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Pollutant emissions from a tractor towing a seeder-fertilizer in an area with controlled machinery traffic

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ABSTRACT: Controlled machinery traffic is a technique to increase the efficiency of machines and make better use of inputs. This study evaluated the pollutant gas emissions of an agricultural tractor towing a precision seeder-fertilizer with different plow configurations in an area with varying intensities of controlled machinery traffic. The study was carried out in a commercial agricultural area located in the municipality of Carazinho, Brazil. The experimental design was of randomized 3 x 3 blocks, with three traffic situations (tractor traffic; tractor + harvester traffic; and tractor + harvester + sprayer traffic), as well as three plow settings. The pollutant gases analyzed were: particulate material (PM), nitrogen oxides (NO_x), carbon dioxide (CO_2), and oxygen (O_2). We concluded that greater controlled traffic intensity, compared to an area without traffic, yields a PM reduction of 43% using the double disk, and 67% using the double disk without a ridge plow. The absence of plows on the traffic lines reduces the PM, NO_x, and CO_2 emissions by, respectively, 73%, 12%, and 17% with tractor + harvester traffic; and 80%, 12%, and 15% with tractor + harvester + sprayer traffic, compared to cultivation using ridge plows.
Key words: diesel cycle engine., greenhouse gases, traffic intensity.

Emissões de poluentes de trator tracionando semeadora-adubadora em área com tráfego controlado de máquinas

RESUMO: O tráfego controlado de máquinas é uma técnica para aumentar a eficiência das máquinas e melhor utilizar os insumos. O objetivo deste trabalho foi avaliar as emissões de gases poluentes de um trator agrícola tracionando uma semeadora-adubadora de precisão com diferentes configurações de sulcadores em uma área com intensidades variadas de tráfego controlado de máquinas. O estudo foi realizado em uma área agrícola comercial localizada no município de Carazinho, Brasil. O delineamento experimental foi em blocos casualizados 3 x 3, com três situações de tráfego (tráfego de trator; tráfego de trator + colheitadeira; e tráfego de trator + colheitadeira + pulverizador), além de três configurações de sulcadores. Os gases poluentes analisados foram: material particulado (MP), óxidos de nitrogênio (NOx), dióxido de carbono (CO2) e oxigênio (O2). Concluiu-se que a maior intensidade de tráfego controlado, em comparação com área sem tráfego, proporciona redução de MP de 43% usando o disco duplo e 67% usando o disco duplo sem haste. A ausência de sulcadores nas faixas de tráfego reduz as emissões de MP, NOx e CO2 em 73%, 12% e 17% respectivamente, com tráfego trator + colheitadeira e 80%, 12% e 15% com tráfego de trator + colheitadeira + pulverizador, em relação ao cultivo com sulcador haste.
Palavras-chave: motor ciclo diesel., gases de efeito estufa. intensidade de tráfego.

INTRODUCTION

Technology use in mechanized processes is important for obtaining maximum economic and productive efficiency in agriculture. Currently, most machines used in the rural property are equipped with Diesel cycle engines, thus dividing efficiency and reliability (PERIN et al., 2015).Conversely, such engines pollute more compared to Otto cycle engines, emitting especially NO_x and PM (BRIJESH& SREEDHARA, 2013).

In the theoretical analysis of Diesel fuel's complete combustion process, its resulting products would be only water vapor and CO_2; however, this does not occur due to transient engine conditions (PETRANOVIC et al., 2017). The emissions associated with the use of direct energy in the field operations contribute, primarily, to environmental impacts such as climatic alterations and the acidification of ecosystems (STRANDDORF et al., 2001).

An option to reduce energy consumption and; consequently, pollutant emissions, is the

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adoption of controlled machinery traffic due to the permanent dislocation of the wheels in trafficked areas, resulting in a lower energy requirement in areas with less compaction, occupied by spaces destined for plant cultivation and without machinery traffic (CHEN&YANG, 2015). However, subsoil operation using ridge plows, for example, yields an increase in energy demand, requiring more traction force for working in greater depths, possibly resulting in more environmental pollution (CEPIK et al., 2010).

Despite there being positive results in the use of this technology, CHEN & YANG (2015) stated that an in-depth exploration into the effect of the system of controlled machinery traffic on culture productivity, fuel economy, and pollutant gas emissions by engines is necessary. In this sense, the present study has the objective of evaluating the pollutant gas emissions of an agricultural tractor towing a precision seeder-fertilizer with different plow configurations, in an area with varying intensities of controlled machinery traffic.

MATERIALS AND METHODS

The study was carried out in the municipality of Carazinho, RS, Brazil, (28°14′15″ S, 52°40′08″ W, 596 m above sea level) in a commercial agricultural area, which has been adopting the systems of controlled machinery traffic and direct planting for three years. The soil is classified as Red Latosol, of clay texture with slightly wavy topography. The experimental area had 2.3 Mg ha^{-1} of dry matter. The soil water content was 22%, 20%, 22%, and 23% at the 0 - 0.05 m, 0.05 - 0.10 m, 0.10 - 0.15 m, and 0.15 - 0.20 m depths, respectively.

The agricultural tractor used to tow the seeder-fertilizer was a Massey Ferguson MF 7415 Dyna-6, with auxiliary front wheel drive, manufactured in 2014, with 1,200 hours of use. Equipped with a four-stroke Diesel cycle engine with six cylinders, 24 valves, a dislocated volume of 7,400 cm^3, and overloaded by a turbocharger with intercooler. According to the essay report, in test wit dynamometer, its maximum power is of 145.6 kW (198.0 hp) at 1,795 rpm.

The tractor had a total mass of 11,690 kg (114.64 kN), with a static mass distribution of 60% over the rear axle and 40% over the front. The tractor was operated with Firestone 30.5L32 R-1 diagonal rear tires and Goodyear 18.4-26 R-1 diagonal front tires, the four having 75% of hydraulic ballasting. Attached to the tractor, we used two Semeato SSM 27 seeder-fertilizers in tandem, set with 52 seeding lines, spaced 0.17 m apart. To simulate a real condition, we filled them with 2,060 kg of fertilizer in the reservoirs, characterizing half the maximum cargo capacity of the seeders.

The study was done in randomized blocks, in a two-factor statistical design, with three traffic situations and three plow configurations, in three blocks, totalizing 27 experimental units. Namely:

- Factor A: controlled machinery traffic, composed of the passing of only the tractor, characterizing its movement in an area without traffic (NT), with it towing the seeder-fertilizer outside the lanes demarked for traffic. The second level was characterized by the sum of the tractor's passage, in the seeding operation, and that of a harvester while harvesting soybean, thus defining the tractor + harvester scenario (TH). The third level was composed by the sum of the traffic of the tractor, the harvester, and a cultural treatment sprayer, which totalized seven traffic in area, characterizing the tractor + harvester + sprayer (THS).
- Factor B: configuration of the seeder-fertilizer plows, according to the different traffic intensities existing in factor A. The initial setting was composed of 52 double disk (DD) plows fixed at the same rotation center, with a depth of 0.03 m. The second level of factor B was the association of double disk and ridge plows (DDR), using 42 double disks and 10 ridge plows, which were characterized for coinciding over the traffic lines of the agricultural machinery wheels, with a depth of 0.13 m. For the third level, we maintained the previous 42 double disks, but removed the ridge plows, denominating this setting the *double disks without ridge plows* (DDnR).

Due to the impossibility of measuring the pollutant gas emissions directly in the field, we measured the traction forces required by the seeders, obtained through a 100 kN charge cell installed between the tractor's traction bar and the tandem header. The data, transformed into torque values, were applied through a dynamometric brake, in laboratory, with the objective of simulating the charges demanded by the seeders in the field.

The dynamometric brake used to simulate the torque values required by the seeders was model PT 301 MES by EGGERS. Through the EGGERS Power Control software, was performed the braking control and recorded the torque and engine rotation data, under the same intensity required by the seeders, for the different situations studied, according to figure 1.

It was performed analyses of the emitted pollutant gases using EGGERS Infrality ELD gas analyzer, which measured the concentrations of CO_2 (% vol.), O_2 (% vol.), NO (ppm), and NO_2 (ppm), which compose the chief greenhouse gases.

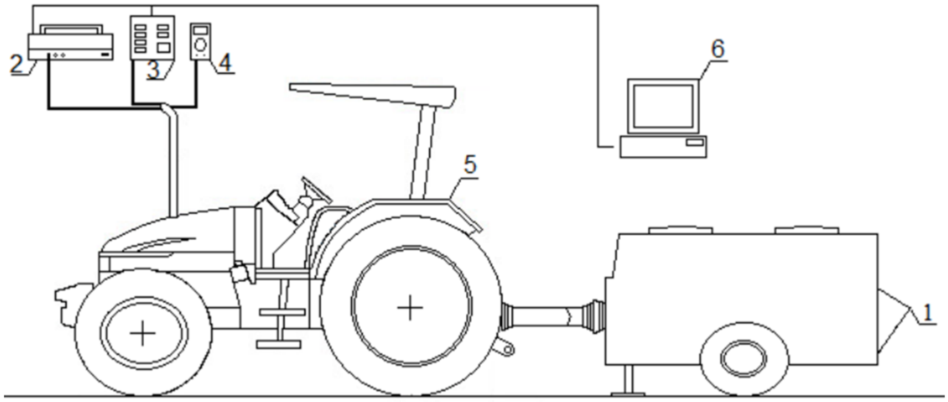

Figure 1 - Schematic representation of the torque simulation of the agricultural tractor's engine (1. Dynamometric brake, 2. Opacimeter, 3. Gas analyzer, 4. Thermocouple, 5. Agricultural tractor, 6. Manager software).

Weobtained the gas opacity values using an EGGERS Opacilyt ELD partial-flow opacimeter.

The samples were collected directly at the tractor's tailpipe, through a metallic probe, conducting them into the equipment for analysis. We used the MW IELD O1030 software for analyses of the gases and particulate materials.

Before starting the data collection, was warmed the tractor's engine for 20 minutes using the dynamometric brake. For this purpose, the engine was put into its maximum free rotation (2,300 rpm) and a charge equivalent to 75% of this rotation was imposed. We tabulated the results obtained and submitted them to an analysis of variance (ANOVA), while was compared the means through the Tukey test at 5% error probability using the statistical program SISVAR (FERREIRA, 2014).

RESULTS AND DISCUSSION

The pollutant gas emissions of the engine of the agricultural tractor presented an interaction among all the traffic intensities and plow configurations (Table 1). Moreover, upon analyzing the primary effects, a difference was observed among all the variables evaluated.

The traction demand on the bar to tow the set of seeders varied according to the plow configurations. Such variation modifies the engine's functioning, especially the air and fuel mixture responsible for combustion. Combustion within the engine is one of the processes that control the power, efficiency, and production of pollutant gases (HEYWOOD, 2018).

In this sense, the existence of interactions between the traffic intensities and the plow configurations demonstrated that the controlled machinery traffic, as well as the different plows, interferes in the functioning of the tractor's engine; and consequently, affects its pollutant gas emissions. Table 2 shows the values of pollutant gases emitted by the engine for the different traffic systems and plow configurations of the seeder.

The PM emissions from the tractor's engine were higher at the NT area for almost all plow configurations except for the DDR plow, which did not present a difference between the NT and TH areas (Table 2). This demonstrated that the controlled traffic (THS) for all plow configurations, upon allowing the accumulation of agricultural machinery passing over the same location, yields reductions of up to 67% in the PM emissions for the DDnR setting.

This PM emission reduction in the highest traffic intensity (THS) may be justified by the fact that a tractor, when going over firm soil, has a lower rolling resistance. In addition, the lower energy demand allows the engine to work at maximum efficiency, i.e., with an adequate mixture of air and fuel, without the need for fuel overload. This favors combustion and may reduce the PM emissions, as made evident in this research.

The lowest PM emissions occurred during the use of DDR in all traffic intensities evaluated (Table 2). The employment of this configuration proved to be sustainable, in view of the significant reduction of emitted PM. For FURLANI et al. (2008), grain production within a sustainable system must be based on conservationist practices and the rational use of agricultural machinery.

Table 1 - Analysis of variance with mean square for particulate materials, nitrogen oxides, carbon dioxide, and oxygen in source of variation.

		---Mean square---		
Source of variation	Particulate materials	Nitrogen oxides	Carbono dioxide	Oxygen
Traffic (T)	0.199*	0.609*	9,376*	8.432*
Plow (P)	1.113*	33.172*	1,046,438*	139.99*
T x P	0.035*	0.185*	4,872*	4.143*
Error	00	0.0	6.198	0.004
CV (%)	11.65	0.94	0.75	0.43
Geral mean	0.065	2.738	332.72	14.206

*Significativ effect ($P \leq 0{,}05$).

Due to the separation of production and machinery circulation areas, controlled machinery traffic is a relevant tool in the sustainable management of the system. In the present study, this division made 82% of the area be destined for plant cultivation, and 18% for machinery traffic.

The THS traffic system presented the lowest NO_x emissions for all plow configurations evaluated (Table 2). We verified a 2% and 3% NO_x reduction from the NT system to THS with the DD and DDnR settings, respectively. Even with the use of the controlled traffic technique, the choice of proper plow mechanisms may contribute to the reduction of NO_x. In the present research,it was demonstrated that the use of disk plows rather than ridge plows is the best option.

When evaluating the plow systems, the DDR configuration yielded the highest NO_x emission compared to the other settings (Table 2). REIS (2013) obtained a direct relation between the increase in NO_x and that of the charges applied to the traction bar. The NO_x emissions of the DDR configuration to the

Table 2 - Particulate materials, nitrogen oxides, carbon dioxide, and oxygen for the area without traffic (NT), tractor and harvester traffic (TH), and tractor + harvester + sprayer traffic (THS), with the double disk, double disk with ridge plow, and double disk without ridge plow configurations.

Traffic	---Plow system---		
	Double disk	Double disk with ridge plow	Double disk without ridge plow
--- Particulate materials (g kW h^{-1}) ---			
NT	0.07 Ba	0.11 Aa	0.06 Ca
TH	0.06 Bb	0.11 Aa	0.03 Cb
THS	0.04 Bc	0.10 Ab	0.02 Cc
--- Nitrogen oxides (g kW h^{-1}) ---			
NT	2.70 Ba	2.94 Ab	2.65 Ca
TH	2.65 Bb	2.96 Aa	2.60 Cb
THS	2.64 Bc	2.92 Ac	2.58 Cc
--- Carbon dioxide (g kW h^{-1}) ---			
NT	323 Ba	368 Ab	316 Ca
TH	315 Bb	372 Aa	309 Cc
THS	312 Bc	366 Ac	311 Cb
--- Oxygen (%) ---			
NT	14.63 Aa	13.78 Cb	14.51 Ba
TH	14.50 Ab	13.78 Cb	14.25 Bb
THS	14.38 Ac	13.84 Ca	14.18 Bc

*Means followed by the same uppercase letter at the line and lowercase at the column in each variable do not differ according to the Tukey test ($Pp \leq 0.05$).

DDnR represent a reduction of 10%, 12%, and 12% for the NT, TH, and THS systems, respectively.

CO_2 emissions were higher in the NT area when using the DD and DDnR configurations, whereas in the TH traffic area they were higher for the DDR setting. This configuration also yielded greater emissions for all traffic intensities evaluated (Table 2). Overall, CO_2 emissions increase due to the joint action of the rise in applied load and the agricultural operation that is being performed (RASHID et al. 2013; REIS et al. 2013).

Conversely, the lowest CO_2 emissions occurred during the use of DDnR for all traffic intensities (Table 2). For PERIN et al. (2015), emissions stemming from the agricultural engine decrease with the reduction of applied load. In the present study, it was also lower when using the double disk without ridge plow (DDnR) configuration.

The use of the DDnR setting in detriment of the DDR reduced the CO_2 emissions by 17% and 15% in the TH and THS traffic conditions, respectively. Again, based on these results, one may state that the adoption of controlled traffic and the use of double disks without ridge plows are significant and sustainable techniques, considering that they reduce CO_2 emissions from agricultural engines.

The O_2 level emitted by the engine after combustion was higher in the NT area for the DD, DDR, and DDnR plow configurations in TH traffic (Table 2). The highest percentage of O_2 not consumed during the engine's internal combustion occurred with the DD plow setting, for all traffic intensities.

The lowest O_2 percentage was observed during the use of the DDR plow configuration, for all traffic intensities evaluated (Table 2). Moreover, we verified that the reduction in O_2 emission by using the ridge plows (DDR) compared to the DDnR was 5%, 3%, and 2% for the NT, TH, and THS traffic intensities, respectively.

In the region around the flame, within the combustion chamber, there may occur a combustion interruption due to an insufficient supply of O_2 (rich mixture) or due to excessive heat loss (TORRES et al., 2003). In agreement with the results obtained in thisresearch, REIS (2013) also stated that there is a reduction of O_2 emissions when there are high demands for power in the power take-off and on the tractor's traction bar.

CONCLUSION

The adoption of controlled traffic of agricultural machinery provides a reduction of the chief pollutant gases emitted by the engine. Double disk plow configurations, which demand less traction force by the tractor, make the engine emit lower amounts of particulate materials, nitrogen oxides, and carbon dioxide into the atmosphere.

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DECLARATION OF CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHORS' CONTRIBUTIONS

All authors contributed equally for the conception and writing of the manuscript. All authors critically revised the manuscript and approved of the final version.

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