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# COMPARISONS OF 540 AND 540E PTO OPERATIONS IN TRACTORS THROUGH LABORATORY TESTS

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## Abstract

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The objective of this study was to determine differences between the standard 540 rpm power take-off (PTO) revolution in tractors and its alternative, namely “the economical PTO revolution (540E).” Loads were applied to three tractors (JD 5625, NH TD85, MF 3085) with similar technical specifications, by means of a PTO dynamometer (Eddy-current) under laboratory conditions. Measurements were made of tractor PTO torque, engine fuel consumption, specific fuel consumption, and engine exhaust gas and cooling water temperatures on the basis of load (power kW) steps applied at a constant PTO revolution of 540 rpm. Data analysis showed an average fuel saving was performed with the 540E PTO of 27.18%, 18.62% and 15.88% for the JD 5625, MF 3085, and NH TD85 tractors, respectively. Fuel savings decreased with the increase in PTO load. Engine-PTO speed rates were also found to be effective in fuel saving. The torque values for the three tractors varied directly proportionally to the increase in the PTO load steps. Exhaust gas temperature data showed that coercions had occurred in the tractor engines when certain load values were exceeded when using the 540E operation (35 kW, 20 kW, and 30 kW, respectively for JD 5625, MF 3085, and NH TD85 tractors). In conclusion, the economical PTO operation was shown to have important advantages, particularly in terms of fuel and specific fuel consumptions for many power-driven machines.

*Key words:* tractor, PTO operations, laboratory tests

## Introduction

Agricultural mechanization has a key role in Agricultural Production. It is a prerequisite for improving production quality, quantity, and timeliness (Hunt, 1983; Landers, 2000). Agricultural mechanization constitutes approximately 40 to 50% of total agricultural production inputs for the period from soil preparation to product harvesting (Isik, 1988; Ruiyin et al., 1999). Thus, the selection of efficient agricultural mechanization instruments and machinery is a necessity for a profitable production. The farm tractor power take-off (PTO) mechanism, which is an important source of power production on farms, is an important

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research subject from the standpoints of both scientific interest and for selection and operation of the related machinery.

Standard tractor PTO speeds are a function of tractor engine speeds and vary according to brand, model, and power rate of the tractor. Although PTO-driven agricultural machines are designed to operate at a standard PTO speed, they need different levels of torque and power to be run effectively. Engine and PTO mechanism in a tractor are designed together to match the power requirements of PTO-driven machines (Goering, 1986). Some agricultural machines, which require very low power at standard speed (540 rpm), waste energy and fuel at high engine speeds. In other words: it is an uneconomical operation.

To address this, tractor producers have developed transmissions that deliver a standard 540 rpm PTO speed at lower speeds of the engine flywheel. The PTO units have two transmission rates, referred to as 540 and 540E. The "540E" is also called "*economical PTO*" (Sümer et al., 2004). Necessarily, the two engine-PTO transmission rates result in different fuel consumption rates. Any fuel savings between the 540 and the "economical" 540 depends also on applied loads.

An international literature search encountered no studies concerning obtaining concrete data on the advantages of using the economical PTO transmission speed under laboratory and field conditions. An internet keyword search of tractor catalogues showed only whether the 540E feature is present on a particular model, and general claims that the feature will provide advantages in fuel consumption. Review of general farming journals suggests that the 540E feature has become widespread recently and that it may be beneficial. At the Agricultural Machinery Test Centers functioning around the world, PTO tests are conducted only considering the standard 540 operation for tractors, and are reported according to an international standard (OECD, 2008). The present study is aimed at obtaining scientific data informing tractor manufacturers and farmers in detail about the properties of tractors with the 540E feature. A series of laboratory studies, designed to measure the differences between 540 and 540E operations, were carried out to this end.

## Materials and Methods

The tests were carried out at the workshop of the Department of Agricultural Machinery at Canakkale Onsekiz Mart University, under laboratory conditions. The tractors used were a John Deere 5625, Massey Ferguson 3085, and New Holland TD85. All were 2006 production year models. Each had a 62.5 kW power rating. The test tractors (JD 5625, MF 3085, NH TD85) provided 540 and 540E operations at engine speeds of 2400-1700 rpm, 1979-1421 rpm and 2200-1715 rpm, respectively. Use of the tractors was donated by John Deere Company (Turkey Branch of Deere & Company), New Holland Trakmak Co., and Uzel Makine Sanayi Co., which are the companies supported this study.

To load the tractors at different rates, an "*eddy-current PTO dynamometer*" (Power Test Inc., USA) with 150 kW capacity was used. The loads applied by means of the dynamometer were controlled using a data collection system (Power Test Inc., USA) composed of a computer and "*Powernet LT*" software.

The maximum PTO power each tractor developed with 540 and 540E was initially determined in the tests. Dynamometer loads were applied in increments of 5 kW for 540 and 540E PTO operations. Tractors were warmed-up prior to load testing. For this purpose each tractor was run until the cooling system thermostat was opened. The tests were completed approximately at the 5 hours for each tractor. The PTO speed was kept constant at 540 rpm at the all experiments because tractor PTO speeds are same for both PTO operations. At each load (power, kW) step applied to the PTO, measurements of torque, speed, fuel consumption, exhaust gas temperature, and engine cooling water temperature were performed. Three trials were made for each tractor. Each tractor was able to maintain the PTO speed of 540 rpm at the standard transmission rate until loaded almost to 54 kW. When in 540E mode, none of the three tractors could maintain a PTO speed of 540 rpm at a load greater than

45 kW. Therefore, comparisons between the two PTO operations were done considering maximal PTO load up to 45 kW.

The fuel consumption values were found by using a flow-meter (Macnaught M05, Macnaught Pty. Ltd., Australia) measuring the amount of fuel passing from the fuel supply line between the fuel tank and the injection pump and a flow-meter measuring the amount of fuel returning to the tank from the injection pump and the injectors. The difference between the two measurements represents net fuel consumption.

To measure engine exhaust gas and engine cooling water temperatures, thermocouples were placed in the exhaust manifolds of the tractors for measuring the exhaust gas temperature, and in the inlet of the engine temperature switch for measuring the cooling water temperature. In addition, ambient air temperature and relative humidity were measured, and found to vary between 14-20°C and 50-60%. These levels are considered to be unlikely to affect other measurements.

By using the PTO power and fuel consumption data, "the Specific fuel consumption", defined as the fuel consumed per unit of power developed, was calculated by using equation 1 for each power load step (OECD, 2008; Sabanci, 1997).

$$SFC = \frac{B_e}{N_{pto}} \qquad (1)$$

Where:

SFC: Specific fuel consumption, g/kW-h,

$B_e$: The amount of fuel that the tractor engine consumes per unit time, g/h.

$N_{PTO}$: PTO power, kW

Initially $B_e$ values in the equation were determined as L/h during the tests. Later the data were converted to g/h by the specific density (827 g/L) of the Diesel fuel used.

Variance analysis was carried out according to factorial experimental design by using SPSS statistical software. The tractors, PTO operations and load steps were the independent variables (treatments). The effects of the three factors individually and the interac-

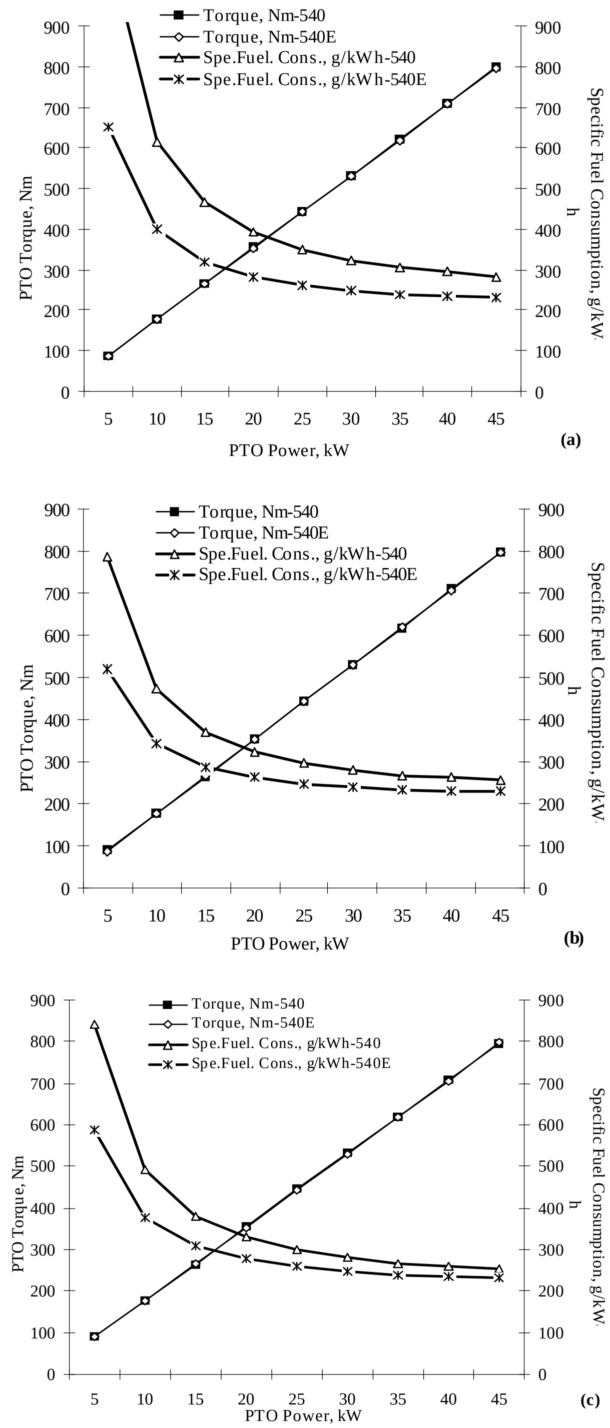



**Fig. 1. PTO torque and engine's specific fuel consumption depending on the loads applied to the tractor PTO at 540 and 540E operations (a) JD 5625, (b) MF 3085, (c) NH TD85**

tions of them on torque, fuel consumption, specific fuel consumption, exhaust gas temperature of the engine, and cooling water temperature were examined. The means were compared by Duncan's multiple range test.

## Results

Variations in torque, fuel consumption, specific fuel consumption, exhaust gas temperature, and cooling water temperature, with loads applied to the tractor PTO at 540 and 540E operations, were examined for each tractor. The torque values for the three tractors varied directly proportionally to the increase in the load steps applied to the PTO (Figure 1). In other words, increasing the power value while keeping the PTO speed constant also causes an increase in the torque value. Torque curves for 540 and 540E operations in each tractor overlapped because the PTO speeds were constant for both operations although engine speeds were different (Figure 1). Mean torque values for all tractors ranged between 87.70 Nm-797.70 Nm for 5-45 kW PTO loads.

Specific fuel consumption decreased with power increase for both PTO operations in each tractor (see Figure 1). Specific fuel consumption in 540E operations was lower than for the 540 operation in all tractors (Figure 1). Average decrease in specific fuel consumption for the 540E operation was 27.18%, 18.62%, and 15.88%, respectively, for JD 5625, MF 3085, and NH TD85 tractors (Figure 2). These are equal to the mean fuel consumption saving rates for the 540E operation for each tractor. Fuel consumed by each tractor at each load step is given in Table 1.

In 540E operation, the fuel consumption by the three tractors was similar (Table 1). The fuel consumption of the MF 3085 tractor, which provides the 540E operation at a lower engine speed (1421 rpm) than the other two tractors, was slightly lower. The NH TD85 tractor was found to have a slightly lower saving rate than the MF 3085 tractor (Figure 2). This study also showed that the fuel saving rates resulting from 540E operation in comparison to 540 operations at each load step applied to the tractor PTO tends to decrease depending on the increase in the load applied to the PTO (Figure 2). At all load steps (5-45 kW) applied to the PTO, the fuel saving rates achieved by 540E operation varied between 18.13-40.68%, 10.03-33.81%, and 8.04-30.24%, respectively, for JD 5625, MF 3085, and NH TD85 tractors. Regression equations for Fuel consumption, fuel saving rate, PTO torque with respect to PTO loads were obtained (Table 2).

Exhaust gas and cooling water temperature, thought possibly to be indications of coercion of tractor engines under different load conditions, and were

**Table 1**
**Fuel consumption values for the tested tractors**

| Power, kW | Fuel consumption, L/h | | | | | |
|---|---|---|---|---|---|---|
| | 540, rpm | | | 540E, rpm | | |
| | JD 5625 | MF 3085 | NH TD85 | JD 5625 | MF 3085 | NH TD85 |
| 5 | 6.62 ± 0.02 | 4.76 ± 0.04 | 5.09 ± 0.07 | 3.93 ± 0.01 | 3.15 ± 0.03 | 3.55 ± 0.01 |
| 10 | 7.45 ± 0.07 | 5.72 ± 0.05 | 5.95 ± 0.05 | 4.81 ± 0.03 | 4.14 ± 0.01 | 4.58 ± 0.02 |
| 15 | 8.44 ± 0.01 | 6.73 ± 0.06 | 6.9 ± 0.07 | 5.79 ± 0.01 | 5.22 ± 0.04 | 5.6 ± 0.04 |
| 20 | 9.52 ± 0.04 | 7.79 ± 0.03 | 8.02 ± 0.03 | 6.85 ± 0.03 | 6.38 ± 0.01 | 6.75 ± 0.01 |
| 25 | 10.55 ± 0.03 | 9 ± 0.02 | 9.08 ± 0.01 | 7.89 ± 0.03 | 7.5 ± 0.02 | 7.81 ± 0.08 |
| 30 | 11.66 ± 0.07 | 10.17 ± 0.10 | 10.21 ± 0.03 | 8.98 ± 0.01 | 8.73 ± 0.03 | 8.95 ± 0.01 |
| 35 | 12.92 ± 0.01 | 11.34 ± 0.05 | 11.3 ± 0.01 | 10.08 ± 0.07 | 9.88 ± 0.06 | 10.06 ± 0.05 |
| 40 | 14.33 ± 0.12 | 12.7 ± 0.02 | 12.53 ± 0.09 | 11.36 ± 0.06 | 11.17 ± 0.07 | 11.33 ± 0.08 |
| 45 | 15.38 ± 0.06 | 13.93 ± 0.08 | 13.78 ± 0.04 | 12.59 ± 0.06 | 12.54 ± 0.08 | 12.67 ± 0.03 |

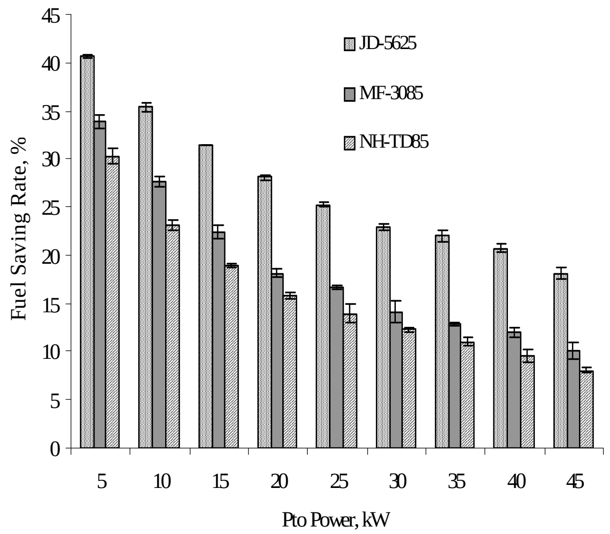



**Fig.2. Fuel saving rates resulting from 540E operation in comparison to 540 operation**

measured at each load step. When the exhaust gas temperature curves of the engines in 540 and 540E operations are examined, it is observed that the curves of both operations intersect after a certain load value in all three tractors (Figure 3).

For JD 5625, MF 3085 and NH TD85 tractors, these intersection points are at 35 kW, 20 kW and 30 kW power values, respectively (Figure 3). Since the engine run at a higher throttle position in 540 operations, it is expected that higher temperatures would be measured up to these loading points. However, the opposite case after the intersection points expresses that the engine is coerced at low speeds, where it provides 540E operation, in return for the increasing PTO load.

The highest and lowest exhaust gas temperatures measured in 540 and 540E operations for the JD 5625 tractor varied between 238-423°C and 181-440°C, respectively. Exhaust temperatures varied between 268-532°C and 219-603°C for the MF 3085, and between 248-515°C and 204-540°C in the NH TD85.

The cooling water temperatures of the engines varied between 79-83°C, 63-77°C and 65-71°C, respectively, for the JD 5625, MF 3085, and NH TD85 tractors. During the tests, no obvious variations were observed between the cooling water temperature values of the engine for the two PTO operations (Figure 3). When a general evaluation was made according to the variance analysis, it was determined that the effects of tractor difference, 540/540E operation, and different dynamometer loads, chosen as independent variables in the tests, were statistically significant ($P<0.01$) on the torque, fuel consumption, specific fuel consumption, water temperature, and exhaust gas temperature, considering both the individual factors and the interactions. The measured highest and the lowest values of the dependent variables are summarized in Table 3 as triple interactions results of independent variables.

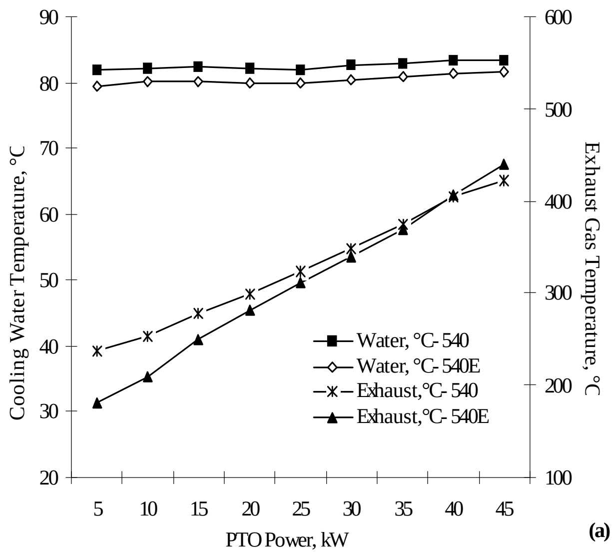
When the mean values of the measurement parameters depending on the main factors were examined, the torque values measured for 540 and 540E operations at each load step applied to the PTO by means of the dynamometer were found to be very

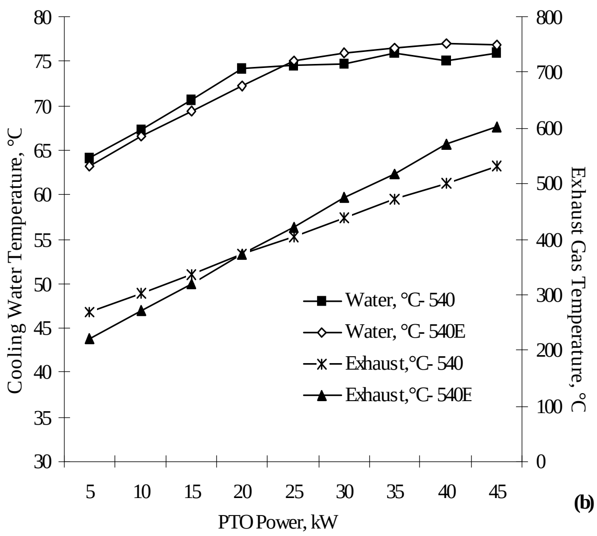
**Table 2**

**Regression equations for fuel consumption, fuel saving rate, PTO Torque**

| | Fuel Consumption | | Fuel Saving Rate | PTO Torque | |
|---|---|---|---|---|---|
| | 540 | 540E | 540 vs 540E | 540 | 540E |
| JD | FC = 1.113 L + 5.201<br>R2 = 0.996 | FC = 1.083 L + 2.615<br>R2 = 0.998 | FSR = -2.634 L + 40.347<br>R2 = 0.946 | PT = 88.745 L - 0.436<br>$R^2 = 1$ | PT = 88.665 L - 0.703<br>$R^2 = 1$ |
| MF | FC = 1.154 L+ 3.355<br>R2 = 0.998 | FC = 1.172 L + 1.773<br>R2 = 0.998 | FSR = -2.751 L + 32.377<br>R2 = 0.906 | PT = 88.483 L - 0.05<br>$R^2 = 1$ | PT = 88.578 L - 0.725<br>$R^2 = 1$ |
| NH | FC = 1.091 L + 3.749<br>R2 = 0.998 | FC = 1.132 L + 2.264<br>R2 = 0.998 | FSR = -2.482 L + 28.296<br>R2 = 0.902 | PT = 88.28 L + 1.022<br>$R^2 = 1$ | PT = 88.383 L + 0.261<br>$R^2 = 1$ |

FC: Fuel Consumption, FSR: Fuel Saving Rate, PT: PTO Torque, P: Load , $R^2$: Coefficents of Determinaton



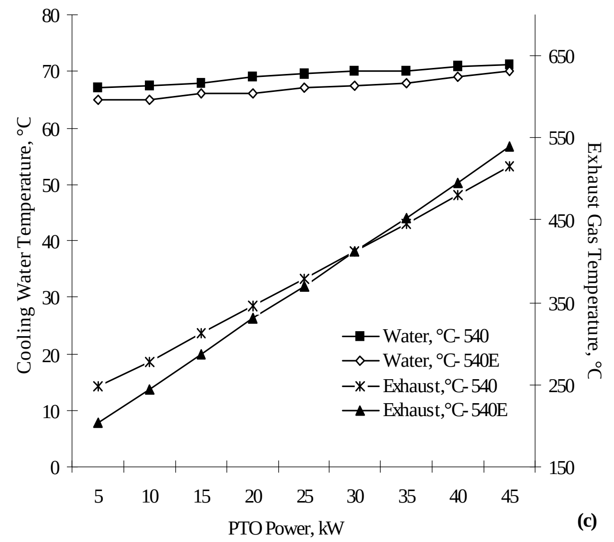




**Fig. 3. Exhaust gas and cooling water temperatures depending on the loads applied to the tractor PTO at 540 and 540E operations (a) JD 5625, (b) MF 3085, (c) NH TD85**

close in the three tractors (the mean torque values are 442.69 Nm and 442.32 Nm, respectively, for 540 and 540E).

## Discussion

According to findings, the fuel savings achieved by the 540E operation varied with tractor engine-PTO speed rates and load increase. 540E operation is achieved at lower engine speeds than 540 operations and the difference between the two engine speeds vary particularly according to tractor brands. In 540E operation, JD 5625, MF 3085, and NH TD85 tractors were run at engine speeds 700 rpm, 558 rpm, and 485 rpm lower, respectively, than in 540 operation. Fuel savings from the use of economical PTO tend to increase depending on the amount of decrease in engine speed.

Large decreases in fuel consumption were observed in all three tractors in 540E operation (Table 1). The MF 3085 and NH TD85 tractors have similar fuel consumption in 540 operations. The JD 5625 tractor, however, has slightly higher fuel consumption than the other tractors. This is probably because the JD 5625 tractor drives the 540 operation at a higher engine speed (2400 rpm) than the other two tractors.

To compare with other research, fuel consumption values measured in this study are quite close to tractor PTO tests carried out by TAMTEST (Directorate of Agricultural Instruments and Machinery Test Center, Turkey). For instance, according to the test report of the NH TD85 tractor in 540 operation, fuel consumption and specific fuel consumption were reported to be 13.77 L/h and 249 g/kW-h in 46.5 kW partial load operation (Tasbas et al., 2003), which values are close to those (13.78 L/h) obtained in 45

**Table 3**
**Highest and the lowest values of the dependent variables**

| | Interaction | |
|---|---|---|
| | Minimum | Maximum |
| Torque, Nm | MF x 540E x 5 kW<br>*87.7* | MF x 540E x 45 kW<br>*797.7* |
| Fuel consumption, L/h | MF x 540E x 5 kW<br>*3.15* | JD x 540 x 45 kW<br>*15.38* |
| Specific. Fuel Consumption, g/kW-h | MF x 540E x 45 kW<br>*230.37* | JD x 540 x 5 kW<br>*1095.67* |
| Water temperature, $^{o}$C | MF x 540E x 5 kW<br>*63.2* | JD x 540 x 45 kW<br>*83.4* |
| Exhaust temperature, $^{o}$C | JD x 540E x 5 kW<br>*181.1* | MF x 540E x 45 kW<br>*603.4* |

kW partial load operation in this study (Table 1).

Kim et al. (2005) analyzed improvement of agricultural tractor performance by using the data from 926 diesel tractors tested at the Nebraska Tractor Test Laboratory from 1959 through 2002. They reported that better specific fuel consumption was observed in tractors with higher PTO power levels at the speed of 540 rpm. The results reported in this study were in general agreement with other relevant research carried out for different objectives.

According to the exhaust gas temperatures measured, it may be concluded that in 540E operation, the JD 5625 and NH TD85 tractors are coerced less than the MF 3085 tractor. The fact that 540E operation is achieved at a lower engine speed in the MF 3085 (1421 rpm) tractor than the JD 5625 (1700 rpm) and NH TD85 (1715 rpm) is consistent with this finding. Sumer et al. (1998) examined the relations between temperature of the exhaust gas and specific fuel consumption of the tractor depending upon PTO loads at 540 rpm. For this purpose, three tractors (Fiat-640, Fiat-54C and Universal-445) were loaded step by step with a PTO dynamometer. They reported that specific fuel consumption decreased with PTO load increase; however fuel consumption increased under the same conditions in each tractor. Besides it was expressed that measured exhaust gas temperatures increased with increasing PTO loads in each tractor. Agrawal et al. (2004) conducted an experimental investigation to observe the effect of exhaust gas re-circulation on the exhaust gas temperatures. The experimental setup for the proposed experiments was developed on a two-cylinder, direct injection, air-cooled, compression ignition engine. They stated that the exhaust gas temperature was increased with increasing engine loads.

The small differences among the cooling water temperature levels in the tractors are probably caused by differences in the cooling system thermostats. Nevertheless, the cooling water temperature of the MF 3085 tractor tended to increase slightly with load, which is different from the other tractors (Figure 3). The fact that the exhaust gas temperatures of this tractor are higher than those of the other tractors at small loads may be related.

In this study, findings showed that the two PTO operations may be significant alternatives to one another up to loads of 45 kW for these three tractors. In 540E operations, although coercions were detected in the tractor engines above certain loads, the fuel saving advantage continued up to loads of 45 kW PTO power (Figure 2). It is clear that the use of 540E PTO operation as an alternative to 540 PTO operations, up to the critical load values (Figure 3), will provide important economic advantages. Although the fuel consumption advantage of 540E continues above the critical loads, when the engine is coerced, it may be preferable to use the 540 operation.

## Conclusions

The average fuel saving rates achieved by the 540E power take-off operation, which is an alternative to the standard 540 operation, were 27.18%, 18.62%, and 15.88%, respectively, for JD 5625, MF 3085, and NH TD85 tractors. The fuel savings with the 540E operation was inversely related to increase in the load applied to the tractor PTO. Engine-PTO speed of the tractors also affects the fuel savings achieved by 540E operation. Because the JD 5625, MF 3085, and NH TD85 tractors achieve 540E operation at engine speeds lower by 700 rpm, 558 rpm, and 485 rpm, respectively, than with standard 540 operations, the study results are consistent with the expectation that lower engine speeds use less fuel. In both PTO operations, the PTO torque values tended to increase linearly with the applied load. According to the exhaust gas temperature measurements, it was concluded that the JD 5625, MF 3085, and NH TD85 tractors were coerced at PTO loads greater than 35 kW, 20 kW, and 30 kW, respectively, in 540E operation. The fact that the exhaust gas temperatures, measured in 540E mode following these load operations, are at higher values than those measured in 540 operations supported this result. No obvious correlations were observed between engine cooling water temperature values and the other measured variables. Overall, the study supports a conclusion that the 540E "economical PTO" operation can provide important advantages, particularly in terms of fuel consumption and specific fuel consumption.

***Acknowledgments***

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