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Modeling of operational performance parameters applied in mechanized harvest of coffee

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mean error
mechanical harvesting

ABSTRACT

In super-mechanized coffee harvesting system, all operations are performed mechanically. In order to improve the logistics of mechanized agricultural operations, the knowledge on the variables that affect the operational performance can generate models to accurately estimate these parameters. The use of response surface methodology (RSM) allows to verify the influence of different independent variables and the generated response to allow for a great value. This study aimed to verify, using RSM, the influence of speed, mean length of rows and the slope of the areas on the operational performance parameters in different mechanized operations in coffee production, such as: harvest, sweeping and gathering. The results show that the slope directly influences the operational performance of the mechanical harvesting of coffee. The RSM proved to be an important tool to verify the effect of variables on performance parameters, and the generated models showed high significance.

Palavras-chave:
mecanização
declividade
erro médio
colheita mecanizada

Modelagem dos parâmetros de desempenho operacionais aplicados à colheita supermecanizada de café

RESUMO

No sistema supermecanizado de colheita do café todas as operações são realizadas de forma mecanizada. Com a finalidade de melhorar a logística das operações agrícolas mecanizadas, o conhecimento das variáveis que influenciam no desempenho operacional pode gerar modelos que permitam estimar, de maneira precisa, esses parâmetros. O uso da metodologia de superfície de resposta (MSR) permite verificar a influência de diferentes variáveis independentes em que resposta gerada permite alcançar um valor ótimo. Este estudo objetivou verificar a influência da velocidade, o comprimento médio de entrelinhas e a declividade das áreas nos parâmetros de desempenho operacional em diferentes operações mecanizadas na cafeicultura, utilizando MSR, como: colheita, varrição e enleiramento. Os resultados mostram que a declividade influencia diretamente no desempenho operacional da colheita mecanizada de café. A MSR mostrou-se como importante ferramenta para verificar o efeito das variáveis nos parâmetros de desempenho enquanto os modelos gerados apresentaram alta significância.

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Introduction

According to Oliveira et al. (2007), coffee harvest is a complex and important operation, from the coffee growers' point of view, because it is through this operation that they obtain the production from the field and the return of heavy investments, which represent 30% of the total production costs (Silva et al., 2006).

In the super-mechanized harvest system, all operations of harvest, sweeping and gathering, previously executed manually, started to be performed exclusively mechanically (Silva & Carvalho, 2011). Hence, studies related to the operational performance of the machines used in these steps are still necessary for an increasingly rational planning of field activities.

In modern agriculture, the use of mathematical models went through a great development since the late 1980s, in which one of the ways to understand the behavior of the mechanized set and the interaction of variables that affect its operational performance is the utilization of the response surface methodology (RSM). According to Myers et al. (2009), it is a collection of mathematical and statistical techniques used to simulate and analyze problems in which the response of interest is influenced by many variables. The generated response must reach an optimal value and the form of relationship between the response variable and the independent variables is unknown.

For Colaço et al. (2008), surface models are frequently used in substitution of complex models in order to obtain a correlation between the experimental data, allow to model more than one factor simultaneously and test the interaction of factors involved in the process, reducing the problems of optimization and identifying optimal regions.

This methodology is already largely used in some segments of agricultural sciences; however, for the study of performance parameters in mechanized operations, this methodology is little used. Based on the above, this study aimed to evaluate the utilization of the response surface methodology (RSM) to verify the effect of operational speed, mean length of coffee rows and slope of the areas on the operational performance parameters in super-mechanized coffee harvest.

Material and Methods

The experiment was carried out at the Conquista and Capoeirinha Farms located in the municipality of Alfenas-MG, Brazil, in the seasons of 2013 and 2014. The data were collected in areas apt for mechanization, according to Silva & Carvalho (2011) in areas with slope of up to 20%, totaling 45 plots that served as the basis for the modeling.

As database to carry out present study, the performance parameters of the mechanized operations that compose the super-mechanized coffee harvesting system were used; the operations of harvest and fruit collection were performed using a self-propelled harvester (Jacto - K3 Millennium) with rated power of 61.8 kW (82 hp).

Complementary operations were performed using Massey Ferguson MF275 tractors with rated power of 55.0 kW (75 hp), equipped with auxiliary front wheel drive, which allowed to pull, in the operations of sweeping and windrowing, a windrower (Bertanha - Varre Tudo) working with an operational width of 2.8 m.

The operations of gathering were performed using Massey Ferguson MF275 tractors with rated power of 55.0 kW (75 hp) equipped with auxiliary front wheel drive, which allowed to pull a gatherer (Mogiana 25 C) with gathering width of 1.2 m, equipped with a level compensation system.

To obtain the total area of each plot, interrow lengths in the plots, the track and operational speed of the machines, a GPS (Global Positioning System) receiver was used and the data were collected and stored every five seconds. Based on the information collected by the receiver, data banks were generated and then stored and analyzed by the software CR 7 Campeiro® (Giotto et al., 2013), which allowed to obtain the performance parameters.

The theoretical field capacity (Fct) is a parameter that expresses the maximum working capacity demonstrated by the machine and was determined using the equation described by ASAE (1999). The effective field capacity (Fce), a parameter that expresses the capacity effectively demonstrated by the machine at the field, was determined using the equation proposed by Simões & Silva (2012). Thus, field efficiency (Ef) was obtained by the ratio between the effective and theoretical field capacities of work of the mechanized sets. The demanded time (Td) expresses the time necessary for the operation in a certain area and was determined using the equation proposed by Brandão et al. (2013).

The data used to generate the models were subjected to a previous analysis to verify the presence of outliers, test homogeneity of the variances and normality of the errors (Freund & Littell, 2000).

The response surface methodology is a sequential procedure in which most of the tests begin by analyzing linear models to verify the interaction of the factors; thus, the general models proposed for the response variables effective field capacity, field efficiency and demanded time are described in Eqs. 1 and 2.

$$Zi = Xi \cdot a + Yi \cdot b + c \qquad (1)$$

$$Zi = \frac{a}{Xi} + \frac{b}{Yi} + c \qquad (2)$$

where:

Zi - performance parameter studied;
Xi - mean length of the interrows, m;
Yi - operational speed, km h^{-1}; and,
a, b, c - coefficients of the equation.

The obtained data of each performance parameter in the studied mechanized operations were used to select the model that best represented the characteristics of the studied variables, i.e., linear models that best showed the behavior of the operational speed and mean length of the coffee rows.

The proposed models were generated by the statistical program Statistica 7.0®, performing the regression study with the first-degree models through the nonlinear model fit procedure, with 0.05 significance level. After the proposed models were obtained, the estimators were determined, which allowed to verify the accuracy, precision and bias of each generated model.

The coefficient of determination (R^2) quantifies the quality of fit, since it provides a measurement of the proportion of the variation explained by the regression equation in relation to the total variation of the responses, ranging from 0 to 100%. As to the relative mean error (p), it indicates the fit of the proposed model. In this study, the relative error was obtained according to Eq. 3, described by many authors, such as Almeida et al. (2003):

$$p = \frac{100}{n} \sum \frac{|Y - Yo|}{Y} \tag{3}$$

where:

p - relative mean error, %;
n - number of experimental observations;
Y - value observed experimentally; and,
Y_o - value estimated by the model.

The estimated mean error of the models was obtained according to Eq. 4, described by Reis et al. (2012). The estimated mean error of a model indicates to what extent the value estimated by the model is distant from the true mean.

$$SE = \sqrt{\frac{\sum (Y - Yo)^2}{RDF}} \tag{4}$$

where:

SE - estimated mean error;
RDF - residual degrees of freedom of the model;
Y - value observed experimentally; and,
Y_o - value estimated by the model.

The chi-square (x^2) test compares values observed in the sample with values estimated by the model, i.e., it allows to observe data dispersion, according to Eq. 5:

$$x^2 = \frac{\sum (Y - Yo)^2}{RDF} \tag{5}$$

where:

x^2 - chi-square;
RDF - residual degrees of freedom of the model;
Y - value observed experimentally; and,
Y_o - value estimated by the model.

Results and Discussion

The obtained data showed normal distribution, homogeneity of variance and independence, thus not requiring transformation. Hence, adequate models were defined for the performance parameters effective field capacity (Fce), field efficiency (Ef) and demanded time (Td) for the studied operations and their estimators (Table 1).

The adequate model for each mechanized operation was selected based on the significance of regression parameters

Table 1. Parameters and estimators of the equations obtained for the operational performance as a function of the operational speed and mean length of coffee rows

Fce (ha h^{-1})	a	b	c	R^2	P	SE	X^2
Harvest							
1	0.0067*	0.185*	-0.0129*	0.8364	10.01	0.049	0.02
2	-7.0122*	-0.270*	0.6682^{ns}	0.7806	14.86	0.034	0.12
Sweeping							
1	0.00002*	0.1403*	-0.0011*	0.9996	0.29	0.001	0.001
2	-1.0878*	-0.1244^{ns}	0.2780*	0.9511	2.83	0.005	0.01
Gathering							
1	0.00011*	0.0582*	0.0041*	0.9731	3.39	0.006	0.001
2	0.25235*	-9.325*	-0.122*	0.9544	3.6	0.004	0.001
Ef(%)							
Harvest							
1	0.0013*	-0.100*	0.639*	0.7991	10.12	0.07	0.05
2	-1399.6*	18.424*	71.285*	0.9331	8.74	0.053	0.03
Sweeping							
1	0.00008*	-0.0138*	0.5102*	0.8619	0.37	0.002	0.001
2	-375.9*	1.875*	51.502*	0.9832	0.13	0.001	0.001
Gathering							
1	0.0005*	-0.1145*	0.5986*	0.9161	3.58	0.023	0.005
2	-3616.3*	20.995*	56.356*	0.9639	2.4	0.015	0.003
Td (h ha^{-1})							
Harvest							
1	-0.0077*	-1.501*	6.6846*	0.6955	20.59	0.509	0.261
2	94.76*	2.679*	-0.0667*	0.9984	1.06	0.047	0.02
Sweeping							
1	-0.0007^{ns}	-7.319*	14.639*	0.9517	3.07	0.297	0.08
2	55.55*	6.667*	-	0.9998	0.01	0.001	0.001
Gathering							
1	-0.0068*	-3.931*	16.376*	0.9485	4.41	0.408	0.167
2	583.333*	8.333*	-	0.9995	0.01	0.002	0.001

Models of the equation: 1) z = ax + by + c; 2) z = (a/x) + (b/y) + c; (a,b,c) - Parameters of the model; (R^2) - Coefficient of determination; (p) - Relative mean error; (SE) - Estimated mean error; (X^2) - Chi-square; ^{ns}Not significant and *significant at 0.05 by F test. Fce - Effective field capacity; Ef - Field efficiency; Td - Demanded time and their coefficient of determination (R^2) (Silva et al., 2007). According to the obtained results, it is possible to claim that the generic model 1 showed better coefficient of determination for the effective field capacity (Fce) in all operations, while the field efficiency (Ef) and demanded time (Td) of the operations fitted best to the generic model 2.

Regarding the estimators of the selected models, the estimated mean error (SE) and the chi-square (X^2) showed maximum values close to zero for all generated models. These results indicate that the models adjusted well. According to Molina Filho et al. (2006), the lower the value of these estimators, the lower the discrepancy of the values observed and obtained by the model.

With respect to the relative error (p), the models exhibited satisfactory values for all performance parameters evaluated. According to Kashani-Nejad et al. (2007), p values indicate the deviation of the observed values in relation to the curve estimated by the model and, according to Mohapatra & Rao (2005), values lower than 10% are recommended for the selection of models. Thus, there is no limitation of use of the surfaces generated by the models proposed in the present study.

Figure 1 shows the response surfaces for the effective field capacity; the same behavior occurred for all evaluated operations, i.e., the operational speed of the sets is the variable that most affects the effective field capacity due to the higher slope on the plane of the generated surface.

Figure 2 shows the response surfaces generated for field efficiency, which demonstrates the same behavior for all evaluated operations, i.e., the length of the interrows is the variable that most affects field efficiency (Ef). Based on the results, it is possible to claim that this parameter increases as the length of the interrows increases, because of the reduced number of maneuvers at the end of the rows and the time demanded by these maneuvers due to the roads, besides the irregular geometry of the plots, characteristics that are inherent to most coffee production areas.

The demanded time showed a behavior similar to that of the variable effective field capacity, i.e., with the increase in the operational speed of the mechanized sets there is the reduction of the time necessary for the operation, as observed in Figure 3. Thus, it is possible to claim that the adequate selection of the operational speed of the sets allows the increase in effective field capacity and operational efficiency, and reduction in the time demanded by the operations, corroborating with Cortez et al. (2008).

According to Ramos et al. (2012), the selection of speed, the relationship between forward speed and motor rotation, allows a better adequacy of the tractor with the force required by the implement for a certain operation. In the case of harvest, selecting the operational speed of the harvester is of great importance, because it directly affects not only the operational efficiency of the set, i.e., the time spent per hectare, but also its harvesting efficiency (Silva et al., 2010).

The effect of slope was studied only in the operation of harvest, differently from the other mechanized operations that compose the coffee productive cycle, because the harvesters work surrounding coffee trees in the rows, with their vibrating rods operating around each plant.

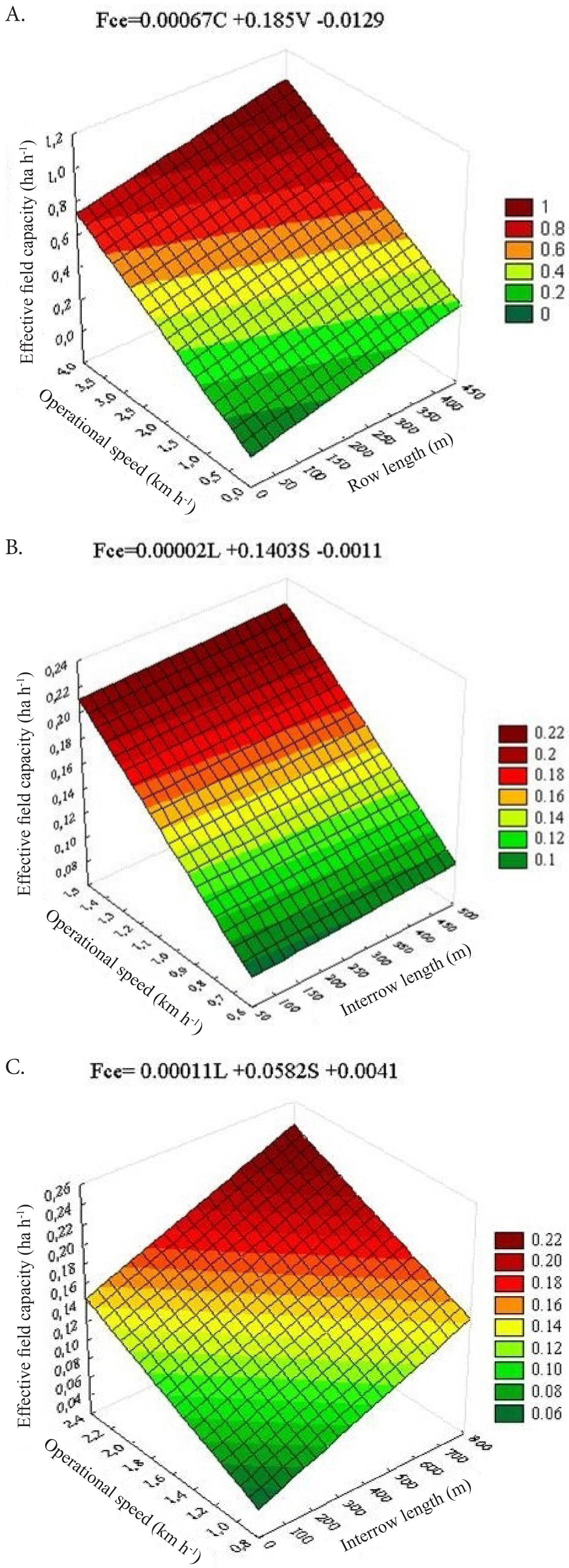

Figure 1. Response surfaces obtained for the effective field capacity (Fce) for: harvest (A); sweeping and windrowing (B); gathering (C)

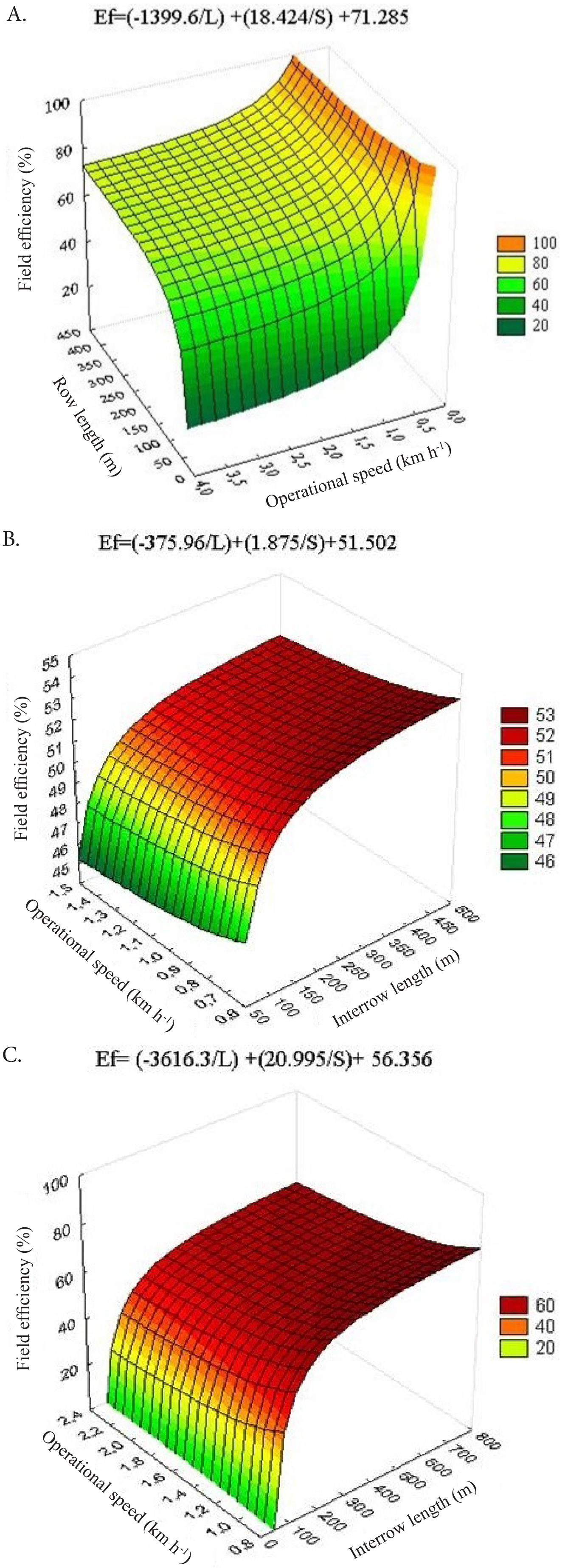

Figure 2. Response surfaces obtained for the field efficiency (Ef) for: harvest (A); sweeping and windrowing (B) and gathering (C)

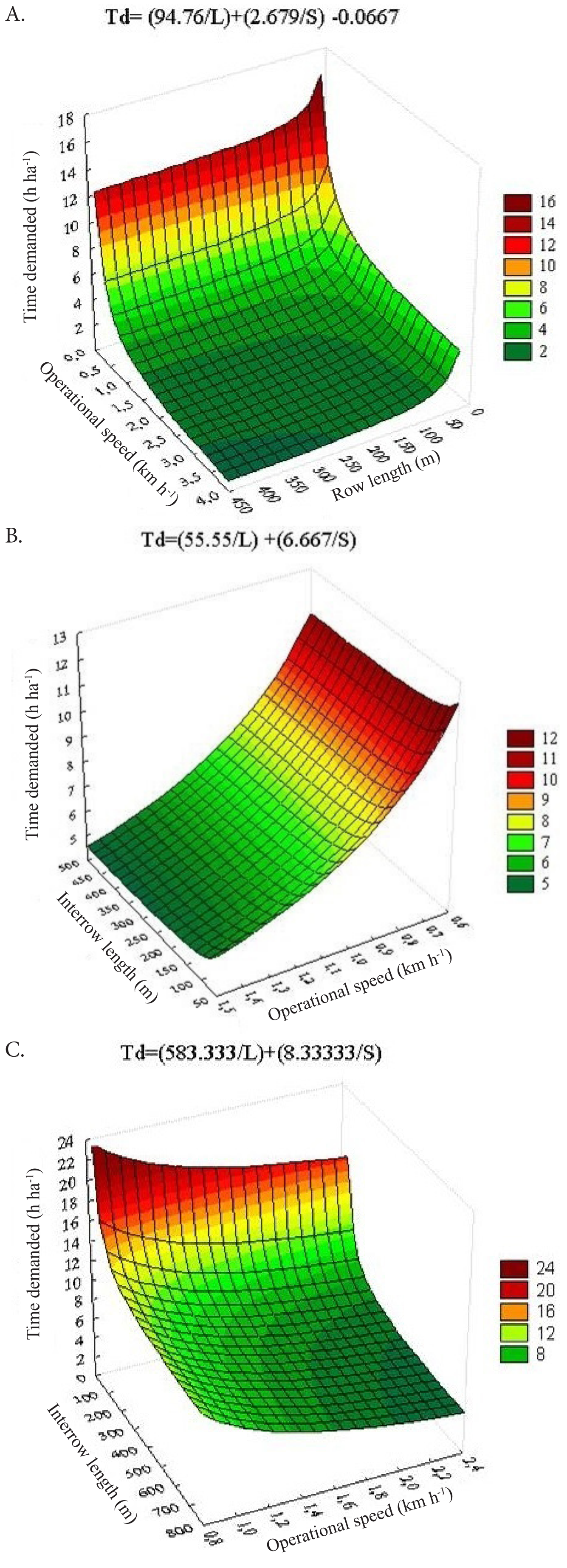

Figure 3. Response surfaces obtained for the time demanded (Td) for: harvest (A); sweeping and windrowing (B); gathering (C)

Slope is a factor that directly influences the operational efficiency of the harvest, especially because of the leveling of the machine. Studies addressing the effect of this parameter are widely explored in silviculture and can serve as comparison for the results obtained in the present study, due to the similarities in relation to cultivated areas of this activity and coffee production.

Burla et al. (2012), studying times and movements of a harvester in the harvest of a eucalyptus forest, observed yield reduction of up to 20% in the harvest on rough terrain in relation to flat areas.

Thus, the analysis of the conditions in which machines operate is of great importance and the determination of the threshold slopes for the use of machines in coffee production becomes necessary, according to Silva et al. (2010) and Höfig & Araújo Júnior (2015), who claimed that areas with slope of up to 15% are considered as ideal for mechanized harvest of coffee, conditions that were found in the present study.

According to Leite et al. (2010), the operation in a very inclined area may cause the overturn of a machine, for having a higher center of gravity, or barycenter.

Based on Pearson's correlation between slope and the studied variables, it is possible to observe that the slope showed correlation only with operational speed (-0.590), while the correlation between slope and mean length of the coffee rows was not significant (0.126^{ns}). According to Khoury Júnior et al. (2009), lateral stability is a parameter of significant influence in the overturn of a tractor or agricultural machine, especially operating on contour lines, such as in coffee production areas or with speeds above the ideal ones.

As to the performance parameters, it is observed that the effective field capacity and the demanded time have moderate and significant correlation, i.e., as slope increases, field capacity reduces (-0.559) and its demanded time also increases (0.602). There was no significant effect of slope on field efficiency and this parameter was more related to the mean length of the coffee rows (0.201^{ns}).

Thus, models that allow to verify the effect of slope on the performance parameters effective field capacity and demanded time were also obtained. Table 2 shows the generated models and their estimators.

According to Leite et al. (2014), slope is a factor that directly influences the efficiency of machines; thus, with a decrease in terrain slope, the operational efficiency tends to increase, reaching values 28% higher in comparison to areas with more pronounced slope (Birro et al., 2002).

In general, the estimators for the proposed models showed acceptable values. In the case of the relative mean error, both models exhibited values lower than 10%, which are considered as fitted. The same models showed acceptable coefficients of determination, which explain satisfactorily the interaction of the factors operational speed, slope and length of the cultivation row on the evaluated performance parameters, i.e., 86.06 and 80.10% for the field capacity and demanded time, respectively.

Table 2. Models proposed for the effect of slope on the parameters effective field capacity (Fce) and required time (Td) in mechanized coffee harvest

Proposed models	R^2	X^2	SE	p
Fce = 0.0007C -0.0006D+0.1602V+0.085	0.8606	0.357	2.78	5.79
Td = -0.008C+0.1418D -0.9659V+ 4.579	0.8010	0.215	0.45	9.36

Conclusions

1. Slope directly influences the operational performance of mechanized coffee harvest and the models generated from its interaction with operational speed and length of the cultivation rows were satisfactory.

2. The generated surface models allow to observe that the increase in speed, combined with greater length of the interrows, allows to obtain shorter demanded times for the operation in the areas.

3. The response surface methodology proved to be an important tool to verify the effect of the variables on the performance parameters, while the generated models showed high significance.

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