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TECHNICAL PAPER

SIMULATION OF DISTANCE BETWEEN FIELD AND REPLENISHMENT PUMP IN MECHANIZED SPRAYING OF SUGARCANE (*Saccharum* spp.)

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KEYWORDS

cost, agricultural mechanization, computational model, hydraulic sprayers, planning and management.

ABSTRACT

Brazil is the world's largest producer of sugarcane destined for mills. Spraying in sugarcane plantations is carried out in extensive cultivation areas and with self-propelled, tractor-driven, and aerial hydraulic equipment. For this, a good positioning of the replenishment pump of agricultural defensives close to the field where the spraying is carried out is necessary. However, it is desirable that the replenishment be carried out at short distances between the field and replenishment pump. This study aimed to assess the impact of the distance between the field and replenishment pump on the operational cost of hydraulic sprayers for sugarcane farming practices. Due to the difficulty in accomplishing the work and meeting the objective under field conditions, we decided to develop a computational model called *"TratoCana"* in a spreadsheet and programming language. The model was verified for possible routine errors, validated, and used in the analysis of factors and in the generation of scenarios. The results showed that the increased average distance between the field and replenishment pump has a negative impact on the operational and economic performance of the machine.

INTRODUCTION

In Brazil, the sugarcane planted area is estimated at 8.61 million hectares in the 2018/2019 season, which represents a total production of 625.96 million tons (CONAB, 2018).

The mechanized spraying system of sugarcane has its productive functioning in the field and auxiliary operation in the roads, the place where the replenishment with agricultural defensives occurs. For this, spraying machines need to run a distance between the field and replenishment pump. However, this distance influences the auxiliary time, especially the equipment service operational time. According to Santos et al. (2015a), the service operational time expresses the managerial conditions for the equipment to perform the operation considering several means of execution such as the distance between the field and replenishment pump.

According to Santos et al. (2015a), the service operational time is composed of productive, accessory, auxiliary, inaptitude, lost, and worked time. These times represent the field efficiency (FE) of the machine in the system. For Araldi et al. (2013); Banchi et al. (2008a); Barbosa et al. (2015); Cervi et al. (2015); Jokiniemi et al. (2012); Oduma et al. (2015); Linhares et al. (2012); Ma et al. (2015); Nascimento et al. (2016); Neres et al. (2012); Rivera et al. (2012); Simões et al. (2011) and Yousif et al. (2013), this is the ratio between effectively used time and total time for equipment operation. The operational time Santos et al. (2015a); Shamshiri & Ismail (2013) and Zhou et al. (2015) and Çanakci et al. (2011); Civelek & Say (2016); Santos et al. (2015b); Santos et al. (2014a) and Zaied et al. (2014) have a participation in the equipment operational performance, which has a direct influence on the economic performance.

For this, the management of agricultural machinery refers to their operational and economic performance. The operational performance considers the variable field efficiency and the economic variable is formed by the annual fixed and hourly costs, as well as with fuel, repair, maintenance, and operational (Balastreire, 1990; Hunt, 1995; Mialhe, 1974).

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However, due to the relevance of the distance between the field and replenishment pump in the operational and economic performance of mechanized spraying system. The aim of this study is to assess the impact caused by the distance between the field and replenishment pump on the operational cost of hydraulic sprayers for sugarcane farming practices.

MATERIAL AND METHODS

We considered a model scenario for a mill, called Fictitious Mill, with an area of 22,000 ha. Spraying system consisted of self-propelled, tractor-driven, and aerial hydraulic sprayers. The economic, technical, and operational characteristics of the equipment are shown in Table 1.

TABLE 1. Economic, technical, and operational variables of the equipment.

Variable	Abbreviation	Unit	Sprayer (self-propelled)	Tractor-driven	Sprayer	Aerial
Initial Value	IV	US$	170,811	38,108	37,838	233,784
Rated Power	RP	kW/CV	147/200	74/100	-	238/324
Number of Tips	NT	Number	56	-	49	42
Spacing between Tips	ST	m	0.5	-	0.5	0.3571
Total Tank Volume	TTV	L	3,000	-	3,000	950
Operating Speed	OS	m s^{-1}	2.5	2.5		61.66
Threshold Maneuvering Speed	TMS	m s^{-1}	1.38	1.38		-
Replenishment Speed	RS	m s^{-1}	5.55	5.55		-
Speed of Transfer from the Runway to the Field	STRF	m s^{-1}	-	-		77.77

A computational model called *"TratoCana" Version 2.0* was developed aiming at meeting the basic characteristics of mechanized spraying for sugarcane cultivation. The model is based on the flowchart shown in Figure 1, elaborated according to the symbology proposed by (Oakland, 2007).

The *"TratoCana" Version 2.0* was developed in an *Excel®* spreadsheet and *Visual Basic®* programming language. The model begins its functioning (1)[2] with the crop data input (2), such as the area to be sprayed. The item (3) refers to the climate data input total number of days to perform spraying, working day, relative air humidity, air temperature, and wind speed. Crop and climate data resulted in the operational pace (4).

Data input (5) refers to the technical/operational characteristics of ground spraying number of tips, spacing between tips, tip flow, replenishment time, average distance between the field and replenishment pump, average length of cultivation strip, operating speed, threshold maneuvering speed, replenishment speed, total volume of the sprayer tank, field efficiency, and others.

Data input (6) refers to the technical/operational characteristics of aerial spraying number of tips, spacing between tips, tip flow, replenishment time, average distance between the field and replenishment pump, average distance between the field and runway, average length of cultivation strip, operating speed, speed of transfer from the runway to the field, effective strip width, time of each return curve, ground time between each flight, aerial application rate, total volume of the sprayer tank, field efficiency, and others.

The operational pace associated with technical/operational characteristics of spraying determines the sprayer[3] operational performance, tractor-driven sprayer, and airplane (7): time available, operational field capacity (OFC), application volume, total application flow rate, total displacement and replenishment time, total distance traveled, machine-hour, and number of equipment required.

[2] The numbers in parentheses refer to the flow chart of Figure 1.

[3] When the text refers to the word sprayer alone, it means the self-propelled equipment.

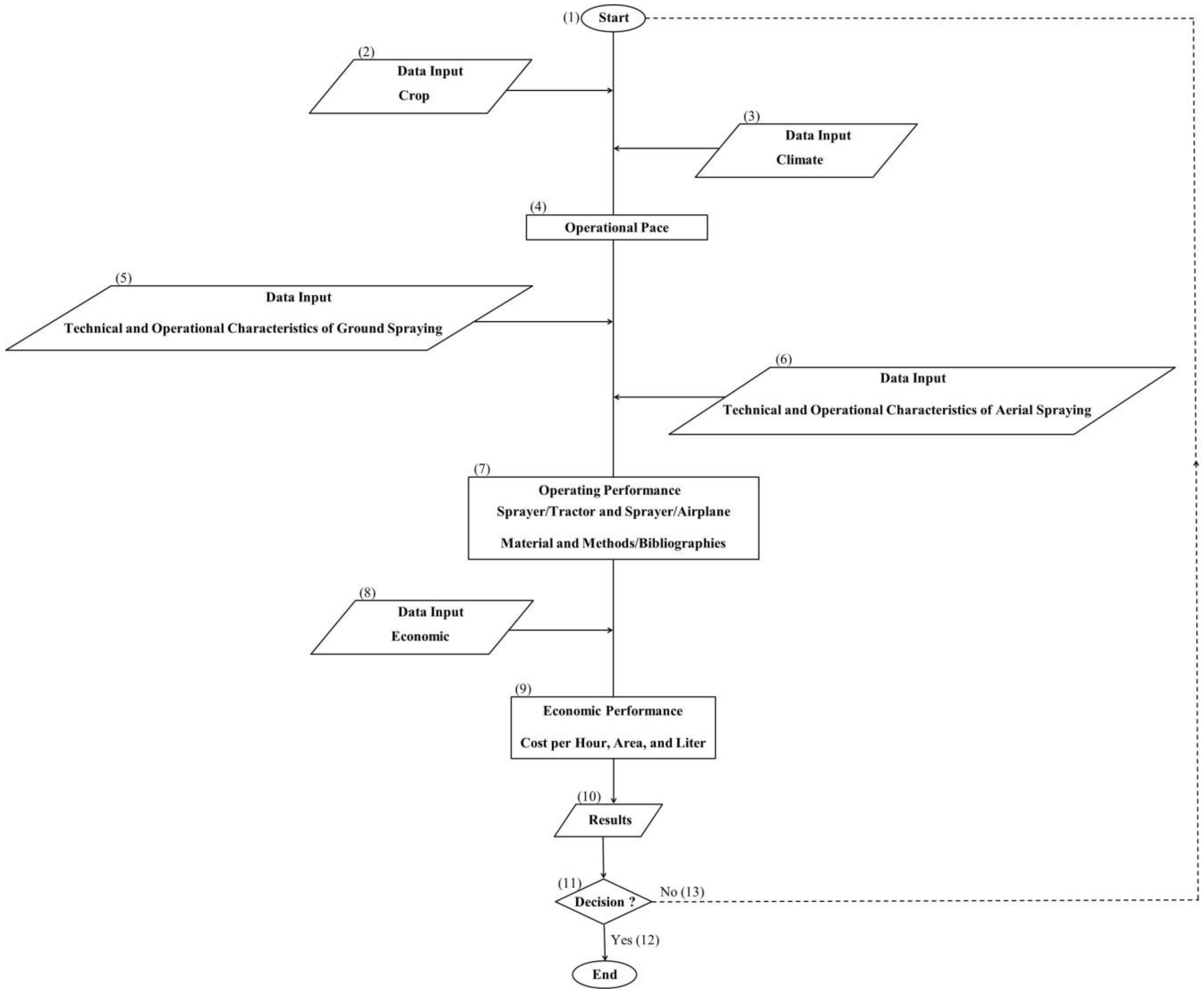

FIGURE 1. General flow chart of the computational model.

The results of the operational performance associated with the economic data input of machines (8) initial value, final value, useful life in years and hours, interest per year, lodging, insurance, and taxes (LIT), fuel consumption, repair factor and maintenance, among others, allow calculating the economic performance (9), which refers to the cost per hour, area, and liter.

Model results (10) allow the user to assess the operational and economic performance of mechanized spraying and decide (11) on viability (12) or not. In case the spraying is not feasible for the user (13) or the user choose to assess another scenario, new data should be inserted.

Agroclimatic factors

Climate factor in the sugarcane mill was defined as the number of working days inappropriate for spraying (NWDIS), as the methodology proposed by (Santos, 2017). This methodology considers agroclimatic parameters such as relative air humidity (RAH), wind speed (WS), and air temperature (AT).

In order to meet this proposal, we considered the average values of agroclimatic parameters of the Mill (Table 2), referring to Rio Largo, AL, Brazil, in 2014. These values are from the Agrometeorological Station of the Center for Agrarian Sciences of the Federal University of Alagoas (CECA/UFAL).

TABLE 2. Average values of the agroclimatic parameters.

Parameter	Abbreviation	Unit	Month of application											
			Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Air Temperature	AT	°C	26.15	26.05	26.75	27.70	25.70	24.50	23.95	23.35	24.65	24.65	26.25	25.60
Relative Air Humidity	RAH	%	65.65	67.60	67.40	68.91	71.75	69.20	67.35	69.95	70.60	69.05	63.95	66.10
Wind Speed	WS	m s^{-1}	2.00	1.70	1.70	1.50	1.50	1.70	1.70	1.70	1.80	1.90	1.90	1.90

Source: CECA/UFAL

The number of working days inappropriate for spraying (NWDIS) was considered in the time available (TA), as the methodology of (Mialhe, 1974).

Operational performance

The operational performance of the sprayer and tractor-driven sprayer were based on the proposals of (Mialhe, 1974; Santos et al., 2014b). The purpose of these proposals is to define the number of equipment necessary to spray agricultural defensive in the sugarcane of the Mill.

The number of machines (NM) was calculated by the ratio between the operational pace (OP) and the operational field capacity (OFC) of the equipment.

The operational pace (OP) was calculated by the ratio between the area to be sprayed (AS) and the time available to perform the agricultural operation (TA).

The operational field capacity (OFC) was calculated by associating the total boom width (TBW), operating speed (OS), and field efficiency (FE).

The volume of spraying solution to be applied is in accordance with the proposal of (Matuo et al., 2010). The application volume (AV) was calculated by the ratio between the tip flow (TF), spacing between tips (ST), and operational speed (OS).

The total application flow rate (TAF) was defined by the association of application volume (AV) and operational field capacity (OFC).

The displacement time for replenishment (DTR) corresponded the round trip time to the field. The displacement time was calculated by the ratio of the average distance between the field and replenishment pump (ADFRP) and the replenishment speed (RS).

The total time for displacement and replenishment (TTDR) corresponded to the time spent on going, replenishing in the pesticide tank, and returning to the field. The total time was calculated by the sum of the displacement time for replenishment (DTR) and replenishment time (RT).

The number of replenishments (NR) was defined by the ratio between the application volume (AV), area to be sprayed (AS), and total tank volume (TTV) of the equipment.

The threshold maneuvering distance (TMD) was determined by the turning radius of the threshold maneuvering (TRTM).

The threshold maneuvering time (TMT) was calculated by the ratio between the threshold maneuvering distance (TMD) and the threshold maneuvering speed (TMS).

The number of threshold maneuvering (NTM) was defined by the ratio between the area to be sprayed (AS), total boom width (TBW), and the average length of cultivation strip (ALCS).

The operational performance of the airplane is also in accordance with the proposal of Mialhe (1974) and Santos et al. (2014b) to define the number of required equipment, as described for the sprayer and tractor-driven sprayer.

The operational field capacity (OFC) of the airplane is in accordance with the adjusted proposal of (Araújo, 2009). It is calculated by associating the total volume of the sprayer tank (TVST), application volume (AV), distance between the runway and the field (DRF), speed of transfer from the runway to the field (STRF), effective strip width (ESW), operating speed (OS), time of each return curve (TERC), average length of cultivation strip (ALCS), and ground time between each flight (GTEF).

Economic performance of sprayer

The total cost of the sprayer (TCS) was determined by the association between the operational cost of the sprayer (OCS) and the area to be sprayed (AS).

The operational cost of the sprayer (OCS) was defined as the ratio between the hourly cost of the sprayer (HCS) and the operational field capacity (OFC).

The operational cost of the sprayer application (OCSA) was determined by the ratio between the hourly cost of the sprayer (HCS) and the total application flow rate (TAF).

The hourly cost of the sprayer (HCS) was calculated by the sum of the fixed hourly cost of the sprayer (FHCS) and the variable cost of the sprayer (VCS).

The fixed hourly cost of the sprayer (FHCS) was calculated according to the methodology proposed by ASABE (2011), defined as the ratio between the annual fixed cost (AFC) and the number of hours worked per year (NHWY).

The variable cost of the sprayer (VCS) was defined by the sum of the cost of fuel (CF) and the cost of repair and maintenance (CRM).

The calculation of sprayer fuel consumption was adapted from Banchi et al. (2008b) by adopting the average values of consumption by motor power range of agricultural tractors.

The calculation of cost with repair and maintenance (CRM) and repair factor and maintenance (RFM) of sprayer are in accordance with (ASABE, 2011).

Economic performance of tractor-driven sprayer

The total (TCTS), operational (OCTS), application operational (AOCTS), and hourly (HCTS) costs of the tractor-driven sprayer were calculated as for the self-propelled sprayer.

The fixed hourly cost of the tractor-driven sprayer (FHCTS) was calculated according to the methodology proposed by ASABE (2011), as the hourly fixed cost was calculated for the self-propelled sprayer.

The variable cost of the tractor-driven sprayer (VCTS) was determined by the sum of the cost of the tractor fuel (CTF) and the repair and maintenance of machines (CRM).

For calculating the tractor fuel consumption, the average values of consumption by motor power range of the tractor were considered as proposed by (Banchi et al., 2008b).

The calculation of cost with repair and maintenance (CRM) and repair and maintenance factor (RMF) of the tractor-driven sprayer are in accordance with (ASABE, 2011).

Economic performance of the airplane

The total (TCA), operational (OCA), application operational (AOCA), and hourly (HCA) costs of the airplane were calculated as for the self-propelled and tractor-driven sprayers.

The fixed hourly cost of the airplane (FHCA) was calculated according to the methodology proposed by ASABE (2011), as calculated for the self-propelled and tractor-driven sprayers.

The variable cost of the airplane (VCA) was determined by the sum of the costs with fuel (CFA) and repair and maintenance of the airplane (CRM).

For airplane fuel consumption, an average value was considered according to the best power to be used and higher working regime, as in (EMBRAER/NEIVA, 2012).

The calculation of cost with repair and maintenance of the airplane (CRMA) is in accordance with (ASABE, 2011). The repair and maintenance factor (RMF) of the equipment is in accordance with the data provided by (PBA AVIATION, 2012).

Validation

The *"TratoCana" Version 2.0* was validated by comparing the simulation results with raw (primary) data obtained in the field and with the bibliography data (secondary). The sensitivity and consistency analysis of the computational model was performed by the cost.

RESULTS AND DISCUSSION

Considering the average values of agroclimatic parameters of the Mill, which is related to the agroclimatic conditions of Rio Largo, AL, Brazil, in 2014, the number of working days inappropriate for spraying (NWDIS) and time available (TA) presented values of 257 days and 2,583 hours, respectively.

According to the results of the model scenario, the average distance between the field and replenishment pump influences the operational cost of the sprayer (Figure 2). The increased distance led to a linear increase in cost.

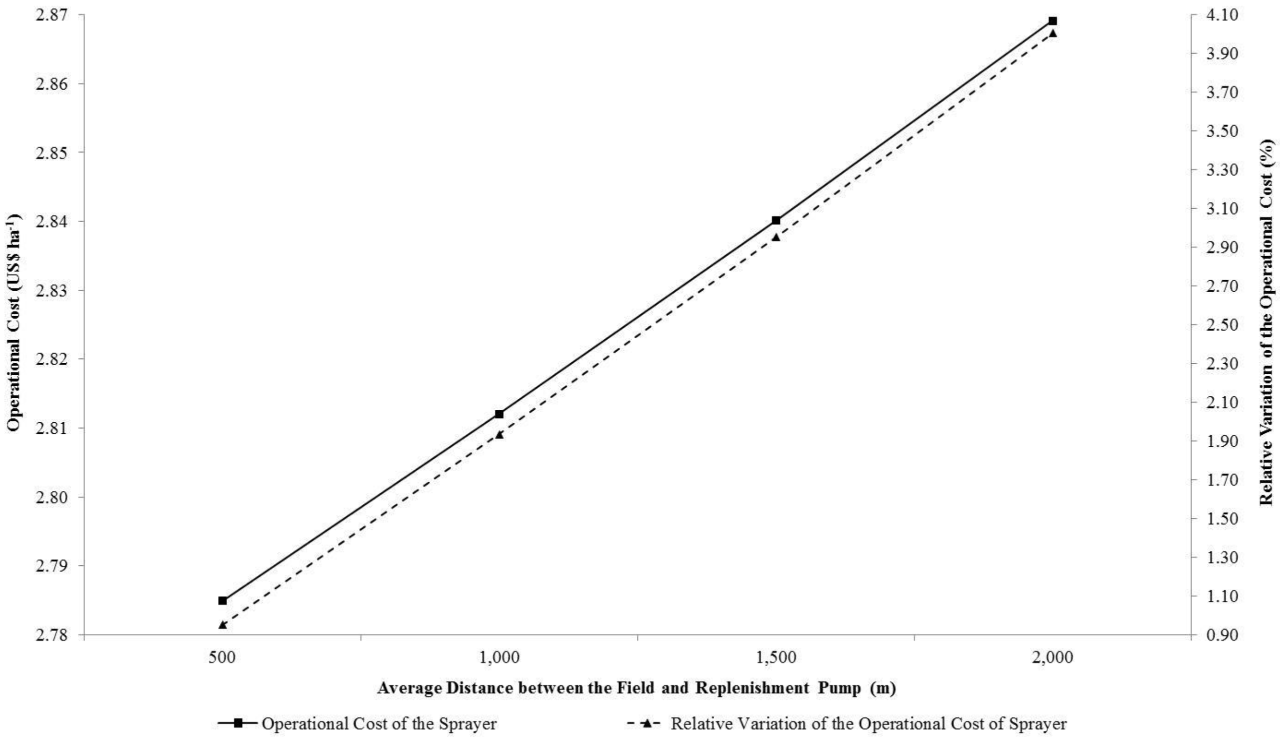

FIGURE 2. Operational cost of the sprayer and relative variation of the operational cost as a function of the average distance between the field and replenishment pump.

Although cost has a linear increase as distance increases, it has a slight influence on cost variation as it increases. In the distance of 500 m, operational cost variation was 0.95%, whereas, in 1,000 m, it was 1.93%. In the distance of 1,500 m, cost variation was only 2.95%, while in 2,000 m it was 4.00%, which represents a difference of 3.05% in relation to 500 m.

The average distance between the field and replenishment pump has a participation in the operational cost of the tractor-driven sprayer (Figure 3). The increased distance increases the cost in a linear way.

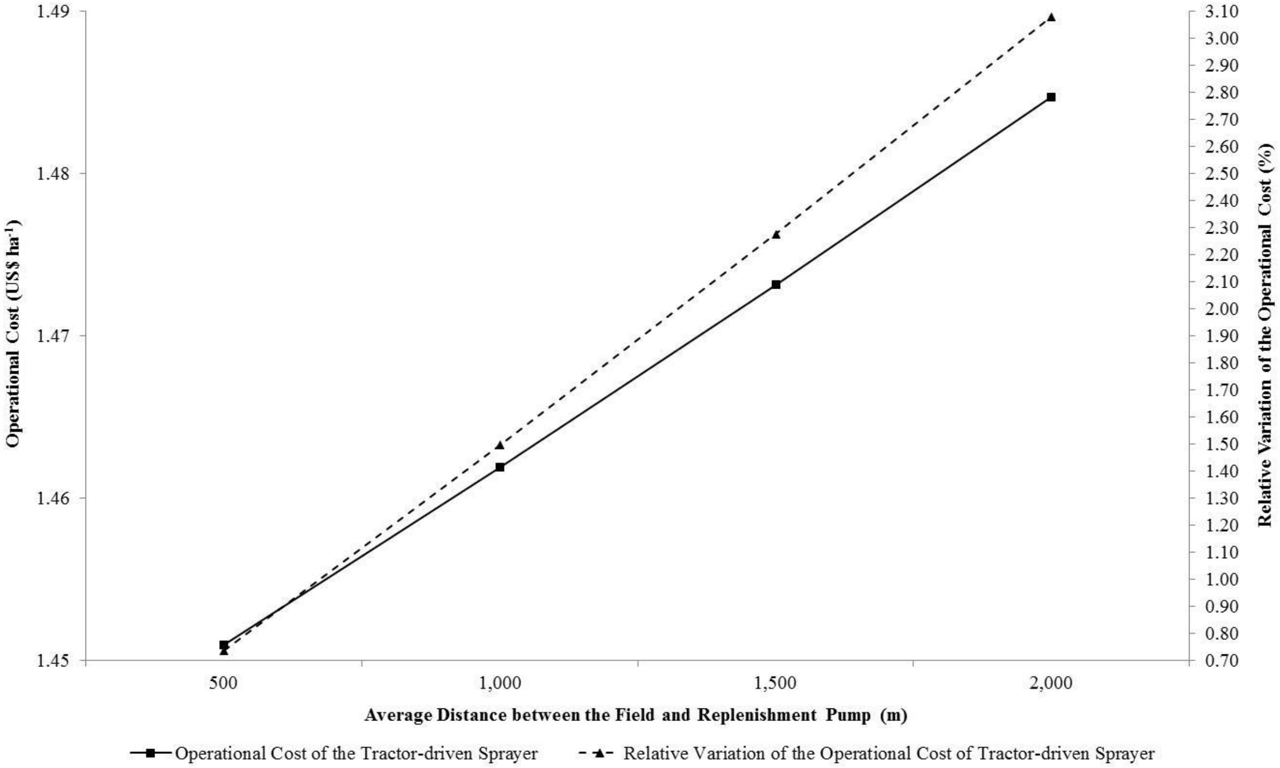

FIGURE 3. Operational cost of the tractor-driven sprayer and relative variation of the operational cost as a function of the average distance between the field and replenishment pump.

In the distance of 500 m, operational cost variation was 0.74% and in 1,000 m, it was 1.50%. For the distance of 1,500 m, cost variation was 2.28% whereas, in 2,000 m, it was 3.08%, which represents a difference of 2.34% in relation to the distance of 500 m.

According to the model scenario (Figures 2 and 3), the increased distance has a negative impact (variation) in the cost due to the time required (auxiliary hours) to go through the distance, which is a direct influence on the worked hours by machines.

The average distance between the field and replenishment pump has an interference with the operational cost of the airplane (Figure 4). The increased distance presents a linear increase in the operational cost of the equipment.

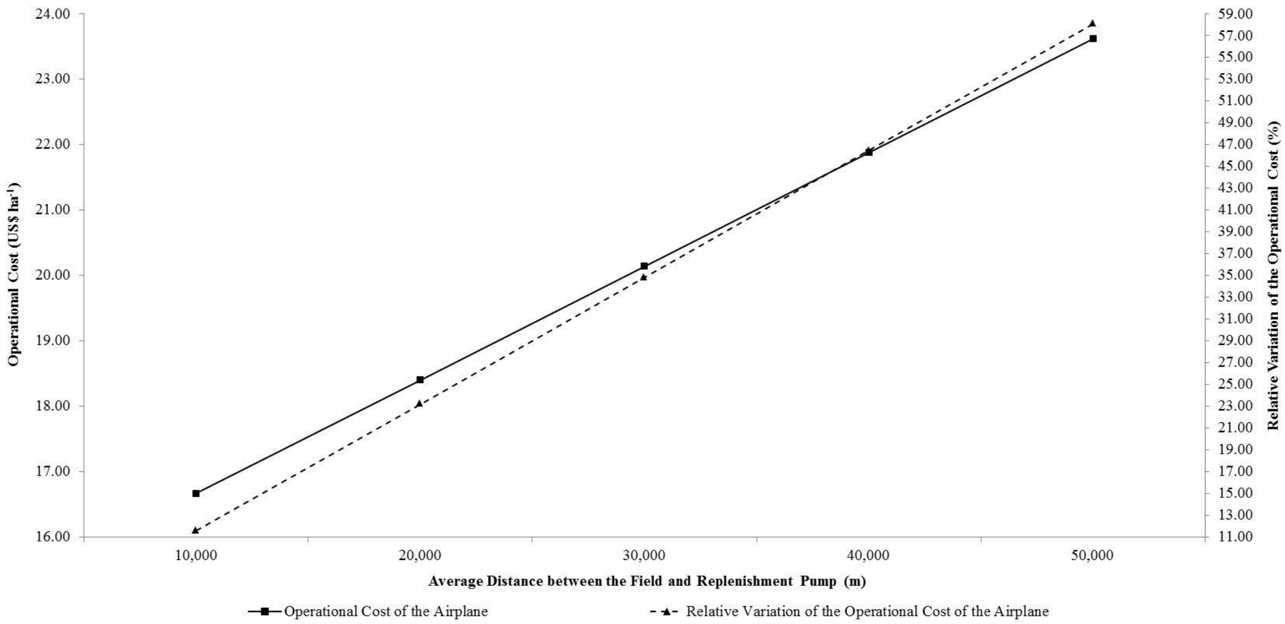

FIGURE 4. Operational cost of the airplane and relative variation of the operational cost as a function of the average distance between the field and replenishment pump.

In the distance of 10,000 m, cost variation increased by 11.59%, while in 20,000 m, this increase was 23.19%. For 30,000, 40,000, and 50,000 m, cost variation was 34.81, 46.44, and 58.07%, respectively. In this case, the negative impact on the operational cost of the machine occurs because the increased distance reduces the operational field capacity and hence the cost increase.

CONCLUSIONS

The increased average distance between the field and replenishment pump is disadvantageous to the operational cost of the machine.

Mills must adopt an excellent management method in order to facilitate the means of execution for the replenishment of agricultural defensives.

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