

## PERFORMANCE AND EMISSION OF POLLUTANTS OF AN AGRICULTURAL ENGINE WITH TWO POWER TAKE-OFF SETTINGS

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**ABSTRACT:** Farming operations are usually performed implements driven by a power take-off (PTO) from tractors. Some manufacturers offer PTO settings named as economic (540E). Such configuration drives implements at lower tractor's engine rotation, thus providing lower fuel consumption. An engine performance using standard (540) or 540E settings are different and poorly studied. The amounts of pollutants emitted by engines vary mainly with the applied load and rotation. The aim of this study was to compare the performance and exhaust emissions of a farming tractor engine under different PTO loads, using both standard (540) and 540E settings. Specific fuel consumption using 540E was an average 14.7% less than the standard setting. However, 540E promoted increasing levels of gas opacity, CO, CO<sub>2</sub>, NO<sub>x</sub>, and HC for the highest PTO power demands.

**KEYWORDS:** fuel consumption, exhaust gases, agricultural tractor, 540E setting.

## INTRODUCTION

The growing societal concern related to the environment has placed increased pressure on the use of fossil fuels. These propellant materials raise costs of production and are responsible for polluting gas emissions. Since the last century, world energy consumption and environmental pollution have significantly augmented, and there are projections of future progressive increases (JANULEVICIUS et al., 2013).

Fuel consumption and environmental pollution intensity are directly related to the number of diesel engines in trucks, farming tractors, and automotive machines, as well as light-duty vehicles as well. Energy, transportation, and agriculture are economic sectors in dire need for reductions of pollution and fuel consumption (PÉREZ-MARTÍNEZ, 2012).

As energy demand has risen, adverse environmental effects have also emerged, such as emissions of CO (carbon monoxide), CO<sub>2</sub> (carbon dioxide), NO<sub>x</sub> (nitrogen monoxide and nitrogen dioxide), HC (hydrocarbons), and PM (particulate matter) from fuel burn (LEBEDEVAS et al., 2013).

Tractors are the most widely used machine in farms, with about 29 million tractors worldwide (BILSKI, 2013). These machines have a diversified use; therefore, optimization of their performance is justified (VALE et al., 2011). A tractor transmission system consists of a set of elements ensuring transfer of power from tractor's engine to other systems such as hydraulic, power take-off (PTO), and driving wheels (MÁRQUEZ, 2004), thus providing useful power to farm equipment.

Several manufacturers have made available tractors equipped with a so-called 540E setting, which, unlike a standard PTO, drives a machine by maintaining its standard rotation of 540 rpm at a lower engine speed. The use of a 540E is limited to light agricultural operations such as spraying, cutting low-density materials, centrifugal delivering, among others (FRANTZ et al., 2014).

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Sumer et al. (2010) stated that 540E and standard PTO rotations are related to a given tractor engine speed, varying according to its brand, model, and power range. According to the same authors, engine rotations to achieve a standard PTO rotation generate varied fuel consumptions, and any further fuel saving between 540 standard and 540E will vary with the loads applied to the system as well.

Agricultural tractor performance tests are conducted using standard PTO (OECD, 2008). By these tests, specific fuel consumption values are estimated at certain points of engine operation (SILVEIRA et al., 2008).

This study aimed to compare performance parameters and emissions of pollutant gases from a farming tractor's engine subjected to different loads on the PTO, using standard and 540E settings.

## MATERIAL AND METHODS

A TL 75E tractor (New Holland, Curitiba, Brazil) equipped with a four-stroke diesel cycle engine with 12 hours of operation, from the same manufacturer, was used in the experiment. The engine model consisted of an FPT (Fiat Power Train), series F5, with four cylinders and conveyed the volume of 3,908 cm<sup>3</sup> induced by natural aspiration. According to the manufacturer, the engine maximum power is of 57.4 kW (78 hp) at 2400 rpm. Fuel supply system has rotary type mechanical injection pump (Delphi, DP150). Diesel oil was purchased from a local automobile supply network, with a specific mass of 0.875 kg L<sup>-1</sup> at 18.3 °C. This tractor features both standard and 540E PTO.

PTO torque and power, as a function of engine speed, were estimated by an electric dynamometer (EGGERS, PT 301 MES) with a braking force of up to 551 kW (750 hp). Fuel consumption was measured by an EGGERS flowmeter (FM3-100). Two sensors measured the amount of consumed fuel, which was also used for specific fuel consumption. One of them measures the content of fuel entering the injection pump. The other sensor measures the return, i.e. after passing through injection nozzles. The difference between both of them indicates the total fuel consumption. Engine performance data were gathered using EGGERS Power Control computer software, which controls both the dynamometer and the flowmeter.

The main engine exhaust gases, O<sub>2</sub> (% volume), CO<sub>2</sub>, (% volume), CO (ppm), NO<sub>x</sub> (ppm), and HC (ppm) were measured by a gas analyzer (SAXON, Infralyt ELD). Exhaust gas opacity was measured by the light absorption coefficient of smoke (k value), using an opacimeter (SAXON, Opacilyt 1030). Control and acquisition of data from both devices were made through MW IELD 01030 software. Additionally, gas temperature values (°C) were collected by a type k thermocouple. Figure 1 displays a diagram of the experiment.

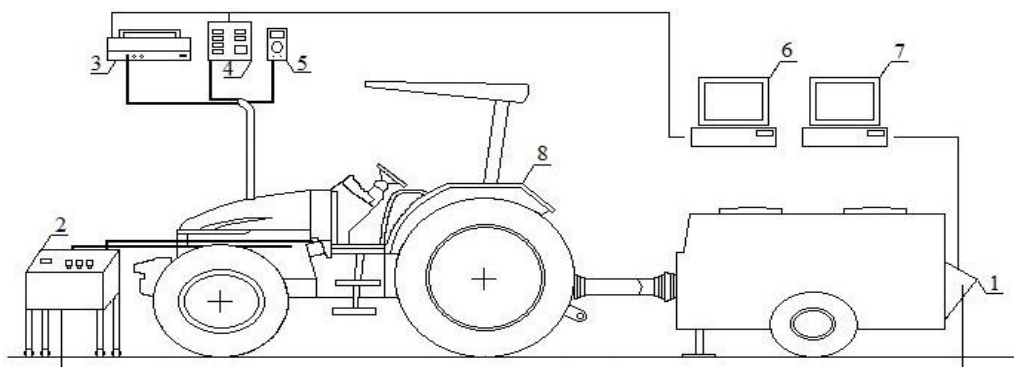


FIGURE 1. Diagram of the experiment (1. electric dynamometer - EGGERS, PT 301 MES model; 2. flowmeter - EGGERS, FM3-100 model; 3. opacimeter - SAXON, Opacilyt 1030 model; 4. gas analyzer - SAXON, Infralyt ELD, model; 5. type k thermocouple - 6 MW IELD 01030 software; 7. Power Control software; 8. Farming engine testing).

Transmission ratio for both 540 and 540E PTO was determined before starting the experiment. They reached standard rotation (540 rpm) at 2208 and 1719 engine rpm, respectively.

In order to reach an optimum operating temperature, the engine was loaded by the dynamometer for twenty minutes.

Once this was done for each of the evaluated settings, tractor engine was speed up until reaching the PTO standard rotation. Later, after dynamometric brakes were manually activated, eight increasing loads were applied. Each 5-kW power increment in PTO was considered a measurement point where torque, hourly and specific fuel consumption, gas emissions, and opacity were recorded. Each measurement point was maintained for five minutes to stabilization of emission values, and the last 20 seconds were used to collecting the analyzed parameters.

By setting PTO draft speed at 540 rpm, the engine was able to withstand loads until reaching a maximum power of 45 kW at PTO shaft with an engine speed of 1950 rpm. For the 540E setting, the engine could withstand loads of up to a maximum power of 40 kW at PTO shaft working at 1550 rpm. Therefore, comparisons between both settings, 540 and 540E, were made considering loads applied to provide a power of 40 kW at PTO shaft.

For statistical analysis, a two-phase design was used, in which the evaluated factors were PTO setting (540 and 540E) and engine-applied loads (5, 10, 15, 20, 25, 30, 35, and 40 kW). Treatments were set in a completely randomized design with three replicates. Afterward, with the aid of SISVAR software, version 5.3, (FERREIRA, 2011), data underwent analysis of variance (ANOVA) and Tukey's test was applied for mean comparisons at 5% error probability.

## RESULTS AND DISCUSSION

Table 1 shows the analysis of variance. The results of torque and specific fuel consumption for both PTO settings (Factor A) and for engine-applied loads (Factor B) demonstrate statistically significant variations.

TABLE 1. Analysis of variance (ANOVA) for the assessed parameters: torque (N m) and specific fuel consumption ( $\text{g/kW h}^{-1}$ ).

Sources of variation	Degrees of freedom	Mean squares	
		Torque	Specific fuel consumption
Factor A	1	10710.19	38576.98
Factor B	7	27480.83	148988.67
A x B	7	445.24	5626.04
Residue	32	0.04	61.84
Fc (A x B)		10685.64	90.98
C.V. (%)		0.17	2.18

Torque values for both settings varied directly and proportionally with the increase in power, i.e. increasing power values and keeping the PTO rotation initially at 540 rpm, there was an increase in torque (Figure 2). By providing 40 kW of power in both PTO settings, 540 and 540E, the engine had its speed reduced by 200 rpm (9.07%) and by 184 rpm (10.67%), respectively, if compared to the initial one.

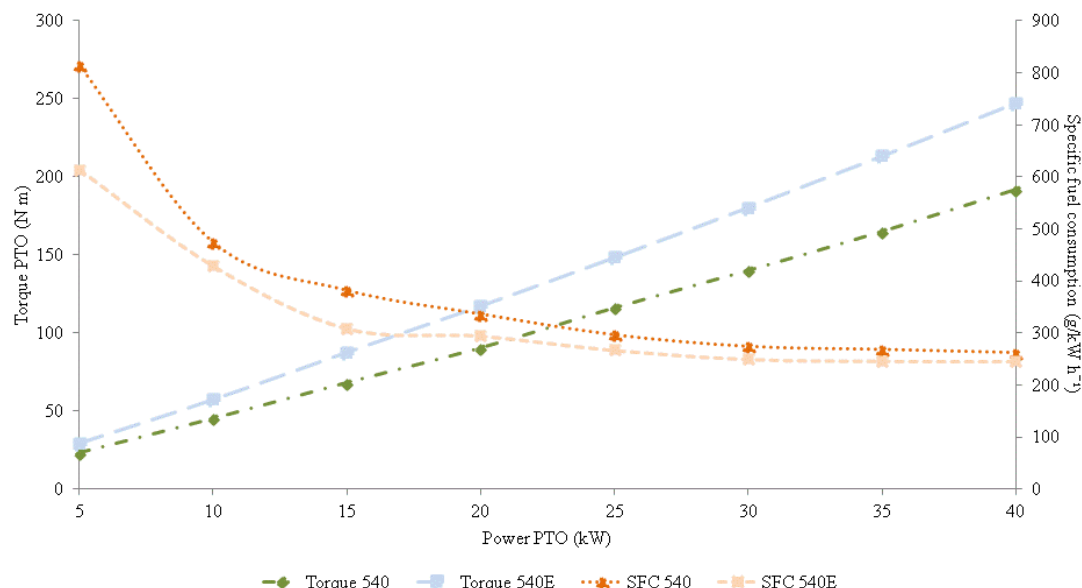


FIGURE 2. PTO torque and engine specific fuel consumption (SFC) according to the power provided to the tractor PTO for both evaluated settings.

Torque values found for the 540E setting were higher than were those of the standard one. The difference between them was similar to all applied loads, being higher than 26.0% and reaching 29.52% for a power of 20 kW at PTO shaft. For 540E, torque values ranged from 29 N m to 247 N m, for power from 5 to 40 kW at PTO shaft, and from 23 N m to 192 N m for the standard setting, within the same power range.

Specific fuel consumption decreased as the power at PTO shaft increased. Engine specific consumption at 540E was lower than were those at the standard setting. The average specific consumption was 14.68% lower when using the setting 540E. Assessing a New Holland tractor, model TD85 (62.5 kW), using an economical PTO setting, SUMER et al. (2010) obtained a 15.88% average saving of specific fuel consumption.

For both settings, the findings could be explained by engine rotation values. When using the 540E, engine presented higher torque values, which was because of a lower engine speed working in this setting. In order to provide a certain power, torque values have to be increased to offset the lower rotation. In addition, since this setting operates at low engine speeds, there is less specific fuel consumption and, thus, providing fuel saving.

Hourly fuel consumption for both PTO settings increased as the power at PTO shaft increased. The largest consumption differences between both configurations were seen for low PTO power demands, reaching a 28% fuel economy for 5 kW power at 540E. For farming operations requiring power from 30 kW at PTO shaft, a fuel saving of less than 10.5% was achieved using the 540E. However, when reaching a maximum power at PTO shaft (40 kW), the fuel economy was reduced to 6.9% (Figure 3).

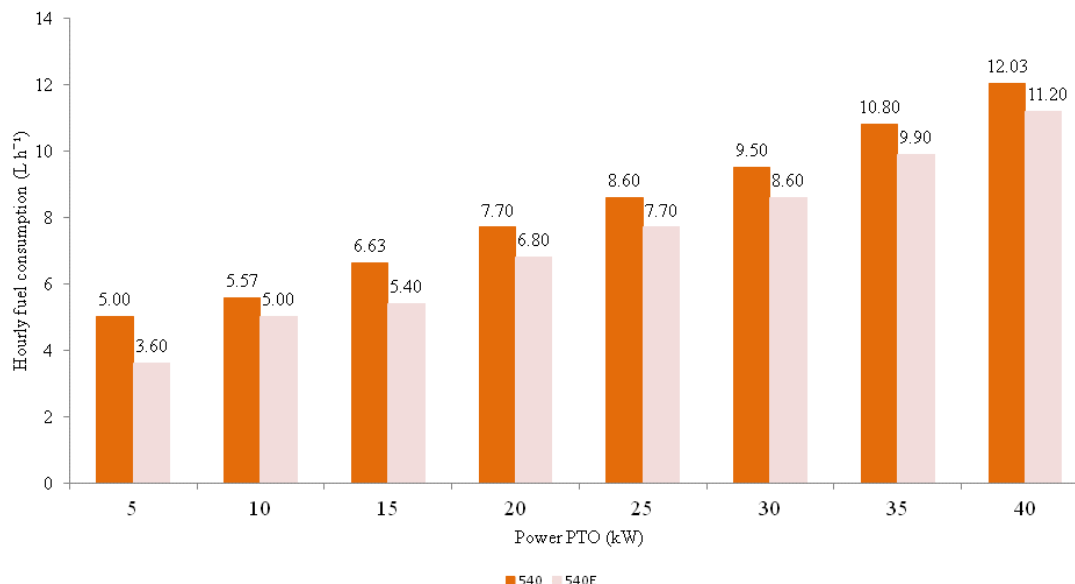


FIGURE 3. Engine hourly fuel consumption ( $\text{L h}^{-1}$ ) using standard (540) and 540E settings according to the power provided to PTO.

According to the smoke opacity of exhaust gases, both settings presented a similar behavior. It is important to highlight that the highest powers at PTO shaft reached a marked increase in the economic setting (Figure 4).

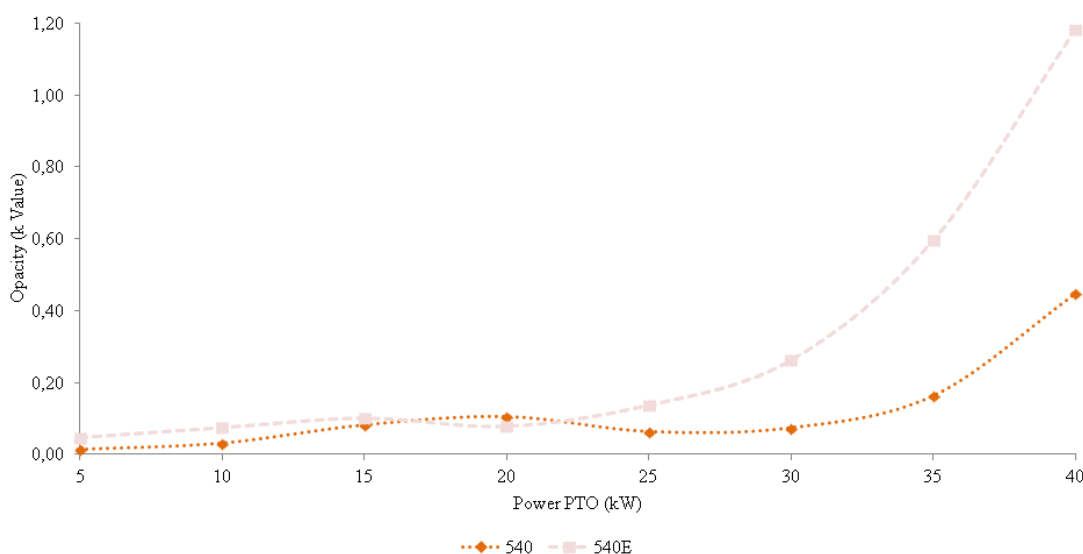


FIGURE 4. Smoke opacity of exhaust gases for standard (540) and 540E settings according to the power at PTO shaft.

In comparison to the 540E, the standard setting significantly reduced the smoke opacity of exhaust gases, in operations requiring power above 25 kW at PTO shaft. Providing a power of 35 kW, using this configuration, smoke opacity was reduced by 3.75 times, from  $0.6 \text{ m}^{-1}$  to  $0.16 \text{ m}^{-1}$ .

Figure 5A shows that CO emissions within a power range from 5 to 25 kW were reduced 0.87 times, on average, by using the setting 540E. However, for power above 25 kW, CO emissions when using the 540E were higher, being that, for a 40-kW power demand, such a difference was 2.05 times greater.

The greatest amount of CO emitted by an engine operating at high power demand and using the 540E setting can be explained by a small amount of  $\text{O}_2$  delivered by it (Figure 6B). Using this setting at lower rotation speed values, besides admitting a smaller amount of  $\text{O}_2$  to the injection

pump, and trying to offset falls in rotation, it injects a greater amount of diesel oil inside combustion chamber, increasing the ratio between air and fuel and, thus, emitting more CO whether compared to the standard setting. These results corroborate those of AN et al. (2013) and YUSAF et al. (2010), who concluded that reductions of CO emissions in exhaust gases derives from a complete combustion.

For both settings, CO<sub>2</sub> emissions increased as power demand at PTO shaft was higher (Figure 5B). When power was 40 kW, CO<sub>2</sub> emitted by the engine set at 540E was 1.16 times superior compared to the standard setting. Such an increase in CO<sub>2</sub> emissions points to an improved fuel burn and hence a better exploitation of O<sub>2</sub> entering the burning chamber, reducing its exhaust (Figure 6B). The greatest amount of CO<sub>2</sub> emission indicates an efficient fuel burn within the burning chamber of the engine (SAYIN, 2010).

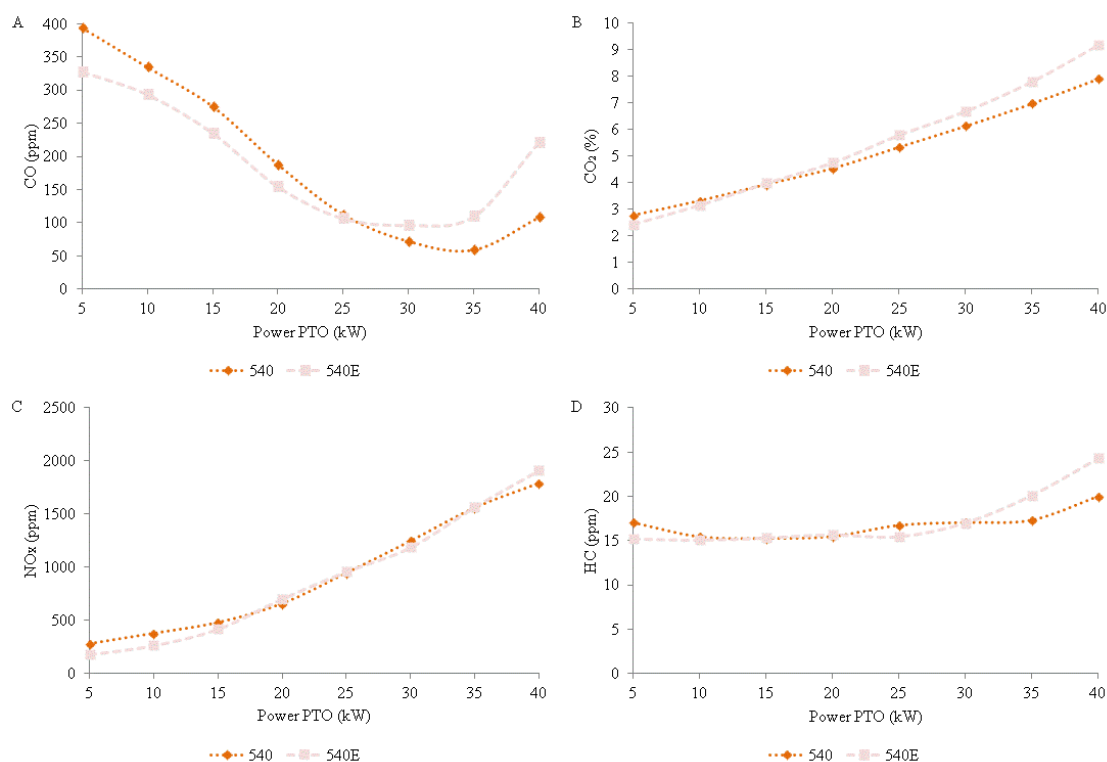


FIGURE 5. Variation of exhaust emissions: A) CO; B) CO<sub>2</sub>; C) NO<sub>x</sub> and D) HC, as a function of the power provided to the PTO, for both settings.

As for engine emissions of NO<sub>x</sub> (NO+NO<sub>2</sub>), averages of 87.54% and 88.16% NO were reached for all analyzed powers, in both 540 and 540E, respectively. The highest values of NO<sub>x</sub> emissions for both settings were achieved when the power demand at PTO shaft was of 40kW (Figure 5C). According to BUYUKKAYA (2010), engine-applied loads favored NO<sub>x</sub> emissions, and as loads were raised, the higher the emissions of these gases.

NO<sub>x</sub> emissions for both PTO settings showed the same trend. These emissions increased as exhaust gas temperature of the engine rose (Figure 6A). By setting PTO at 540E and providing 40 kW power, exhaust temperature of the engine reached the highest values, coinciding with the highest NO<sub>x</sub> emission (1909.68 ppm). Still, in this setting, the lowest gas temperature was found for a power of 5 kW, when the lowest NO<sub>x</sub> emission was recorded (175.38 ppm). According to MURILLO et al. (2007), NO<sub>x</sub> emissions are sensitive to combustion temperature, which generally increases with higher engine-applied loads.

Figure 5D shows results of HC emissions. One can point out that up to a power of 30 kW, emissions are similar for both settings (540 and 540E), being, on average, of 16.13 and 15.59 ppm, respectively. However, for powers of 35 and 40 kW, the emissions rise, and 540E setting stands out



for the highest averages of emission, nearly 22.21 ppm, while the standard one emits around 18.63 ppm.

As above mentioned, the greatest HC emissions can be explained by a low content of oxygen emitted by the engine using the 540E setting (Figure 6B). For these powers, engine works at low rotations, making the fuel injection pump to supply larger volumes of diesel oil, generating an inefficient fuel burning with less oil being used. HC emissions come from problems in the mixing of fuel with air, being mostly affected by a rich mixture formation (CHALLEN & BARANESCU, 1999).

Table 2 presents the best-fit regression equations and the adjusted coefficients of determination ( $R^2$ ) for both PTO settings.

TABLE 2. Regression equations and respective adjusted  $R^2$  for smoke opacity and emissions for  $\text{CO}_2$ , CO,  $\text{NO}_x$ , and HC for 540 and 540E settings.

Gas	540	540E
Smoke opacity	$Y = 0.0005p^2 - 0.0137p + 0.113$ $R^2 = 0.7719$	$Y = 0.0017p^2 - 0.0496p + 0.349$ $R^2 = 0.9432$
$\text{CO}_2$	$Y = 0.0013p^2 + 0.0879p + 2.299$ $R^2 = 0.9999$	$Y = 0.0018p^2 + 0.1081p + 1.878$ $R^2 = 0.9993$
CO	$Y = 0.3246p^2 - 24.2678p + 531.981$ $R^2 = 0.9635$	$Y = 0.4634p^2 - 25.9094p + 480.849$ $R^2 = 0.8833$
$\text{NO}_x$	$Y = 0.7701p^2 + 10.7905p + 178.357$ $R^2 = 0.9941$	$Y = 0.7939p^2 + 14.8315p + 56.583$ $R^2 = 0.9977$
HC	$Y = 0.0081p^2 - 0.2774p + 17.821$ $R^2 = 0.8994$	$Y = 0.0142p^2 - 0.4133p + 17.514$ $R^2 = 0.9579$

p = power at PTO shaft (kW).

Exhaust gas temperature increased as the power demand at PTO shaft was higher for both settings (Figure 6A). Gas average temperatures for both 540 and 540E were 236.67 °C and 227.67 °C, respectively. AGRAWAL et al. (2004), observing the behavior of exhaust gas temperature, claimed that increases, while loads were applied to the engine, were larger.

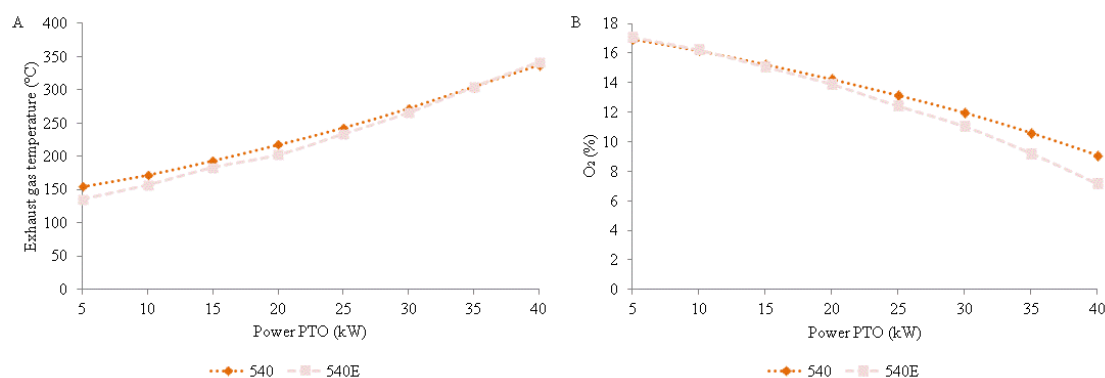


FIGURE 6. A) Exhaust gas temperature and B) engine emission of  $\text{O}_2$  for 540 and 540E as a function of the power provided to the PTO.

Figure 6B shows the behavior of  $\text{O}_2$  emissions as a function of engine-applied loads. In contrast, it is noted that until a power of 20 kW, the emissions are decreasing and similar for both settings, 540 and 540E, being on average of 15.65% and 15.58%, respectively. From that point on,  $\text{O}_2$  emissions were further reduced and when power demand at PTO shaft was 40 kW when the engine was working with the 540E setting, emissions were 1.27 times less than were with the standard one.

## CONCLUSIONS

Torque averages measured for both PTO settings tended to increase as a function of the engine-applied load. However, using the 540E, higher values were obtained.

Fuel savings, for both PTO settings, were inversely proportional to the increasing loads applied to the engine and, when using the 540E, engine consumed less fuel if compared to the standard PTO setting.

Exhaust smoke opacity values increased when there was a high power demand. By using the 540E, the opacity levels were accentuated for higher powers.

Emissions of CO, CO<sub>2</sub>, NO<sub>x</sub>, and HC had similar behaviors. For low power demands at PTO shaft, emissions were superior when the standard setting was used. However, for high power demands, the emissions were higher when using the setting 540E.

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