TECHNICAL PAPER

OPERATIONAL PERFORMANCE OF THE MECHANIZED AND SEMI-MECHANIZED POTATO HARVEST

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ABSTRACT: Potato is an important crop plant throughout the world. Harvesting is a fundamental step in its production system. Maybe, it is the most complex and expensive operation. Thus, the objective of this work was to compare the cost of the mechanized and semi-mechanized harvest, the operational capacity and the production losses during the potato harvest process. The work was accomplished in a commercial farming, cultivated under pivot system, in the municipal district of Perdizes - MG, Brazil. A completely randomized design with two treatments was used: mechanized and semi-mechanized harvest. The mechanized harvest used a self-propelled harvester. In the semi-automated harvest, a digger mounted on tractor was used and the potato was manually harvested. It was concluded that the cost of mechanized harvest was 49.03% lower than the cost of semi-mechanized harvest. On average, the harvester had a work for 23 workers in manual harvest. Mechanized harvest showed losses of 2.35% of potato yield, while the semi-mechanized harvest showed losses of 6.32%.

KEYWORDS: mechanical harvest, field efficiency, operational cost, *Solanum tuberosum*.

DESEMPENHO OPERACIONAL DA COLHEITA MECANIZADA E SEMIMECANIZADA DE BATATA

RESUMO: A batata é a cultura olerácea mais importante em todo o mundo. Dentre os processos que compõem seu sistema de produção, a colheita apresenta-se como etapa essencial, sendo uma das operações com maior custo agregado. O objetivo deste trabalho foi comparar a colheita mecanizada e semimecanizada da cultura da batata no que diz respeito aos custos, capacidade operacional e perdas de produção. O trabalho foi realizado em lavoura comercial, cultivada em área sob sistema de pivô central, no município de Perdizes-MG. O delineamento experimental utilizado foi o inteiramente casualizado, com dois tratamentos: colheita mecanizada e semimecanizada. A colheita mecanizada foi realizada utilizando-se de uma colhedora autopropelida. Na colheita semimecanizada, empregou-se um arrancador tratorizado seguido de catação manual. De acordo com os resultados, pôde-se concluir que o custo da colheita mecanizada foi 49,03% menor do que o custo da colheita semimecanizada. Em média, a colhedora realizou um trabalho relativo a 23 trabalhadores em catação manual. A colheita mecanizada apresentou perdas de 2,35% em relação à produtividade da área, enquanto a colheita semimecanizada apresentou perdas de 6,32%.

PALAVRAS-CHAVE: colheita mecânica, eficiência de campo, custo operacional, *Solanum tuberosum*.

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INTRODUCTION

The potato (*Solanum tuberosum* L.), Solanaceae, is the most important oleracea culture around the world. It is considered the fourth largest source of human food, standing after rice, wheat and corn. The global annual production of potato is around 321 million tons, being cultivated in about 125 countries. More than a billion people eat potatoes every day around the world (MULLINS et al., 2006; STRECK et al., 2006).

In Brazil, the South and Southeast regions are the main producers of potatoes, and are grown by small, medium and large farmers (FERREIRA & HENRIQUE NETTO, 2007). However, many of them are moving away from the activity due to the increased production costs, mainly related to labor and inputs, making it an urgent need to discover alternatives for its reduction (FIOREZE & CERETTA, 2006).

Among the processes that make up the production system of potato cultivation, harvesting is presented as a crucial step, and one of the most expensive in the production process (MILNE, 2007). In Brazil, harvesting is usually performed manually or semi-mechanized, and share responsibility for the high cost of production (GOMES, 2002).

In the semi-mechanized harvesting, diggers are used, coupled to a tractor, which degrade the furrows and expose the tubers. Later, the collection is done manually by men or young women who also carry out a preliminary selection field. However, self-propelled harvesters have been used in advanced countries for potato culture. The trend toward mechanization of the total harvest is related to the availability and cost of manpower. These harvesters chop the furrows apart and collect the potatoes, in two or more rows, directing them to the carrier trucks. They are larger machines, which require elongated rows to avoid maneuvers and frequent loss of time (FILGUEIRA, 2003), which reduce the operational capability of the machine.

According to GOMES (2002), the process of mechanized harvesting of potatoes can represent a great advance for the producing regions, mainly to optimize the production process, with increased production area, faster removal of tubers from the ground when free risk of attack from pests and diseases, and stronger compliance with delivery dates of production. However, the decision to invest invariably involves risks, which must be provided when one decide to invest in certain equipment. The acquisition of harvesters involves high investment, and is only justified if there is a significant effect on the profitability of the activity (DIAS et al., 2007). The selection of an agricultural machine can become a daunting task, because there are many variables to consider, and choose the most appropriate equipment to a farm is one of the most important stages of the production process (BAIO et al., 2004).

The potato harvesters specialized in supplying the potato industry began a movement for the acquisition and exchange of experiences with imported potato harvesters, and this created, consequently, a demand for information relating to real opportunities for the improvement that the harvest mechanization has facilitated (GOMES, 2002). With the advent of new technologies, studies are needed to quantify the real operational capability and costs of these new harvesters, as well as any loss of tubers during harvest, given the low availability of such data and the recent entry of self-propelled harvesters in Brazil.

Thus, this study aimed to compare harvest and semi-mechanized regarding the costs, operational capacity and production losses during the harvest of potato.

MATERIAL AND METHODS

The work was conducted in a commercial potato crop grown in the area under the center pivot system, in Agua Santa, owned by Emilio John Rochet, in the municipal district of Perdizes, State of Minas Gerais, Brazil. The varieties that were planted were Asterix and Cupid, spaced 0.38 m between plants and between rows, and 0.8 m depth of 0.12 m. The crop was planted on June 24th, 2009 and the harvesting began on October 21st, 2009. The predominant soil type is sandy clay loam soil.

The experimental design was completely randomized with two treatments: mechanized harvesting and semi-mechanized harvesting. Initially, we determined the average productivity, using 10 random samplings throughout the studied area.

For the analysis of the theoretical (Cot) and effective (Coe) operational capacity of the mechanized harvesting and the digger mounted on tractor, five samples were made, and for the analysis of theoretical and effective operational capacity of the gathering of tubers by collectors, four samples were made six different laborers. For the analysis of losses in the semi-mechanized harvest, 10 samples were made on randomly chosen points in each area.

Mechanized harvesting of potatoes was carried out in 54 acres using a self-propelled harvester from the brand German Grimme (Figure 1). The economic and operational characteristics of the combine were described in Table 1. All operational data were obtained directly from the manufacturer of the machine, and the economic data were obtained on the property where the work was done.

(a)

(b)

(c)

(d)

FIGURE 1. Self-propelled potato harvester Grimme SF 150-60. (a) Harvester overview. (b) Intake. (c) Deposit. (d) Moving floor bunker.

In the semi-mechanized harvesting, held on 38 hectares, we used a tractor-implement digger followed by manual picking. The economic and operational characteristics of the tractor and the digger (Figure 2), used in semi-mechanized harvesting, were described in Table 1.

TABLE 1. Technical-economic characteristics of the self-propelled harvester, tractor and potato digger.

Characteristics	Description
Self-propelled harvester	
Brand	Grimme
Model	SF 150-60
Number of rows	2
Harvest width	1.30 m
Engine Power	206 kW
Acquisition value	R$ 882,023.99
Service life	10 years
Average work speed	6.5 km h^{-1}
Interest rate	7.5% per year
Salary + operator charges	R$ 1,569.6 $month^{-1}$
Salary + laborers charges	R$ 981.6 $month^{-1}$
Diesel	R$ 1.70 L^{-1}
Lubrificanting oil	R$ 7.86 L^{-1}
Grease	R$ 9.8 kg^{-1}
Annual work hours	1,000 hours
Tractor	
Brand	John Deere
Model	6300 4 x 2 TDA
Engine Power	74 kW
Acquisition value	R$ 60,000.00
Service life	10 years
Average speed with the digger	2.5 km h^{-1}
Interest rate	7.5% per year
Salary + operator charges	R$ 1,081.25 $month^{-1}$
Diesel	R$ 1.70 L^{-1}
Lubrificanting oil	R$ 7.86 L^{-1}
Grease	R$ 9.80 kg^{-1}
Annual work hours	1,000 hours
Potato digger	
Brand	Hennipman
Model	WH 20 2L
Number of rows	2
Working Width	1.3 m
Acquisition value	R$ 36,190.00
Service life	5 years
Interest rate	7.5% per year
Annual work hours	1,000 horas

(a) (b)

FIGURE 2. Semi-mechanized potato harvest. (a) Digger mounted on tractor. (b) Manual harvest.

The productivity of the area was analyzed by collecting and weighing up all the tubers in plots of 4 m², chosen at random in the area to be harvested mechanically, and in the area to be semi-mechanically harvested.

Subsequently, we assessed the operational capacity of the combine, the digger mounted on tractor and the tubers of potatoes, following the methodology of CENTENO & KAERCHER (2010), which can be consulted for details. For mechanized sets, operational capacity was calculated theoretically taking into account the working width and speed, and effective operating capacity was calculated taking into account the area actually worked per unit of time, considering the time lost.

The theoretical operational capability of hauling operation of the tubers was calculated with the average speed of the collection of the tubers, and the width of the swath of potatoes collected. To determine the speed of collection, we marked an area of 4 square meters (1.30 m x 3.08 m), where the tubers were removed from the soil by a digger mounted on tractor. Subsequently, the time period of the collection of the tubers made by the collector without stopping was timed. The same operation was repeated by six laborers, with four repetitions. The laborers studied were: a 23-year-old man with 7 months experience in the operation of collecting potatoes; a woman, 21 years old, 5 months of experience; a man, 19 years, 6 months experience; woman, 22 years, one year of experience; man, 23 years old, 2.5 years of experience; and woman, 23 years old, 3 years of experience.

To determine the effective operational capacity of the collecting operation of the tubers, the total time to complete the bag used in the harvest (50 kg) was clocked and then the area needed to fill the bag measured. The study considered the total time, that is, the time spent at the collecting operation, the time spent on necessary stops and shifts in the area harvested and emptying the bag. As the bags are standardized, the operation was carried out by six employees and four repetitions for each worker.

All the costs of mechanized (harvester, an operator and four assistants for the separation of stones and clods) and semi-mechanized (digger mounted on tractor, an operator and the cost of collecting tubers) potato harvestings were also estimated, following the methodology proposed by CENTENO & KAERCHER (2010). As a fixed cost, the study considered: depreciation, costs on capital (interest), shelter and insurance. As variable costs: fuel, lubricant, grease, maintenance and manpower. For shelter and insurance, 3% per year on the original purchase price was considered. To calculate the number of hours worked per month by the machine operators, the study considered eight hours per day and 22 days per month, in a total of 176 hours per month.

The cost of collecting operation of the tubers was estimated at R$ 0.90 (Brazilian currency) per bag (50 kg), according to data obtained on the property where the study was done, in view of the amount paid to the manpower.

The assessment of crop losses was performed by collecting and weighing, in each of the sampling points, the remaining tubers, immediately after the passage of the harvester and collectors. A hoe for the manual tilling of the soil was used for this evaluation in order to collect all the tubers remaining under and above the ground. The loss data were obtained in an area of four square meters for each of the ten sampled points.

The results obtained for effective operational capacity and losses in the mechanized and semi-mechanized harvestings were compared by Student's t test, at 0.05 probability level.

RESULTS AND DISCUSSION

The average productivity of the area was 44,350 kg ha^{-1} (887 bags of 50 kg per hectare), with a coefficient of variation of 5.09%. According to Agrianual 2010 (AGRIANUAL, 2010), the Brazilian average productivity is around 24,300 kg ha^{-1}, which shows that in the studied area a high technological level is used. We also emphasize that it is an irrigated area, which maximizes production.

The theoretical operational capability of the harvester was 0.850 ha h^{-1}, that is, if all the time that the harvester is in the field is spent exclusively with the operation of the harvest, this has the capacity to gather, in one hour, 0.85 hectares, or 8,500 m2 h^{-1}. For the effective operational capacity, an average of 0.650 ha h^{-1} was found, that is, taking into account the time with stops in the field, whether to refuel or unloading of potatoes harvested, the harvester is considered capable of harvesting 0.650 ha h^{-1} or 6,500 m2 h^{-1}. This results in a field efficiency of 77%, which means that, during the harvest, 77% of the time is spent exclusively with the harvest and 33% of the time is spent on other activities. A similar result was found by GOMES (2002) to evaluate the operating performance of five potato tractor-implement harvesters.

According to MOLIN et al. (2006), this information about the operational capability are of great importance in mechanized agricultural systems management, assisting in decisions made by management, aiming its optimization. It is noteworthy that an important point, detected on the property, to increase the efficiency of the harvest field is the logistics of the fleet of trucks to unload the machine. In the virtues of its productive capacity, there is a need for efficient management of the availability of trucks to prevent the stop of the harvest time to wait for them.

Regarding the semi-mechanized harvesting, the analysis of the theoretical operational capacity of the digger mounted on tractor resulted in a 0.325 ha h^{-1}. The effective operating capacity was 0.227 ha h^{-1}. The theoretical operational capacity of the collecting operation of the tubers was 0.0374 ha h^{-1}, that is, if the worker spent all the time that he remained in the field exclusively collecting the tubers, he could collect an area of 374 m^2 h^{-1}. The effective operating capacity of the collecting operation of the tubers found was to be 0.0321 ha h^{-1}, resulting in a field efficiency of 86%.

SILVEIRA et al. (2006), studying the efficiency of field machinery for soil preparation, planting and cultivation, found efficiency values of field ranging from 49% to 66%. According to the authors, this parameter for machines that work with tillage, as in the present study, is quite variable and may be influenced by several factors, including soil characteristics.

Knowing, then, that the effective operational capacity of the digger mounted on tractor is 0.227 ha h^{-1}, we discover that, to work one hectare, 4.40 hours are spent. Knowing also that the effective operational capacity of the collecting operation of the tubers is 0.032 ha h^{-1} per worker, we discover that, to collect the tubers of one hectare, 31.15 hours are spent. Adding to the time of the removal and collection of tubers, we obtain 35.55 hours to harvest one hectare, that is, the digger mounted on tractor and a laborer to collect the tubers have the capacity to harvest 0.0281 ha h^{-1} or 281 m^2 h^{-1}.

The effective operating capacity of mechanized harvesting is 0.650 ha h^{-1}, since the capacity of semi-mechanized harvesting is 0.028 ha h^{-1}. This shows that there is a ratio of 1 to 23, that is, a harvester is equivalent to 23 laborers, i.e., to obtain the same as analyzed the harvester, 23 laborers would be theoretically necessary. It is important to point out that the evaluations of the theoretical and effective operational capacities of the collection of the tubers were held in the morning, that is, on the period of the day on which laborers have a higher efficiency, thus, during the day, laborers efficiency may decrease.

These results obtained for effective operational capacity of mechanized and semi-mechanized harvestings proved to be statistically different when subjected to t test for two samples, assuming unequal variances at a 0.05 probability. GOMES (2002), evaluating the operating performance of five potato harvesters, found lower values of effective operational capacity, however, all the machines evaluated were tractor-implement and smaller in comparison to the self-propelled harvester evaluated in this study.

Concerning the study cost, mechanized harvesting of potatoes had a total fixed cost of R$ 142.22 h^{-1} and total variable cost of R$ 204.60 h^{-1}. Table 2 presents the breakdown of fixed and variable costs of mechanized harvesting. Armed with effective operational capability of mechanized harvesting, we have that the total cost per hectare was R$ 533.57.

TABLE 2. Fixed and variable costs of the mechanized harvest system.

Fixed Costs		Variable Costs	
Description	Value (R$ h^{-1})	Description	Value (R$ h^{-1})
Depreciation	79.38	Fuel	77.99
Interest	36.38	Lubricant	1.11
Shelter and Insurance	26.46	Grease	0.49
		Maintenance	88.20
		Manpower	36.81
Total	142.22	Total	204.60

Note that among the variable costs (Table 2), the expenses on fuel and maintenance were the most expressive, requiring special attention with regard to controlling spending. Similar results were found by FREITAS et al. (2004). One way to keep this cost within the standards would be to establish a rigorous preventive maintenance schedule.

The tractor used in semi-mechanized harvesting had a fixed cost of R$ 9.68 h^{-1} and variable cost of R$ 35.41 h^{-1}. Table 3 presents the details of each component of fixed and variable costs of the tractor. The total cost per hectare was R$ 198.63, however the costs of gathering starter and should be analyzed in conjunction with the tractor. The fuel costs were the most expressive, agreeing also with FREITAS et al. (2004).

TABLE 3. Fixed and variable costs of the tractor used in the semi-mechanized harvest system.

Fixed costs		Variable costs	
Description	Value (R$ h^{-1})	Description	Value (R$ h^{-1})
Depreciation	5.40	Fuel	22.31
Interest	2.48	Lubricant	0.47
Shelter and Insurance	1.80	Grease	0.49
		Maintenance	6.00
		Manpower	6.14
Total	9.68	Total	35.41

The root system showed a fixed cost of R$ 9.08 h^{-1} and a variable cost of R$ 2.30 h^{-1}. In Table 4, we have the details of each component of fixed and variable costs of the digger. The total cost per hectare was R$ 50.13.

TABLE 4. Fixed and variable costs of the digger used in the semi-mechanized harvest system.

Fixed Costs		Variable Costs	
Description	Valor (R$ h^{-1})	Description	Value (R$ h^{-1})
Depreciation	6.51	Grease	0.49
Interest	1.49	Maintenance	1.81
Shelter and Insurance	1.08		
Total	9.08	Total	2.30

Knowing that the operational capability of collecting the tubers is 0.032 ha h^{-1}, and in 1 acre of property studied 887 bags were found, the study concludes that in 0.032 hectares 28.38 bags are found. As the cost of the collecting operation is R$ 0.90 per bag, the operation of collection of the tubers has the value of R$ 25.54 h^{-1}. The cost per hectare, then, is R$ 798.13.

Comparing these data, it is observed that the total cost per hour of mechanized harvesting is R$ 346.82, and per hectare of R$ 533.57. However, semi-mechanized harvesting has a total cost per hour of R$ 82.01 per hectare and a cost of R$ 1,046.89. There is therefore a difference of approximately R$ 513.32 between the costs per hectare of semi-mechanized and mechanized harvesting. Similar comparison was performed by RODRIGUES & SAAB (2007), studying the mechanized and manual harvesting for cane sugar. The authors observed a reduction of 33% in favor of the cost per ton harvested mechanically.

With respect to losses, the study observed in the mechanized harvesting an average of 1,042 kg ha^{-1}, and in the semi-mechanized harvesting, 2,801 kg ha^{-1}. These results were statistically different when subjected to t test for two samples assuming unequal variances, at a 0.05 probability level.

It is also noteworthy two other important characteristics of the harvesting process, not evaluated in this study: not causing damage to potatoes (MILNE, 2007) and not causing large losses of soil (RUYSSCHAERT et al., 2006). In addition to affordable costs, the harvesting process should minimize injury to potatoes, objecting the enhancing of the quality of the final product, whether for industry or consumer, and not promote the removal of soil from cultivated areas.

CONCLUSIONS

The total cost of mechanized harvesting was 49.03% lower than the total cost of the semi-mechanized harvesting;

The effective operating capacity of mechanized harvesting was greater than the semi-mechanized harvesting. On average, the harvester performed a work relating to 23 laborers in manual collecting; and

Mechanized harvesting showed losses of 2.35% compared to the productivity of the area, while semi-mechanized harvesting showed losses of 6.32%.

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