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PERFORMANCE AND EFFICIENCY OF GLASS AND CARBON FIBER BARS FOR SELF-PROPELLED SPRAYERS

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ABSTRACT: Agribusiness has a fundamental role in the Brazilian economy, responsible for stimulating the Gross Domestic Product, creating investment and development opportunities. High yields have been faced in pest-free areas in different crop regions. However, pest control with high efficiency is a challenge for many farmers. In this context, self-propelled sprayers with a high efficiency are necessary to increase the quality and speed of application, directly decreasing equipment's operational cost. This work aims: (i) present the advantages of using carbon fiber booms in the performance of self-propelled sprayers; (ii) compare weight and fuel consumption of self-propelled sprayers with carbon fiber booms and conventional carbon steel booms. The results showed that the self-propelled sprayers with glass/carbon fiber boom presented better application performances, considered 6% more productive, 1.8% lighter, and 44% more economical in fuel consumption than the conventional carbon steel boom. Based on the results, the self-propelled glass/carbon fiber boom is a better alternative to increase agricultural spraying productivity.

Keywords: efficiency of the application, fiber, composite, fuel consumption.

DESEMPENHO E EFICIÊNCIA DE BARRAS DE VIDRO E FIBRA DE CARBONO PARA PULVERIZADORES AUTO-PROPELIDO

RESUMO: O agronegócio tem papel fundamental na economia brasileira com significante participação no Produto Interno Bruto, criando oportunidades de investimento e desenvolvimento no Brasil. Em todas as culturas, altas produtividades estão associadas a áreas livres de pragas, no entanto, o controle de pragas é um desafio para muitos agricultores. Nesse contexto, a escolha de pulverizadores eficientes para aplicação de pesticidas torna-se uma necessidade para aumentar a qualidade e velocidade da aplicação, e diminuir o custo operacional deste equipamento. Este trabalho tem como objetivos: (i) apresentar as vantagens do uso de barras de fibra de carbono no desempenho de pulverizadores; (ii) comparar o peso e o consumo de combustível de pulverizadores com barras de fibra de carbono, e pulverizadores com barras convencionais de aço carbono. Os resultados mostraram que os pulverizadores com barra de fibra de vidro/carbono apresentaram melhores desempenhos de aplicação, considerado 6% mais produtivo, 1,8% mais leve, e 44% mais econômico em consumo de combustível em comparação com a barra de aço carbono convencional. Portanto, pode-se concluir que para otimizar a pulverização de culturas agrícolas, a barra de fibra de vidro/carbono é uma alternativa mais eficiente para aumentar a produtividade na pulverização agrícola.

Palavras-chaves: eficiência de aplicação, fibra, composto, consumo de combustível.

1 INTRODUÇÃO

The incidence of pests in plants negatively affects quantity and quality of food production, considered the main risk factors for agricultural production and threatening food security (BRUCE, 2010; FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, 2020a). In agriculture, the main plant-pests are weeds, pathogens, and

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animal pests (OERKE, 2006). Savary et al. (2019) showed that there is a reduction in food production between 17 and 30% of wheat (*Triticum* spp.), maize (*Zea mays* L.), rice (*Oryza sativa* L.), potato (*Solanum tuberosum* L.), and soybean (*Glycine max* (L.) Merrill) associated with the incidence of pathogens and pests. Oerke (2006) described that among agriculture crops, cotton (Gossypium L.), wheat, and potatoes are the most affected by pests with a possible mean reduction of production, respectively, in 80; 50 and 50 %. Therefore, pests' incidence can impact the food production for next years, estimated to increase by 70% in 2050 (FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, 2020b).

Synthetic pesticides are one of the alternatives to reduce the incidences of pests in plants. Compared with other alternatives (i.e., resistant crop cultivars and biocontrol with natural enemies), synthetic pesticides provided a low control-cost with easy availability of products to farmers (BRUCE, 2010). The use of synthetic pesticides, seeds, and fertilizers are considered the main production costs in Brazilian agriculture (CENTRO DE PESQUISAS ECONÔMICAS, 2020; INSTITUTO MATO-GROSSENSE DE ECONOMIA AGROPECUÁRIA, 2020). Oliveira and Dalchiavon (2019) showed that it is requested nine and four applications of crop defensives (pesticides and herbicides) to produce soybean and corn in the Cerrado, respectively, with an application cost of R$ 16.40 ha^{-1} using a self-propelled.

The applications of synthetic pesticides (liquid) are performed using spraying machines (hydraulics, pneumatics, and electrostatic) (AZEVEDO; OLIVEIRA FREIRE, 2006). Recently, the use of self-propelled sprayers has increased due to the better quality of pulverization (ČEDÍK; PRAŽAN, 2015; FARIAS et al., 2015). The self-propelled can be associated with articulated spray bars to increase the working width and operating speed, causing higher productivity and reducing the number of passes over a field. Fernandes et al. (2007) showed that the spacing between nozzles and the kind of spray bars are important decisions to increase defensive application efficiency. In literature, studies showed the positive effect of nozzles in spray bars (FREITAS et al., 2005; FERREIRA et al., 2007; FERNANDES et al., 2007; ZAIDAN et al., 2012), but there are few studies showing the influence of spray bars in defensive application efficiency.

In the 1960s, the size of spray bars did not exceed 40 feet in length (12.2 meters), but pulverization bars' size is getting higher. For example, Zaidan et al. (2012) testing the performance of spray nozzles used a pulverization bar of 32 meters, while in 2003/04, Raetano and Bauer (2003) and Raetano and Bauer (2003) used a pulverization bar of 14 meters. The high length of spray bars increases the weight and decreases operation speed. Pontelli (2008) showed that long bars can cause weight displacement with an unbalance in the application.

Self-propelled spray bar composed of glass and carbon fibers has been presented as an alternative to a long spray bar with a low weight. Commonly, the self-propelled spray bar is composed of steel and aluminum, explaining the high weight. A self-propelled sprayer has an average weight of 10-11 tons and can reach a weight of 13-14 tons when filled (CARPENEDO, 2014). Therefore, studies that demonstrate the performance of spray bars composed of glass and carbon fibers are requested, and, therefore, justify this study.

The hypothesis is that self-propelled spray bars composed of glass and carbon fibers have a better application performance than steel and aluminum bars. The present study aims: (i) present the performance and efficiency of glass and carbon fiber bars; (ii) compare weight and fuel consumption of self-propelled sprayers with carbon fiber bars and the conventional bars of carbon steel and aluminum.

2 MATERIAL E MÉTODOS

2.1 Study characterization

The study was carried out on an experimental farm located in Goiás, Brazil (latitude, -15° 34' 50 S; longitude, -49° 38' 10 W), 2018/2019. The region presents a climate classified as Tropical with a dry season in winter, according to Köppen-Geiger. The soil was classified as a Latossolo according to the Brazilian Soil classification (EMBRAPA, 2018), corresponding to an Oxisol in the soil taxonomy (SOIL TAXONOMY, 2014).

The experimental design was based on the application of synthetic pesticides using a self-propelled spray with (i) bars of glass and carbon fibers (GCF), (ii) and bars of carbon steel and aluminum (CSA), using three replications. The performance of the bar was monitored in an area of soybean production. The experimental area presented a dimension of 23.000 hectares and an altitude of 1200 m. Three machines were used with 30 meters of wider steel boom, and three machines with 36 meters of the wider carbon fiber boom.

The soybean was cultivated in crop succession with corn, with cultivation of soybean from September to March. The applications of synthetic pesticides (herbicides, insecticides, and fungicides) were performed using an average of 25 applications during crop cultivation to desiccation and pest-control. When there was the defensive application, the plants had a size of 10 cm (height), in the phenological stage V1 and V2, except for the herbicide application, which the plants were in the vegetative phase of growth. In this area, herbicides were applied before and after planting to control weeds, fungicides to control fungi, mainly Asian soybean rust and defoliant for harvest, and insecticides for various pests.

The fiber of glass and carbon had an anisotropic nature, a composition reinforced with unidirectional fiber, and a density of 1.8 and 1.6 g cm^{-3}, respectively. The densities of fibers of glass and carbon presented densities more than four times lower than steel and aluminum (Table 1).

Table 1. Characterization of steel (ASTM A500; DOMEX), aluminum, and fibers of glass and carbon in bars used in the self-propelled spray.

	Steel (ASTM A500)	**Steel (DOMEX)**	**Aluminum (6061-T6)**
Density (g cm^{-3})	7.8	7.8	2.7
Elasticity (GPa)	208	208	70
Shear (GPa)	80	80	26
Traction (MPa)	355	689	240
Compression (MPa)	425	800	310
Shear (MPa)	206	400	140

	Glass fibers		**Carbon fibers**	
	0º	90º	0º	90º
Density (g cm^{-3})	1.8	1.8	1.6	1.6
Elasticity (GPa)	20-40	7-12	125-200	8-12
Shear (GPa)	3-6	3-6	5-9	5-9
Traction (MPa)	500-1000	30-50	1500-3500	20-100
Compression (MPa)	300-600	100-140	1000-1500	150-250
Shear (MPa)	30-60	30-60	50-100	50-100

Also, the alloy of glass and carbon presented a mean of elasticity, shear, traction, compression, and shear of 96 GPa; 6 GPa; 1625 MPa; 850 MPa; and 60 MPa (0º), and 10 GPa; 6 GPa; 50 MPa; 160 MPa; and 60 MPa (90º), respectively. Generally, the high mean of elasticity, traction, and compression in 0º is due to its anisotropic nature and the composite building with unidirectional fibers following the load flow. The alloy of steel (ASTM A500; DOMEX) and aluminum (6061-T6) presented a mean of elasticity, shear, traction, compression, and shear of 162 GPa; 62 GPa; 428 MPa; 512 MPa; and 249 MPa, respectively.

The bars of glass and carbon fibers presented a high rigidity and low density with a weight of 10,169 and 13,197 kg empty and filled, respectively. The dimensions were about 4.17 m in height and 36.57 m of long in the spray position. The bars of carbon steel and aluminum presented a weight of 10,351 and 13,379 kg empty and filled, respectively, with dimensions of 3.96 m of height and 30.48 m of length in the spray position. The material of bars influences weight, as observed bars of glass and carbon fibers presented a lower density and weight than bars of carbon steel and aluminum.

2.2 Measurements and Statistical analysis

The speed and the working width were monitored in the field using a fleet monitoring system. The speed data were collected with a controller that sends data via telemetry to the database. The working width was determined by the size of the self-propelled sprayer boom. There was no additional manual monitoring in the experiment. The operational efficiency was monitored using the relation between the time of machine operation versus time of not spraying (transport or stop), according to Eq. 1. The data were collected with a control unit that sends data via a CAN protocol (electric support), in which it is possible to determine the exact moment of the beginning of the spraying. Where, TMO: is the time of machine operation; TNS: is the time of not spraying.

$$Ef\ (\%) = \frac{TMO}{TNS} * 100 \tag{1}$$

With the data of speed, working width, and operational efficiency calculated the productivity of spray bars (hectares day^{-1} hour^{-1}), according to Eq. 2. Where, P is the productivity of application (Mg h^{-1}); W is the working width (m); S is the average speed (Km h^{-1}); Ef is operational efficiency (%).

$$P\ (\mathrm{Mg\ h^{-1}}) = L * W * S\ \frac{\left(\frac{Ef}{100}\right)}{10} \tag{2}$$

The fuel consumption was calculated according to Eq. (3), where, the Cop is the operational fuel consumption (L ha^{-1}); C is the fuel consumption (L h^{-1}); S is the average speed (Km h^{-1}); BS is bar size (m). The data of fuel consumption were collected with a control unit that sends data via the CAN protocol (electric support), in which it is possible to determine the fuel consumption over time—considered a constant average of bar size with 30 meters of wider steel boom and 36 meters of the wider carbon fiber boom.

$$Cop = C * 10 * \left(\frac{1}{S * BS}\right) \tag{3}$$

With the data, the assumptions of normality and homogeneity of variance were tested by the Shapiro-Wilk-test and Levene-test ($p \leq 0.1$), respectively. The results of each self-propelled spray bar were treated as populations and submitted to the t-test (Student test; $p \leq 0.05$; unilateral test). The statistical analysis was performed using R Statistical Software (version 4.0.0; R Foundation for Statistical Computing).

3 RESULTS AND DISCUSSION

GCF presented a higher working width with a mean of 36.5 m, representing an increase of 20% compared with CSA (Figure 1). The working width represents the area covered by the self-propelled sprayer during one pass direction along the field. The working width is impacted by the width of the machine and the percentage of the machine width (RICHEY; JACONSON; HALL, 1961). The high working width was expected in GCF due to higher height (4.17 m) and longer in the spray position (36.57 m), compared with the bars of steel and aluminum that presented a low height (3.96 m) and long in the spray position (30.48 m).

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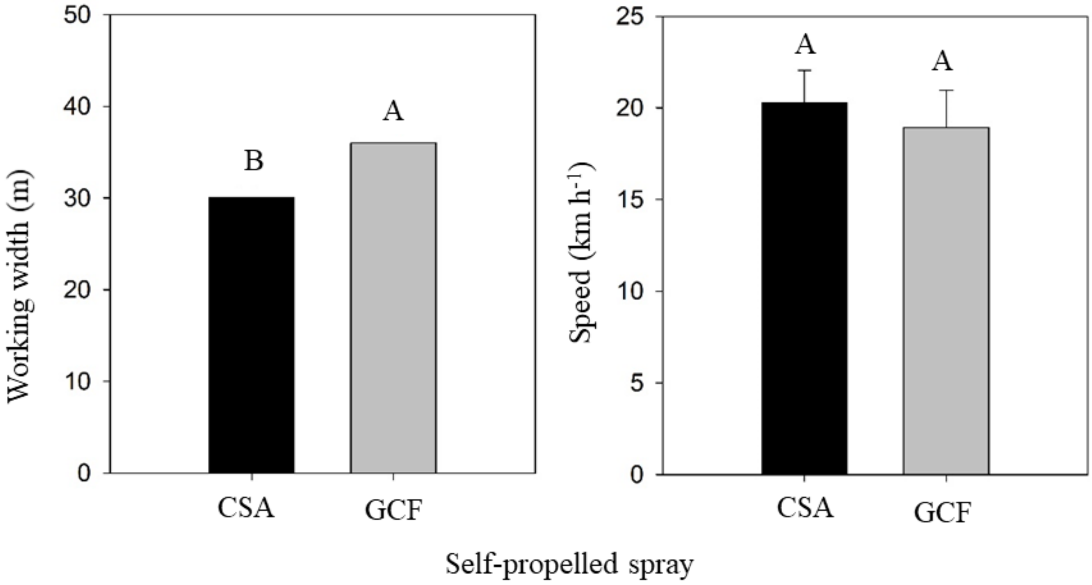
Figure 1. Working width (m) and speed (km h^{-1}) of self-propelled spray with bars of glass and carbon fibers (GCF); and bars of carbon steel and aluminum (CSA). Means were compared by the t-test ($p \leq 0.05$).



Interestingly, there was no difference in speed between spray bars with a mean of 20.3 and 18.9 km h^{-1}, respectively, to CSA and GCF (Figure 1). The lack of difference in speed due to the farmer's spraying culture at a specific speed to preserve the boom integrity and control the boom stability without hitting it on the ground. Dierings (2020) testing speed of application noticed that the increase in speed interfered in the quality of applications, with an adequate speed found at 15 km h^{-1}. If compared with study's speed, there was a higher speed (20.3 and 18.9 km h^{-1}) in the application in study. Santos and Chioderoli (2018) showed that the increase in application speed decreased operational cost and applied defensive volume. It may explain the higher speed of application herein to reduce costs, without interference in bars' model.

The productivity of GCF was 16% higher than CSA (25.1 ha h^{-1}), Figure 2. The increase in productivity was associated with the increment of the working width (Figure 2). The greater effect of GCF is associated with the low weight with a mean of 1.167 Kg, considered 13 % lighter than CSA. If considered the whole machine's weight, the GCF was 1.8 % lighter than CSA, with a lower difference. The low weight impacts soil quality positively to plants' development due to the adequate distribution of pores (ARRUDA et al., 2016). Keller et al. (2019) demonstrated that the increment of farm vehicle weights negatively impacts soil quality with the increase of compaction levels with a direct effect in stagnation in crop yields.

There was no effect of spray bars in the operational efficiency with a mean of 40 and 50 % in CSA and GCF, respectively (Figure 2). Operational efficiency depends on the land structure and the times lost in maneuvers, refueling, calibration, and cleaning the spray nozzles. Operational efficiency is considered an important factor that directly affects the operational field capacity (BAIO et al., 2004). Machado, Queiroz, and Reynaldo. (2015) showed that the machine's unproductive time refueling and returning to the application area increased 37% of application time. The low operational efficiency can increase by 200% in operational costs in applying defensive (TACHIBANA, 2000).

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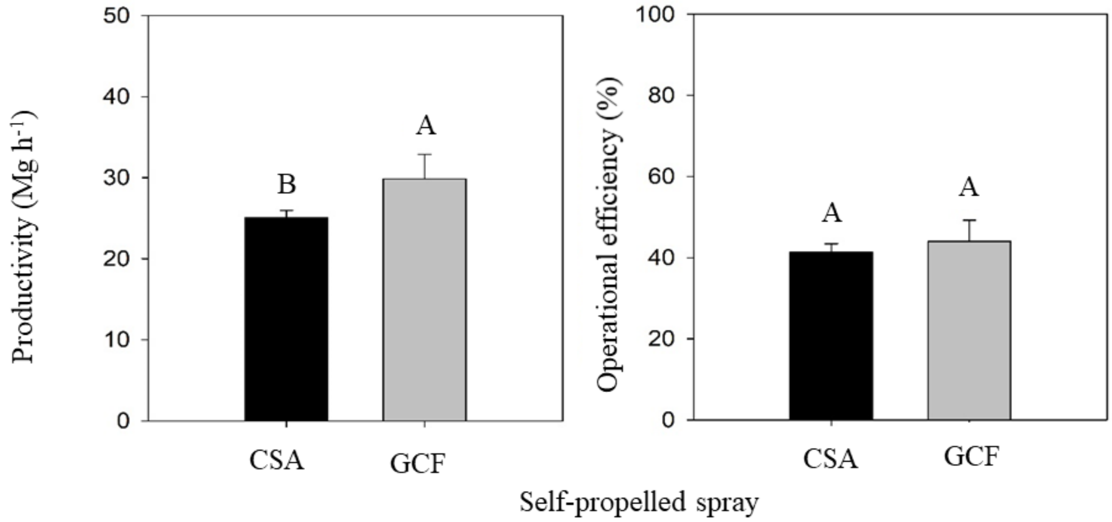
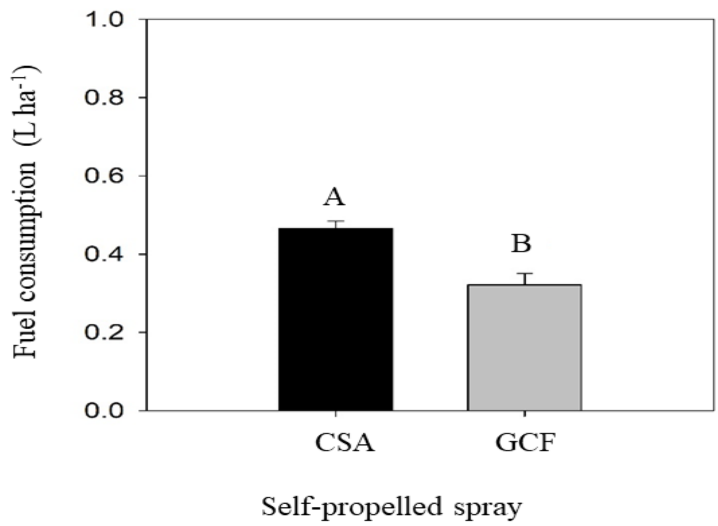
Figure 2. Productivity and operational efficiency of self-propelled spray with bars of glass and carbon fibers (GCF); and bars of carbon steel and aluminum (CSA). Means were compared by the t-test (p≤0.05).



Fuel consumption was 44% lower with self-propelled spray bars of GCF, indicating a fuel economy and viable use compared with CSA (Figure 3). The low fuel consumption resulted from higher productivity and a working width of GCF (Figures 1 and 2). Carvalho Filho (2000) showed that the speed influences fuel consumption in a sugarcane production area, where the high hourly consumption promoted a lower fuel consumption per ton of cane harvested. Other factors also influence fuel consumption, i.e., the machine model (BAIO et al., 2004). However, in study, machines presented similar fuel consumptions to avoid that difference.

Figure 3. Fuel consumption of self-propelled spray with bars of glass and carbon fibers (GCF); and bars of carbon steel and aluminum (CSA). Means were compared by the t-test (p≤0.05).



4 CONCLUSIONS

The use of self-propelled spray with bars of glass and carbon fibers presented a greater productivity and fuel consumption due to low machine weight and better working width. Bars of glass and carbon fibers were 16% more productive, 1.8% lighter, and 44% more economical in fuel consumption than bars of carbon steel and aluminum. Based on study,

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the use of self-propelled spray with bars of glass and carbon fibers is an optimal alternative to increase the use of the defensive application; future studies showing costs between machines, including the purchase price of the machines, fixed costs, and operating costs are requested to demonstrate the economic viability.

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