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OPERATIONAL PERFORMANCE OF AN AGRICULTURAL TRACTOR AS A FUNCTION OF MIXTURE PROPORTIONS AND TYPE OF BIODIESEL

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KEYWORDS

Biofuels, raw material, renewable, consumption, energy.

ABSTRACT

The growing demand for clean energy aimed at reducing greenhouse gas emissions associated with the oil crises has encouraged the search for biofuels, among which biodiesel has stood out in the gradual replacement of diesel. This study aimed to evaluate the performance of an agricultural tractor fueled with four types of biodiesels (peanut, sunflower, soybean, and waste frying oil) added to diesel at five proportions (0, 25, 50, 75, and 100% biodiesel, that is, B0, B25, B50, B75, and B100, respectively). The experiment was carried out at the Laboratory of Biofuel and Machinery Testing at FCAV–UNESP. A Valtra BM100 4×2 FWD tractor with a power of 74 kW (100 hp) was used. The drawbar pull force (DF), displacement velocity (V), drawbar power (DP), volumetric fuel consumption (VC), weight fuel consumption (WC), and specific fuel consumption (SC) were studied. The factors did not influence DF, V, and DP. The proportion factor influenced ($p<0.01$) the volumetric fuel consumption, in which diesel S50 was 14% more efficient than B100. Weight fuel consumption was influenced by the type of biodiesel in the blend. Diesel had the lowest specific fuel consumption (328 g kW h^{-1}). The biodiesel fraction showed a direct relationship with the consumption parameters, with sunflower showing the lowest WC value in the B75 and B100 blends.

INTRODUCTION

Conventional energy sources such as crude oil, coal, and methane are non-renewable energy sources (Singh et al., 2020). It is already practically undeniable that the causes of climate change related to global warming are due to an increase in concentrations of greenhouse gases (GHG) in the atmosphere related to deforestation, agricultural production, and mainly the burning of fossil fuels, responsible for 90% of the emissions of these gases (Tayra & Reis, 2020). The current CO_2 level is 394.5 parts per million by volume (PPMV) and is projected to reach 500 PPMV by 2050 if emissions are not reduced (Mathimani & Mallick, 2018).

Population growth associated with increased energy consumption, the possibility of depletion of fossil fuels, and high prices, together with issues related to environmental pollution, have encouraged countries to seek innovative and clean energy sources (Vieira & Pereira, 2020). In this context, biofuels, when derived from renewable raw materials and produced by processes of recognized environmental sustainability, have been alternatives of broad social and political interest in replacing the use of non-renewable fuels, particularly when their use does not require significant adjustments in the technology currently used in combustion engines (Ramos et al., 2017). Biodiesel is a biofuel obtained from plant biomass or animal fats and can partially or totally replace the use of fossil fuel in the coming decades, directly contributing to reducing GHG emissions and mitigating the greenhouse effect.

A report by the International Energy Agency [3] suggests that Indonesia has taken the lead as the largest global producer of biofuels, contributing 17% to the share

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of global production. Indonesia's growing production of biofuels has surpassed the United States (14%) and Brazil (12%), followed by Germany (8%), France (6.3%), and Argentina (5.3%) (Rianawati et al., 2021).

Brazil has a large territorial extension and presents edaphoclimatic characteristics favorable to the cultivation of a great diversity of raw materials for biodiesel production, such as soybean (*Glycine max* (L.) Merr.), sunflower (*Helianthus annuus* L.), peanut (*Arachis hypogaea* L.), castorbean (*Ricinus communis* L.), corn (*Zea mays* L.), Barbados nut (*Jatropha curcas* L.), cottonseed (*Gossypium* spp.), rape (*Brassica napus* L.), babassu (*Attalea speciosa* Mart.), muriti (*Mauritia flexuosa* L. f.), African oil palm (*Elaeis guineensis* Jacq.), and macaúba palm (*Acrocomia aculeata* L.). Beef tallow, chicken and pork fat, frying oils, and fish viscera oils are also used as alternative raw materials for biodiesel production (Ramos et al., 2017).

The study of oilseed species can guide biodiesel production in Brazil, considering the energy potential of each source. Therefore, this study aimed to evaluate the operational performance of an agricultural tractor fueled with four types of biodiesels (peanut, sunflower, soybean, and waste frying oil) and five biodiesel proportions added to common diesel (0, 25, 50, 75, and 100%).

MATERIAL AND METHODS

The experiment was carried out at the Laboratory of Biofuel and Machinery Testing (BIOEM) in the facilities of the Department of Engineering and Exact Sciences (DECEx) at the School of Agricultural and Veterinary Sciences of the São Paulo State University (FCAV–UNESP).

Four types of biodiesels were used: filtered ethyl peanut, filtered ethyl sunflower, filtered ethyl soybean, and filtered ethyl waste frying oil biodiesels, the latter collected from a restaurant. The types of biodiesels evaluated were produced and supplied to FCAV–UNESP by the Laboratory of Development of Clean Technologies of the University of São Paulo (LADETEL–USP), located in Ribeirão Preto, SP, Brazil. The used diesel consisted of S50, with 50 mg kg^{-1} total sulfur, regulated in the Brazilian market by PROCONVE (Air Pollution Control Program by Motor Vehicles), purchased from a gas station in Jaboticabal, SP, Brazil.

The experiment was completely randomized in a 5×4 factorial arrangement, with three replications, totaling 60 observations. The first factor consisted of five biodiesel proportions mixed with common diesel, that is, B0, B25, B50, B75, and B100, in which the number indicates the percentage of biodiesel in the blend. The second factor consisted of four types of biodiesels from different raw materials (peanut, sunflower, soybean, and waste frying oil collected in a restaurant). The blend was prepared gradually in 5-L plastic containers by stirring for 30 seconds, with the content used immediately after filling the tank. The tank was emptied at the end of each test and the engine was operated for 10 minutes to avoid residues of the previous blends. The performance analysis was carried out with experimental plots of 20 m in length each, with a spacing of 15 m between plots intended for maneuvers.

A Valtra BM100 4×2 FWD tractor with a power of 74 kW (100 hp) at 2,300 rpm in the engine and a mass of 5.4 tons, in which 40% of the mass was distributed on the front axle and 60% on the rear axle, was used. The machine was equipped with 14.9-24 tires on the front axle and 23.1-26 on the rear axle, and the tractor was properly instrumented to carry out the tests.

A second Valtra BH140 4×2 FWD tractor with an engine power of 103 kW or 140 hp at 2400 rpm and a mass of 7.4 tons was used to generate load to the drawbar on the test tractor during the tests. This second tractor was coupled to the test tractor using a wire rope. The braking tractor was used turned off and geared in second low gear. A Dick RVS II radar was used to determine the travel speed.

Two sets equipped with an Oval Flowmate LSN48 flowmeter, with a nominal flow rate precision of 1% and a maximum flow rate of 100 L h^{-1}, and a PT100 temperature sensor, with a resistance of 100 ohms at 0 °C, one for feeding the injection pump and the other for fuel return, were used to measure volumetric, weight, and specific fuel consumption.

The tractive force was obtained by [eq. (1)]:

$$TF = P / v \tag{1}$$

In which:

TF is the tractive force (N, 1 N = 9.81 kgf ≅ 10 kgf),

P is the power (W, 1000 W = 1 kW = 1.36 hp), and

v is the displacement velocity (m/s, 1 m s^{-1} = 3.6 km h^{-1}).

A Dick RVS II radar was used to determine the displacement velocity. The values were obtained in m h^{-1} and later converted into km h^{-1}.

The drawbar power was obtained by [eq. (2)]:

$$DP = TF \times v \tag{2}$$

Where:

DP is the drawbar power (kW);

TF is the mean tractive force on the drawbar (kN), and

v is the displacement velocity (m s^{-1}).

The volumetric fuel consumption was calculated by [eq. (3)]:

$$VC = (Vf - Vr) / (t) * 3.6 \tag{3}$$

In which:

VC is the volumetric fuel consumption (L h^{-1});

Vf is the fuel filling volume at the injection pump inlet (mL);

Vr is the total fuel volume returned from the nozzles and injection pump (mL);

t is the travel time on the plot (s), and

3.6 is a conversion factor.

The influence of temperature relative to the density was considered to calculate the hourly weight fuel consumption, according to [eq. (4)]:

$$WC = (3.6 / 1000 * t) * (Vf * Da - Vr * Dr) \tag{4}$$

Where:

WC is the weight fuel consumption (kg h^{-1});

3.6 and 1000 are conversion factors;

t is the travel time on the plot (s);

Vf is the fuel filling volume at the injection pump inlet (mL);

Da is the fuel density at the filling time (g L^{-1});

Vr is the total fuel volume returned from the nozzles and injection pump (mL), and

Dr is the density of the fuel returned from the nozzles and injection pump (g L^{-1}).

The specific fuel consumption was determined using [eq. (5)]:

$$SC = (WC / DP) \times 1000 \quad (5)$$

In which:

SC is the specific fuel consumption (g kW^{-1} h^{-1});

WC is the hourly weight fuel consumption (kg h^{-1});

DP is the drawbar power (kW), and

1000 is a conversion factor.

The data were subjected to the test for normality of residuals (errors) by the Shapiro-Wilk and Kolmogorov-Smirnov methodology, both showing normality. Analysis of variance (ANAVA) was performed for all variables. Tukey's test of means was applied at a 5% probability for the qualitative factor type of biodiesel, using the R statistical software. A regression analysis was carried out for the quantitative factor proportion, in which the linear, quadratic, or cubic models were chosen based on the highest significant exponent of the coefficients of determination of the regression (R^2), using the AgroEstat statistical software (Barbosa & Maldonado, 2015).

RESULTS AND DISCUSSION

No significant interaction was observed between factors for the variables drawbar pull force (DF), displacement velocity (V), and drawbar power (DP) and the factors did not influence ($p<0.05$) the variables when evaluated individually (Table 1). The coefficients of variation were low (<10%) for all variables evaluated in this experiment, indicating little variation between the collected data. The evaluated raw materials did not significantly influence the volumetric fuel consumption, with mean values of 13 L h^{-1}, being similar to each other for all types of biodiesels.

TABLE 1. Summary of analysis of variance, regression analysis, and test of means for the variables drawbar pull force (DF), displacement velocity (V), and drawbar power (DP).

Sources of variation	Mean square (MS)		
	DF (kgf)	V (km h^{-1})	DP (kW)
Proportion (P)	245.35^{NS}	0.01^{NS}	0.06^{NS}
Type of biodiesel (TB)	180.38^{NS}	0.01^{NS}	0.28^{NS}
P*TB	438.63^{NS}	0.01^{NS}	0.13^{NS}
CV (%)	0.93	1.44	1.72
Regression analysis for the proportion factor			
Linear	180.08^{NS}	0.00^{NS}	0.24^{NS}
Quadratic	0.15^{NS}	0.00^{NS}	0.00^{NS}

CV: coefficient of variation; P*TB: interaction between factors; NS: not significant.

Neves et al. (2018) found similar data and concluded that the types of biodiesels (soybean and murumuru) and the blend proportions (B0, B5, B15, B25, B50, and B100) did not influence drawbar power and displacement velocity. Siqueira et al. (2013) evaluated the same variables in a Valmet 65ID tractor fueled with biodiesel blends of waste soybean oil and diesel at proportions of 0, 25, 50, 75, and 100% and concluded that the proportion factor did not influence ($p<0.05$) DF, V, and DP. On the other hand, tests carried out on an MF-399 tractor operating in soil tillage and fueled with three biodiesel proportions from waste vegetable oil added to diesel (10, 20, and 30%) increased the drawbar pull force and its interaction effects were significant at 5 and 1% probability (Mosavi et al., 2021).

The proportion factor significantly influenced ($p<0.01$) the variables volumetric fuel consumption and specific fuel consumption (Table 2). An interaction was observed between factors for the weight fuel consumption.

TABLE 2. Summary of analysis of variance, regression analysis, and test of means for the variables volumetric fuel consumption (VC), weight fuel consumption (WC), and specific fuel consumption (SC).

Source of variation	Mean square (MS)		
	VC (L h^{-1})	WC (kg h^{-1})	SC (g kW h^{-1})
Proportion (P)	5.16^{**}	5.50^{**}	5873.77^{**}
Type of biodiesel (TB)	0.15^{NS}	0.14^{*}	77.97^{NS}
P*TB	0.07^{NS}	0.11^{**}	149.28^{NS}
CV (%)	1.95	1.72	2.66
Regression analysis for the proportion factor			
Linear	20.25^{**}	–	23213.00^{**}
Quadratic	0.03^{NS}	–	35.29^{NS}

CV: coefficient of variation; P*TB: interaction between factors; NS: not significant; **: significant at 1% (p<0.01); *: significant at 5% (p<0.05).

Emaish et al. (2021) studied the performance of a turbocharged Kubota M-90 (66.2 kW) tractor fueled with 0, 5, 20, and 100% biodiesel from waste frying oil and observed that the proportion factor increased volumetric and specific fuel consumption, with the highest values attributed to B100 and the lowest value was observed for the percentage B0 (100% diesel). It may be related to the higher viscosity and density of blends with higher amounts of biodiesel, resulting in difficulty in combustion (Nalgundwar et al., 2016).

The volumetric fuel consumption was influenced by the proportion factor, with a high value of the coefficient of determination (R^2=0.98), showing a high quality of fit of the model relative to the data (Figure 1). The increase in consumption is related to an increase in the percentage of biodiesel in the blends, which is represented on the right y-axis of the graph (percentage). A maximum difference of 14% was found in the values of volumetric fuel consumption between S50 and B100 diesel, with the diesel being more efficient.

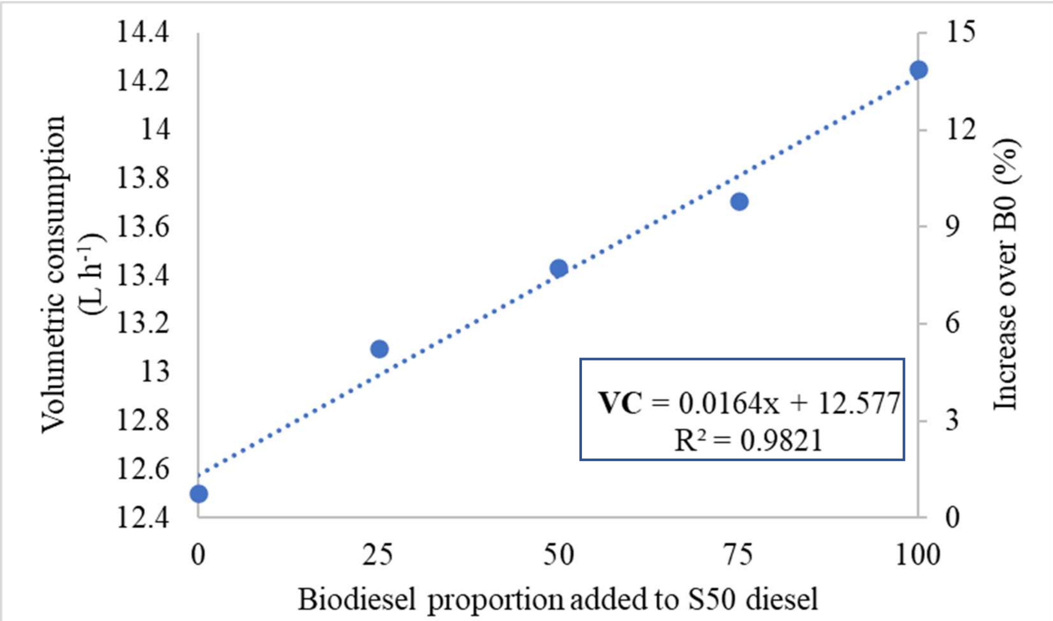
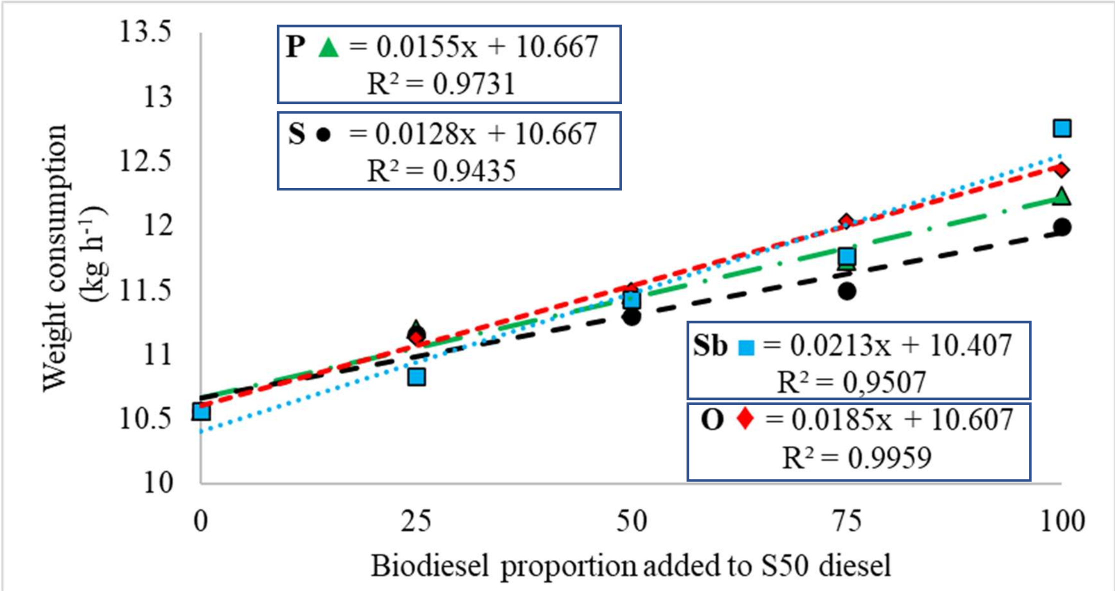


FIGURE 1. Volumetric fuel consumption as a function of biodiesel proportion.

These results are similar to those found by Simon et al. (2018), who evaluated the performance of an agricultural tractor and observed an increase in volumetric fuel consumption of 14.8% when comparing the biodiesel B100 with B0, and B0 was more efficient. Pinto et al. (2021) studied the volumetric fuel consumption in a VALTRA BM100 turbo tractor by comparing B0 and B100 and observed an increase of 10.7% when biodiesel was used. According to the authors, this increase in volumetric fuel consumption can be explained by the lower calorific value of biodiesel compared to diesel. Thus, a higher amount of fuel is necessary to perform the same amount of work.

The evaluated raw materials did not influence the volumetric fuel consumption, with mean values of 13.4 L h^{-1}, being similar to each other for all types of biodiesels. The specific fuel consumption was also not altered by the type of biodiesel (p<0.05).

Weight fuel consumption increased as a function of the percentage of biodiesel in the blends (Figure 2). The use of biodiesel (B100) for all raw materials resulted in the highest weight fuel consumption. The waste frying oil and soybean biodiesels showed the highest WC peaks, with values of 12.4 and 12.8 kg h^{-1}, that is, 14.5 and 17.2% less efficient than B0, respectively.



P – peanut biodiesel; S – sunflower biodiesel; Sb – soybean biodiesel; O – biodiesel from waste frying oil.

FIGURE 2. Weight fuel consumption of fuel as a function of the type and proportion of biodiesel.

Experiments with biodiesel/diesel blends have revealed an increase in fuel consumption as the fractions of biodiesel in the blend were increased due to the lower calorific value of biodiesel.

The results observed for WC occurred because this variable considers the fuel density, which, in turn, is directly related to its molecular structure. The compounds present in biodiesel have longer carbon chains than those in diesel and, therefore, the higher the concentration of biodiesel in the blend, the higher the concentration of alkyl esters with a longer carbon chain, with a higher density, reducing fuel efficiency (Neves et al., 2013).

The analysis of variance showed that all types of biodiesels added at proportions of 25 and 50% to S50 diesel had a weight fuel consumption equal to B0 by Tukey's test at a 5% probability (Table 3).

TABLE 3. Summary of the slicing of the interaction between type of biodiesel and blend proportion for weight fuel consumption by Tukey's test of means.

Type of biodiesel	Hourly weight fuel consumption (kg h^{-1})				
	Proportion of biodiesel added to diesel				
	0	25	50	75	100
Peanut	10.57a	11.20a	11.46a	11.73ab	12.23bc
Sunflower	10.57a	11.16a	11.30a	11.50b	12.01c
Waste frying oil	10.57a	11.13a	11.50a	12.03a	12.43ab
Soybean	10.57a	10.83a	11.43a	11.77ab	12.76a

Means followed by the same lowercase letter in the column do not differ from each other by Tukey's test at a 5% probability.

Sunflower biodiesel stood out as the most efficient in B75, leading to a slight retraction compared to the others, with a value of 11.5 kg h^{-1}. The highest consumption of the blends with B75 was obtained for the biodiesel from waste frying oil, with a value of 12.03 kg h^{-1}.

Fuel consumption tends to increase as the biodiesel fraction in the blends increases, which can be attributed to the lower energy content of biodiesel compared to diesel and the increase in oxygen content and thus higher flame temperatures inside the engine cylinder (Aldhaidhawi et al., 2016; Paul et al., 2017).

Specific fuel consumption was linearly influenced by the proportion factor, with the highest value equivalent to 386.5 g kW^{-1} h^{-1} observed when B100 was used to fuel the test tractor (Figure 3). The minimum consumption value was found with the use of S50 diesel and the was peak reached in B100, with the percentage values of differences shown on the right y-axis.

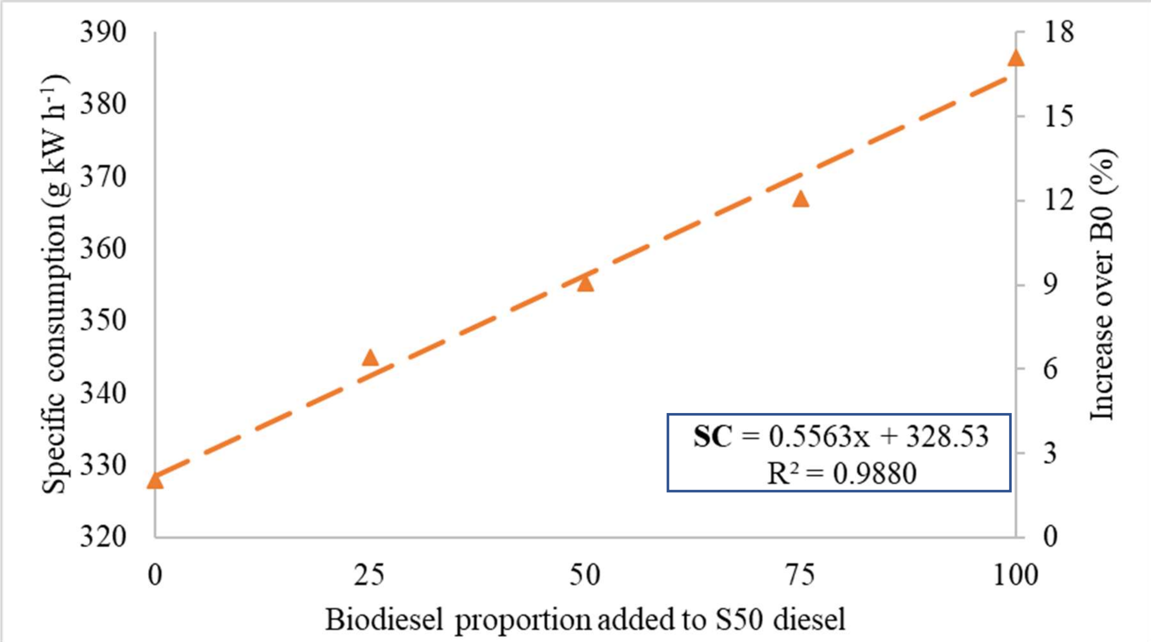


FIGURE 3. Specific fuel consumption as a function of the proportion factor.

A blend of soybean and sunflower biodiesel (50% of each) in an experiment to test the ZS-1100 diesel engine performance revealed that the specific fuel consumption was increased as a function of the amount of biodiesel in the blend. The mean SC increase was 2.44, 7.1, and 11.43% for B30, B50, and B70, respectively, compared to the diesel (Elkelawy et al., 2019).

According to Amaris et al. (2015), the use of blends with more than 20% of biodiesel increases the specific fuel consumption due to the lower calorific value of biodiesel compared to traditional diesel derived from petroleum, and percentages lower than this value led to non-significant changes in consumption. According to Chauhan et al. (2016), the result of combustion characteristics and performance showed that different types of biodiesels from different origins and their blends ranging from 10–20% are better than blends with higher amounts.

CONCLUSIONS

Tractor performance was closely related to the biodiesel fraction in the blends for all evaluated raw materials, showing a direct relationship between proportion (B0 to B100) and fuel consumption. Sunflower biodiesel showed the best result in blends above B75 regarding specific consumption values. Considering all the blend proportions combined with the four types of biodiesels, the comparison between B0 and B100 revealed differences of 14 and 17.8% for VC and SC, respectively.

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