters, effective field capacity and respondent time presented a high correlation with the operating speed of mechanized sets.

Determining the cost of agricultural production is an important tool for controlling and managing productive activities, generating information to support decision-making by farmers, and formulating strategies for the public sector (CONAB, 2010). Centeno & Kaercher (2010) report that the costs related the mechanized agricultural operations in the different cultures, represent between 10 and 30% of the total production cost, demonstrating the importance of the choose the most suitable equipment for the production process.

The total cost is formed by the sum of fixed cost and variable cost. According to Rocha et al. (2009), fixed costs include depreciation, interests on the capital invested besides the insurance and accommodation costs, while the variable costs, which are those dependent on machinery use, are the costs of fuel, lubricants, repairs and maintenance and workmanship. Another important factor is the operating cost, which refers to the cost of all the resources that require monetary outlay for productive activity, including depreciation.

In this context, a technical and economic evaluation was performed for a semi-mechanized transplanting system by studying time and movement and determining the operational costs for the processes that constitute the system.

# 2. Materials and methods

This study was conducted at the Santa Rosa farm located in the municipality of Morrinhos, Goiás, Brazil. The average altitude in relation to sea level is 770 m. The site is a commercial property, with a total area of 290 ha; however, the experimental area was restricted to 58 ha under a central pivot irrigation system. The relief is considered slightly wavy. The predominant soil type is dark-red latosol.

The equipment used to perform the transplanting steps was separated by mechanized series according to their operations. These operations were divided between fertilization (intial step at sowing the soil), supplying fertilizer, harrowing, spraying, and transplanting.

Working times during the different transplanting system processes were determined using a digital timer. The times were recorded on a scale of seconds, considering four replicates in each process. This study estimated the time spent performing the operations, stopping, supplying requirement equipment or materials, and moving equipment and materials.

An 8 hour workday was adopted, where the analysis involved the following activities in order of input to the field: row fertilization, supplying fertilizer, harrowing, spraying, and transplanting the seedlings onto the field.

The times measured were separated into productive and unproductive time. Unproductive time was the sum of standby time, time for maneuvering, and time for repairs and maintenance. Productive time was defined by the action of mechanized series in the field determined from the movement of the mechanized series and the time spent executing the operations. The following components were considered to determine the unproductive times: standby time, time for maneuvering, and time for repairs and maintenance.

From the productive and unproductive times that constituted the transplanting process, an extrapolation was made for the total area of 58 ha because the measurements were restricted to 50 m long experimental units. Three replicates for each operation were considered, and the mean of the observed times was used to determine the yield and capacities.

According to Simões et al. (2010), mechanical availability was defined as the percentage of working time that the machine is mechanically able to operate, ignoring the time taken for repairs or maintenance (Equation 1).

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

where,
$D_m$ = Degree of mechanical availability (%);
$T_{pro}$ = Productive time (hours);
$T_{rep}$ = Time interrupted for repairs or maintenance (hours).

Use efficiency was equivalent regarding the hours used and the total hours and consequently was derived from the unproductive time of the agricultural machine (Equation 2).

$$E_u = \left(\frac{T_{pro} + T_{standby}}{T_{pro} + T_{unpro}}\right) 100 \quad (2)$$

where,
$E_u$ = Use efficiency (%);
$T_{pro}$ = Productive time (hours);
$T_{standby}$ = Standby time (hours);
$T_{unpro}$ = Unproductive time (hours).

To determine the percentage of time effectively worked, the operational efficiency was determined according to the method proposed by Oliveira et al. (2009), as shown in Equation 3.

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

where,
$E_o$ = Operational efficiency (%);
$T_{pro}$ = Productive time (hours);
$T_{standby}$ = Standby time (hours).

After the determination of the mechanical availability, operation efficiency and operational efficiency in each operation. There was the analysis of means of each operation and the comparison between them by Tukey test at 5% probability. The statistical analysis was performed using the Assistat 7.7 Beta program.

The operating costs were estimated using the method proposed by the American Society of Agricultural Engineers (ASAE, 2001) with some adaptations, where the costs were divided between fixed costs and variable costs. The total costs in R$ year-1 were subsequently converted into R$ h-1 as a function of the number of hours used each year for each machine. After determining the hourly cost of each mechanized series, the operating costs were expressed in official U.S. dollars (U.S.$) according to the Central Bank of Brazil (Banco Central do Brasil) (PTAX 800) as a selling price per hour of work (U.S.$ h-1). The price of foreign currency was considered as the exchange rate, measured in units and fractions of the Brazilian national currency, the value of R$ 3.49 (07/06/2016).

# 3. Results and discussion

The mechanical availability of the spraying operation was the lowest of all the operations (Table 1) and this was the only operation in which the mechanical availability was statistically different from the others. This behavior which can be explained by more time spent performing corrective maintenance, which consequently led to a decline in use efficiency, mainly explained by loss or impairment due to stops.

**Table 1.** The mechanical availability, use efficiency, and operational efficiency of the different transplanting operations.

| Operations performed | Mechanical Avalilability (%) | Use Efficiency (%) | Opertational Efficiency (%) |
|---|---|---|---|
| Fertilization | 94.94 a | 93.58 a | 74.63 c |
| Transplanting | 96.63 a | 96.44 a | 80.99 b |
| Spraying | 89.48 b | 87.61 b | 53.07 e |
| Harrowing | 96.23 a | 95.85 a | 86.95 a |
| Supplying Fertilizer | 94.81 a | 93.48 a | 68.08 d |
| Averages evaluated by the Tukey test at 5% of probability. | | | |

Except for the spraying operation, that also presented statistical difference from the other operations. the operational efficiency percentages were above those found by Simões et al. (2011), who obtained percentages between 50 and 61% operating efficiency in a study evaluating the operational and economic performance of a farming tractor used for irrigation after planting eucalyptus in the field at different reforestation sites. The behavior of the spray in this parameter was gave through a longer time with maneuvers and opening and closing of the spray bars, which ended up compromising this parameter in this operation.

There were statistical differences between all analyzed operations, showing that the unproductive times influenced directly in measuring this parameter process.
The spray operation, which there was a higher unproductive time, there was a lower operational efficiency among all the operations analyzed due to increased spending
with the supplies of spray tank. The harrowing operation had the highest operating efficiency that didn’t need none supply of implements, and for this reason has greater operational efficiency values of operational efficiency. Because less time was lost due to standby time, with increased productive time spent during the operation.

These values corroborates with Silveira et al. (2006), that assessing the efficiency of operation in soil preparation operations to find an average efficiency obtained in plowing operations (66.0%), disking (62.1%), seeding (42.9%) and cultivation of corn (60.5%) were considered low when compared to values obtained from literature, which reports an efficiency between 70 to 90%.

Table 2 shows the productive and unproductive times; the latter was composed of the standby time for maneuvering and repair and maintenance during different operations. Regarding productive time, the transplanting operation had the highest value, which is explained by the operation being performed slower and with fewer stops during the activity. The spraying operation had a shorter productive time because there was less time spent on repairs and maintenance and on maneuvering and because spraying is an agricultural operation that works faster.

**Table 2.** The productive time, standby time, maneuvering time, and times for repair and maintenance in different transplanting operations.

| **Operations performed** | **Productive time (hours)** | **Standby time (hours)** | **Maneuvering time (hours)** | **Repair and maintenance time (hours)** |
|---|---|---|---|---|
| Fertilization | 28.66 | 9.74 | 1.11 | 1.53 |
| Transplanting | 66.23 | 15.54 | 0.71 | 2.31 |
| Spraying | 3.93 | 3.48 | 0.59 | 0.46 |
| Harrowing | 19.98 | 3.00 | 0.21 | 0.78 |
| Suppllying fertilizer | 14.93 | 7.00 | 0.71 | 0.82 |

The standby time for the transplanting and fertilizing operations was higher. Although this activity is conducted in the field and has less operational capacity due to its slow working speed, there was stopping time for lunch for the tractor operator and workers who waste time with the transplanter.

The maneuvering time was lower for the harrowing operation because the equipment is easily implemented. In contrast, more time was spent on the fertilizing operation because the fertilizer was pulled by the draw bar and has a remote control system, requiring a stop for suspending and lowering the tool during maneuvers.

Time spent on repair and maintenance was lower during the spraying operation. Spraying required less total time than all the other tasks throughout transplanting and demanded less time for repairs and maintenance.

Figure 1 shows the total times of each operation divided between productive and unproductive times. The fertilizing, transplanting, harrowing, and fertilizing operations had higher percentages of productive time. This pattern is explained by increased mechanical availability, use efficiency, and operational efficiency. The harrowing operation stood out with a greater productive time (83.33%). During these same operations, the highest unproductive time percentage was attributed to supplying fertilizers because the standby times caused this factor to have a higher value.

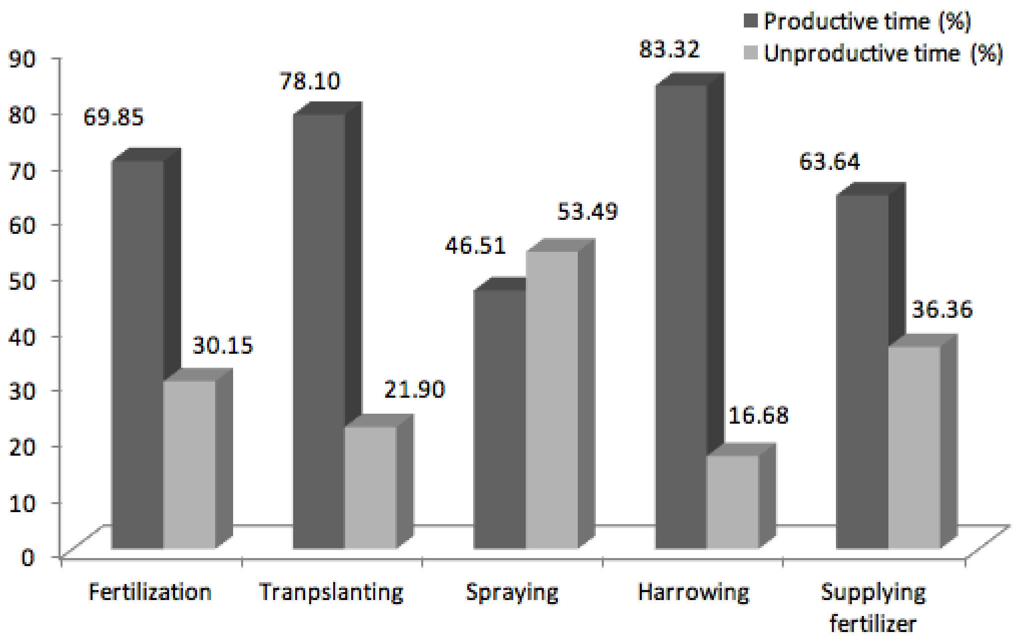


**Figure 1.** Productive and unproductive times of each mechanized operation.

Spraying exhibited contrasting behavior regarding times compared to other operations; the unproductive time (53.50%) was greater than the productive time (46.50%) by 7%. This pattern is explained by the operating speed for the spraying operation being the highest of all the operations, combined with more extensive operational work. Standby time was the main contributor to the increased unproductive time. Because the fertilizer supply was far from the working site, traveling to the site had a relevant contribution to the results obtained. One solution to this problem may be to use reservoir tanks on wheels at sites near the work site, removing the need for the spraying assembly to move to the supply site; however, another mechanical series (tank-tractor) would be required to travel between the supply site and the work site.

According to Simões et al. (2012), the high investment in mechanized operations agroforestry implies secure setting what is the most preconized machine to optimize the operation, bound by the lower costs involved. The authors also describe that the knowledge of the operating performance of an agricultural machine has become a growing concern and of paramount importance, because with the advent of mechanization, production costs were directly influenced by the machine efficiency in the field.

Table 3 shows the production costs of each operation divided between fixed costs and variable costs. The fixed costs consisted of depreciation, interest, overhead, and insurance. The variable costs consisted of labor, lubricants, fuel, and repair and maintenance. These costs were converted to U.S. dollars (U.S.$) and were presented in terms of a working hour.

**Table 3.** Production costs in U.S.$ h-1 of the mechanized series.

| Costs | Fertilization | Transplanting | Spraying | Harrowing | Supplying fertilizer |
|---|---|---|---|---|---|
| Depreciation | 10.32 | 15.27 | 12.13 | 2.88 | 4.05 |
| Interest | 2.43 | 3.26 | 2.38 | 0.95 | 1.23 |
| Over. and ins. | 1.60 | 2.15 | 1.57 | 0.63 | 0.82 |
| Labor | 1.62 | 2.36 | 0.81 | 0.81 | 0.81 |

| | | | | | |
|---|---|---|---|---|---|
| Lubricants | 0.53 | 0.53 | 0.32 | 0.38 | 0.34 |
| Fuel | 7.32 | 7.32 | 3.43 | 4.57 | 6.09 |
| Repair and maintenance | 6.30 | 7.68 | 5.05 | 3.06 | 3.23 |
| Total | 30.12 | 38.57 | 25.69 | 13.28 | 14.38 |

Costs were higher when tractors with higher acquisition costs were used. The hourly total for the transplanting series was highest among all of the mechanized series: the sum of the fixed and variable costs of this operation cost U.S.$ 38.57 h-1. This result can be explained by a higher initial value for the mechanized series used in this operation.

The harrowing operation had the lowest hourly cost, with a value of U.S.$ 13.28 h-1. This low value was possible due to the use of a tractor and low-cost implementation. This operation also had a better cost distribution despite having higher depreciation value because other costs, such as fuel, repairs, and maintenance, were also influential values in this operation.

Cunha et al. (2015) assessed technically and economically various transplanting systems coffee trees of Catuaí IAC 144 cultivar and reported that the depreciation factors, repairs and maintenance and fuel were the cost elements that had the greatest participation in the operating costs of mechanized systems studied, with values above 17%, confirming the trend presented in the present study.

Figure 2 shows the fixed cost and variable cost percentages of each operation. Fixed costs were higher in the transplanting and spraying operations. This pattern indicates that the initial values of tractors and implementing them had more influence on the costs of these operations. There was a greater difference between fixed and variable costs in the spraying operation, where the fixed costs were 25.18% higher than the variable costs.

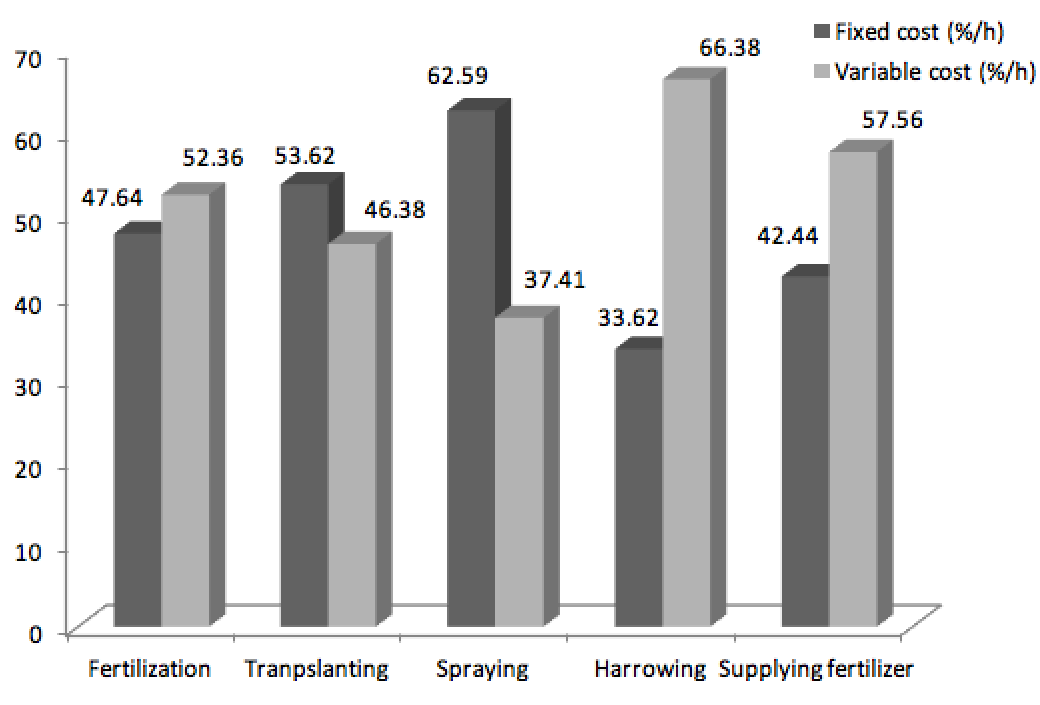


**Figure 2.** Total cost percentages in the various transplanting operations.

This pattern occurs because purchasing tractors and implementing them in the mechanized series does not directly contribute to fuel expense, thus generating a higher fixed cost. This same behavior is explained by Oliveira et al. (2009), who analyzed a Forwarder used to extract pine logs and concluded that the fixed costs together corresponded to 42.8% of the total operating costs, where depreciation was 34.1% of the total fixed cost and was the most influential factor for the final results.

In the operations of fertilization, harrowing, and supplying fertilizers, the variable cost was higher than the fixed cost. Fuel consumption, labor, and repair and maintenance costs drove the higher percentage of variable costs in these operations. Within this context, Simões et al. (2011) found that fuel is the main component of the operational cost of agricultural machinery during a subsoiling operation, directly impacting the final production costs.

Nascimento et al. (2011), that assessed technically and economically that the cut with Fellerbuncher in two tipping positions trees, in eucalyptus forests concluded that the fixed costs corresponded to approximately 30.58% and the variables, 67.35% of the total costs, respectively.

Figure 3 shows the total operation costs for the operations throughout the area of 58 ha, considering the costs associated with productive and unproductive times. Productive times in the operations of fertilization, transplanting, harrowing, and supplying fertilizer to an area of 58 ha cost U.S.$ 863.17, U.S.$ 2554.44, U.S.$ 265.41, and U.S.$ 214.72, respectively. Among all of these operations mentioned, the transplanting operation had the largest difference: the difference between costs in productive and unproductive times was U.S.$ 1,838.84.

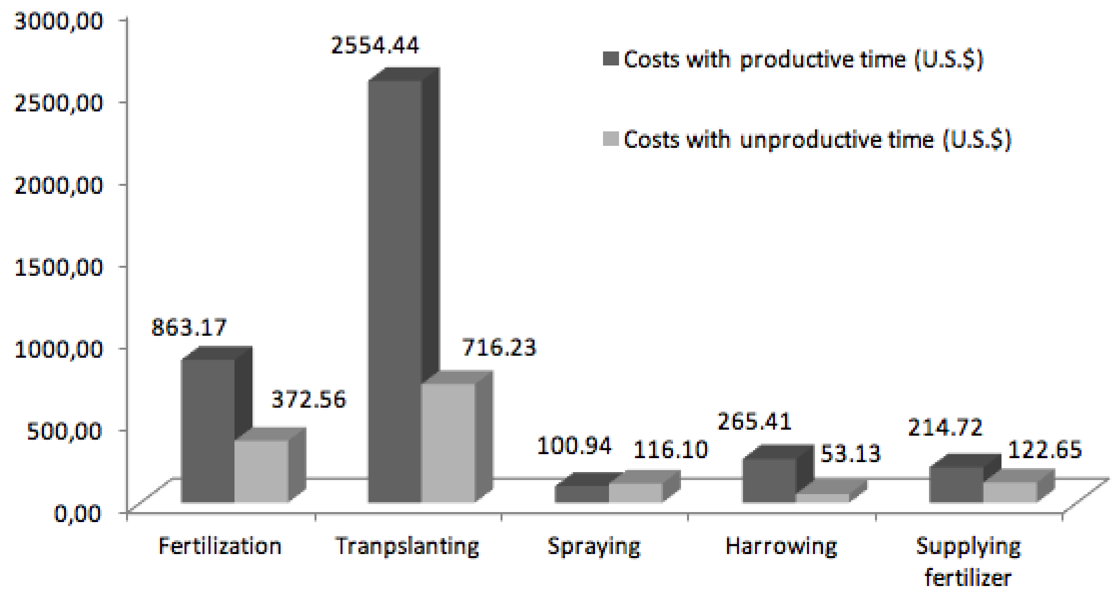


**Figure 3.** Total operation costs regarding productive and unproductive times.

The unproductive times of fertilizing, transplanting, harrowing, and supplying fertilizers did not jeopardize these operations because lower values than the costs during the productive times were obtained for a total area of 58 ha. The operation that had the most balanced productive and unproductive times was the supply of fertilizers, where the productive time cost U.S.$ 92.07 more than the unproductive time.

It is noteworthy that the spraying operation exhibited different behavior compared to the other operations: it is the only one that had higher total costs in unproductive times than the total costs in productive times. The total cost of the operation was U.S.$ 217.04, the lowest cost of all the operations. However, the difference between costs in productive and unproductive times was altered: the unproductive times were more costly (U.S.$ 116.10), and consequently, the smaller portion of the total cost was due to production costs (U.S.$ 100.94). The difference between the productive and unproductive costs was U.S.$ 15.16. This pattern was observed due to increased unproductive time as a function of supplying water and pesticides via spraying, opening and closing times of the equipment bars and time spent maneuvering.

The total cost of mechanization for industrial tomato production with the respective mechanized series, for a total area of 58 ha, was U.S.$ 5,379.36 for the entire transplanting operation period, where 73.59% and 26.40% of the total time was productive and unproductive, respectively.

# 4. Conclusion

Under the conditions in which the experiment was conducted, it can be concluded that the total operation times alter the final values in the mechanized series studied. Also, the time required for repairs and maintenance directly affects the mechanical availability of mechanized series by affecting the number of unforeseen stops.

Depreciation is the main component of the fixed costs of operating farm machinery during the transplanting operation, directly affecting the final production costs.

Fuel is the main component of the variable cost of operating farm machinery during the transplanting operation, directly impacting the final production cost.

In general, transplanting (with all its required operations) had the highest cost of all the operations studied, with a value of U.S.$ 3,270.67. The operating cost for the total area of 58 ha was U.S.$ 5,379.36.

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