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**Research**
**Araştırma**

# COMPARING OPERATIONAL CHARACTERISTICS OF 540 RPM AND 750 RPM PTO IN TRACTORS THROUGH LABORATORY TESTS

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**ABSTRACT:** The objective of this study was to determine the differences in operational characteristics between standard power take-off (PTO) 540 rpm and 750 rpm operations in tractors. 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 stable conditions. Measurements were done to determine tractor PTO torque, engine fuel consumption, specific fuel consumption, and engine exhaust gas and cooling water temperatures. The torque values measured for 540 and 750 rpm at load steps (5-50 kW) were 88 Nm-888 Nm and 63 Nm-638 Nm, respectively. Data analysis showed that the fuel consumption in 750 rpm increased by 1.00-2.80%, 7.56-12.63%, and 7.59-14.64%, respectively, for JD 5625, MF 3085, and NH TD85. Specific fuel consumption decreased with power increase in both PTO operations in each tractor. Exhaust gas temperatures varied between 237-562 ºC and 229-562 ºC, respectively for 540 and 750 rpm in all tractors. The cooling water temperatures of the engines varied between 79-87 ºC, 63-77 ºC and 66-72 ºC, respectively, for the JD 5625, MF 3085, and NH TD85 tractors. Findings showed that the 750 rpm PTO operation had lower pto torque, higher fuel consumption and specific fuel consumption values than those of the 540 rpm pto operation for the all tested tractors. However, 750 rpm operation may be an alternative to 540 rpm operation for some PTO driven machines.

**Key Words:** Tractor, 540 rpm, 750 rpm, PTO, performance.

## TRAKTÖRLERDE 540 VE 750 KUYRUK MİLİ UYGULAMALARININ ÇALIŞMA ÖZELLİKLERİNİN ATÖLYE KOŞULLARINDA KIYASLANMASI

**ÖZET:** Bu çalışmada, traktörlerde 540 d/dak ve 750 d/dak kuyruk mili hızları arasındaki farklılıkların laboratuar koşullarında belirlenmesi amaçlanmıştır. Bu amaç için, benzer teknik özelliklerde üç farklı marka traktöre (JD 5625, NH TD85, MF 3085), laboratuar koşullarında bir kuyruk mili dinamometresi (eddy current) ile yükler uygulanmıştır. Her iki kuyruk mili uygulaması için ayrı ayrı yürütülen denemelerde traktör kuyruk mili torku, traktör motoruna ait yakıt tüketimi, özgül yakıt tüketimi, motor egzoz gazı ve soğutma suyu sıcaklığı parametreleri belirlenmiştir. Traktörlerin kuyruk millerine, 540 d/dak ve 750 d/dak çalışma hızlarında, uygulanan yük adımlarında ölçülen tork değerleri sırasıyla 88 Nm-888 Nm ve 63 Nm-638 Nm arasında değişmiştir. Veri analizleri, maksimum dinamometre yüklerine kadar (0-50 kW) 540 yerine 750 uygulamasının yakıt tüketimi değerlerinde JD 5625, MF 3085, ve NH TD85 traktörleri için sırasıyla %1.00-2.80, %7.56-12.63 ve %7.59-14.64, oranlarında artışlara neden olduğunu göstermiştir. Denemelerde kullanılan üç traktörde ölçülen motor egzoz gazı sıcaklıkları, 540 ve 750 uygulamaları için sırasıyla, 237-562 ºC ve 229-562 ºC arasında değişim göstermiştir. Motor soğutma suyu sıcaklığı değerleri ise, JD 5625, MF 3085, ve NH TD85 traktörleri için sırasıyla, 79-87 ºC, 63-77 ºC ve 66-72 ºC arasındadır. Araştırma bulguları, 750 d/dak uygulamasının 540 d/dak uygulamasına kıyasla daha düşük kuyruk mili torku, daha yüksek yakıt tüketimi ve özgül yakıt tüketimi değerlerine sahip olduğunu ortaya koymaktadır. Sonuç olarak, 750 d/dak kuyruk mili uygulamasının maksimum yüklenmelere kadar, bir çok kuyruk milinden hareketli tarım makinası için 540 uygulamasına önemli bir alternatif olarak kullanılabileceği sonucuna varılmıştır.
**Anahtar Sözcükler***:* Traktör, 540 d/dak, 750 d/dak, kuyruk mili, performans.

## 1. INTRODUCTION

The performance of farm tractors can be expressed in many ways. The criterion for the best description of their performance depends largely upon the intended use of the tractor. Maximum drawbar power is normally the most useful criterion for farm tractors. For the farmer who uses a tractor extensively on machines requiring a PTO drive, the most important criteria is the maximum PTO power that can be developed (Liljedahl et.al, 1989). A PTO drive provides a means for transmitting rotary power to machines that are used with the tractor (Srivastava et.al., 1993). In 1926, the American Society for Agricultural Engineers (ASAE) published a standard on PTO drives, which has since been updated periodically (for instance ASAE S333.2 March 1987). Besides national and international standards on PTO drives published by many country, the direction of rotation, rotational speed, approximate location, and exact dimensions of the PTO shaft are specified in the standards. The standard rotational speed was 540 rpm in the early standards. A 1000 rpm PTO was subsequently developed to provide greater power-transmitting capability (Goering, 1989).

Standard tractor PTO speeds are a function of tractor engine speed 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, 1989). Some agricultural machines, which require very low power at standard PTO speed, waste energy and fuel at high engine speeds, resulting in higher operations costs. To address this, tractor producers have developed transmissions that deliver a standard 540 rpm PTO speed at lower speeds of the engine flywheel. These units have two transmission rates, referred to as 540 and 540E. The "540E" is also called "*economical PTO*". This feature in tractors is known as 750 operation by farmers and some tractor salers because transmissions that deliver 540E operation also provides 750 rpm PTO speed (Sümer et al., 2004). 750 and 540 rpm operations are achieved at same speeds of engine flywheel, but differ from 540E operation. Differences between 540 and 540E PTO operations in tractors were also examined in the other research, but not published yet.

Recently, the use of 750 rpm has become widespread. For instance, manure spreaders, threshing equipments, sprayers, seed broadcasters, disc fertilizers (Engürülü et.al., 2005). No sufficient information was found in the literature on the advantages of 540E and 750 PTO transmission speeds under laboratory and field conditions. Tractor catalogues only show whether the 540E or 750 rpm features is present on a particular model. Review of general farming journals suggests that the 750 rpm feature has become widespread recently and that it may be beneficial. OECD tests are performed by National Designated Authorities, and its testing stations and performance tests are carried out by considering the 540 rpm operation in Code 2 (OECD, 2008).

Sümer 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. 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. Sümer et al. (2010a) carried out a study 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. 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. Sümer et al. (2010b) determined the operating characteristics of economical PTO operation (540E) in field conditions and made a comparison with 540 PTO operation. For this purpose three different brands of tractors (JD 5625, NH TD85, MF 3085) having similar technical properties and three PTO driven agricultural machine (single disc fertilizer spreader, turbo atomizer and rotovator. In the experiments tractor ground speed, slip values, PTO torque, PTO power, fuel consumption per time, effective field capacity and fuel consumption per field parameters were determined for two PTO operations. According to results, if economical PTO operation is used together with the proper gear level and ground speed selections for the tractors, it can be suggested as an important alternative to the 540 operation for machines used in this study and also for those having similar capacities and properties.

The objective of the present study is to determine the differences in operational characteristics between the standard PTO (540 rpm) and 750 rpm in tractors. A series of laboratory studies, designed to measure the differences between 540 and 750 rpm operations, were carried out to this end.

## 2. MATERIALS AND METHOD

The tests were carried out at the laboratory of the Department of Agricultural Machinery at Çanakkale Onsekiz Mart University, under stable conditions. Tractors that were used in the tests were John Deere 5625, Massey Ferguson 3085, and New Holland TD85. All were produced in 2007 and had a 62.5 kW power rating. The test tractors (JD 5625, MF 3085, NH TD85) provided the PTO speeds of 540 and 750 rpm at engine speeds of 2400 rpm, 1979 rpm and 2200 rpm, respectively (Table 1).

In order to load the tractors at different rates, an "*eddy-current PTO dynamometer*" (Power Test Inc., USA) with 150 kW capacity was used (Figure 1). The controls of dynamometer loads on PTO were done using a data collection system (Power Test Inc., USA) composed of a computer and "*Powernet LT*" software.


Figure 1. Tractor PTO test system.

Table 1 – Some technical specifications of the test tractors

| Specifications | MF 3085 | JD 5625 | NH TD95 |
|---|---|---|---|
| Production year | 2007 | 2007 | 2007 |
| **Engine** | | | |
| Engine Type | Diesel, 4-cylinder, Turbo | Diesel, 4-cylinder, Turbo | Diesel, 4-cylinder, Turbo |
| Cylinder volume, L | 4.04 | 4.5 | 3.9 |
| Maximum Power, kW | 62.5 | 62.5 | 62.5 |
| Rated speed (rpm) | 2400 | 2400 | 2500 |
| **Transmission** | | | |
| Main gear shift | Fully synchronized | Fully synchronized | Fully synchronized |
| No. of speeds | 12 forward 4 reverse | 12 forward 12 reverse | 12 forward 12 reverse |
| **PTO System** | | | |
| Type | independent | independent | independent |
| Speed (rpm) | 540, 750, 540E | 540, 750, 540E | 540, 750, 540E |
| Engine speed (For 540, 750, 540E), rpm | 1979, 1979, 1421 | 2400, 2400, 1700 | 2200, 2200, 1715 |
| **Weight (kg)** | 3280 | 2645 | 2940 |

Initially, in the tests, the maximum PTO power developed with 540 and 750 rpm operations of each tractor was determined. Dynamometer loads were applied in increments of 5 kW in both 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 PTO speed was kept constant at 540 rpm and 750 rpm. At each load step applied to the PTO, measurements of torque, power, speed, fuel consumption, exhaust gas temperature, and engine cooling water temperature were performed. Three separated trials were made under each condition. Each tractor was able to maintain the PTO speeds of 540 rpm and 750 rpm at the standard transmission rate until loaded to about 54 kW. In order to make a good comparison between two PTO operations, maximum PTO loads was considered up to 50 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 an extra flow-meter was used for 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. The measurement accuracy, sensitivity and the measurement range of each fuel meter are 0.35%, 0.20%, 0-25 L h$^{-1}$, respectively. The same diesel fuel was used for all tests.

Thermocouples were placed in the exhaust manifolds of the tractors and in the inlet of the engine temperature switch for measuring the engine exhaust gas and cooling water temperatures. In addition to these temperatures, ambient air temperature and relative humidity were measured, and found to vary between 14-20°C and 50-60%.

Specific fuel consumption was calculated by using equation 1 for each power load step (OECD, 2008; Sabancı, 1997).

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

Where:

SFC : Specific fuel consumption (g kW$^{-1}$h$^{-1}$),
$B_e$ : The amount of fuel consumed by the tractor engine per unit time (g h$^{-1}$).
$N_{pto}$ : PTO power (kW)

Initially $B_e$ values in the equation were determined as L h$^{-1}$ during the tests. Later the data were converted to g h$^{-1}$ by the specific density (827 g L$^{-1}$) of the Diesel fuel used.

Variance analysis was carried out according to three factors in complete block design with 3 replications by using MiniTab statistical software. The tractors (Factor A), PTO operations (Factor B) and load steps (Factor C) were the independent variables (treatments). Individual effect of each factor and the effect of the interactions of these factors 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.

## 3. RESULTS AND DISCUSSION

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 750 rpm operations, were examined for JD 5625, MF 3085, and NH TD85. The torque curve depending on the loads applied to the tractor PTO at 540 and 750 rpm operations is shown in Figure 2.

The torque values measured for 540 and 750 rpm operations at load steps (5-50 kW) applied to the PTO by means of the dynamometer were found to be between 88 Nm-888 Nm and 63 Nm-638 Nm, respectively.

Specific fuel consumption decreased with power increase in both PTO operations in each tractor whereas fuel consumption increased as the power increased during the tests. Specific fuel consumption at 540 rpm was lower compared to 750 rpm in all tractors, but the difference was more profound in the case of MF 3085 and NH TD85 (Figure 3).

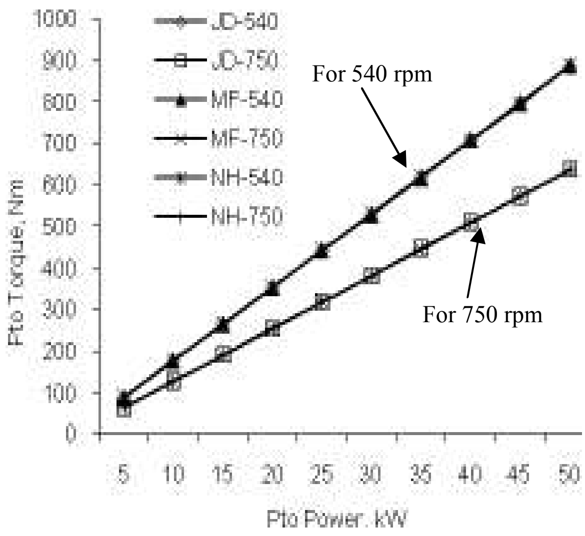


Figure 2 - PTO torque depending on the loads applied to the tractor PTO at 540 and 750 rpm operations.

Average increase in specific fuel consumption for the 750 operation was 1.70%, 9.92%, and 11.16%, respectively, for JD 5625, MF 3085, and NH TD85 tractors (Figure 3). These are equal to the average increase in fuel consumption for the 750 operation for each tractor. Fuels consumed by each tractor at each load step and standard deviations are given in Table 2.

Compared to 540 rpm, fuel consumption rates at 750 rpm increased in the ranges of 1.00-2.80%, 7.56-12.63%, and 7.59-14.64%, respectively, for JD 5625, MF 3085, and NH TD85 tractors. The fuel consumption in both operations varied with tractor engine-PTO speed rates, engine characteristics and load increase on PTO.

The fuel consumption was similar in all tractors at 750 rpm (Table 2). The fuel consumption was higher in the case of JD 5625, which operates at a slightly higher engine speed (2400 rpm) than the other two tractors (Table 2, Figure 3). Besides, JD 5625 has higher cylinder volume than the other two tractors (Table 1). The regression equations were obtained for PTO torque and fuel consumption with respect to PTO loads (Table 3).

Exhaust gas and cooling water temperatures, thought possibly to be indications of coercion of tractor engines under different load conditions, were measured at each load step. It was observed that the curves of both operations are very nearly parallel in all three tractors, since the engine run at equal throttle position in both operations (Figure 4).

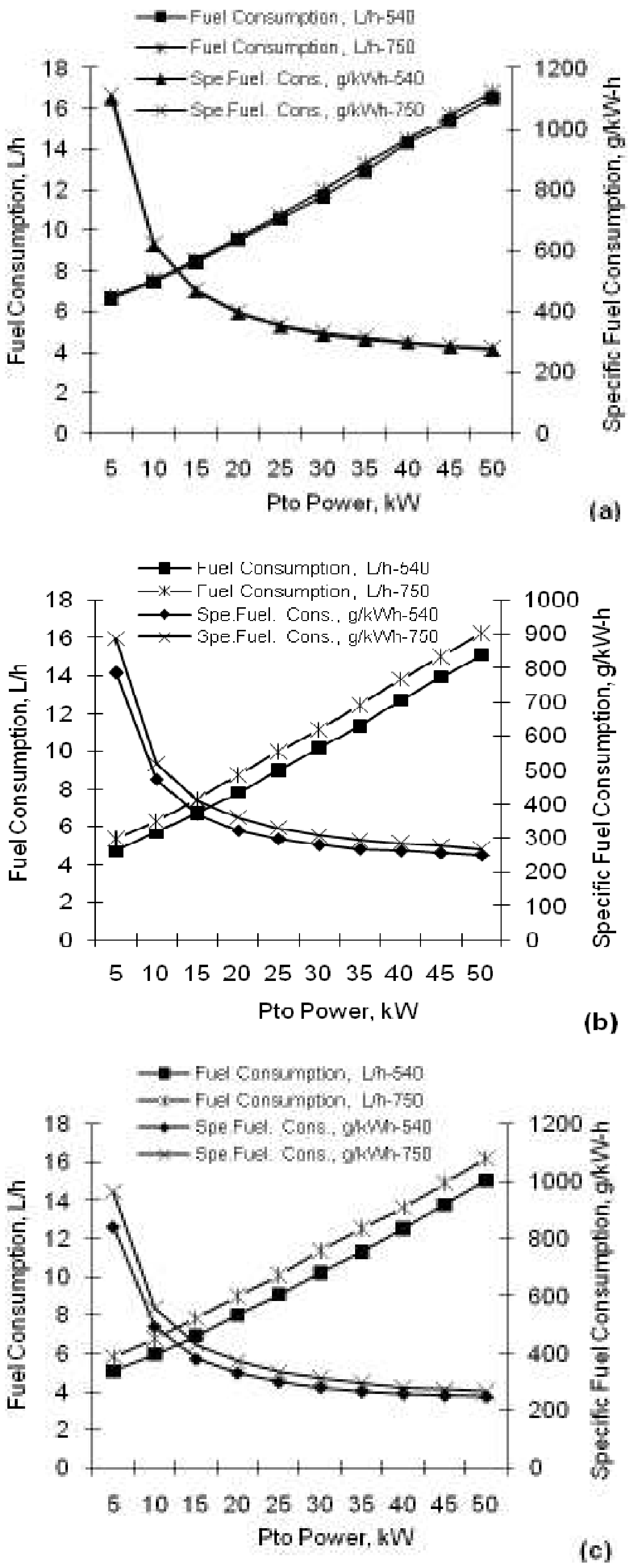


Figure 3 – Fuel consumption and specific fuel consumption depending on the loads applied to the tractor PTO at 540 and 750 rpm operations (a) JD 5625, (b) MF 3085, (c) NH TD85.

Table 2 - Fuel consumption values for the tested tractors.

| PTO Power kW | Fuel Consumption, L $h^{-1}$ | | | | | |
|---|---|---|---|---|---|---|
| | 540, rpm | | | 750, rpm | | |
| | JD 5625 | MF 3085 | NH TD85 | JD 5625 | MF 3085 | NH TD85 |
| 5 | $6.62^{b}$ ± 0.02 | $4.76^{f}$ ± 0.04 | $5.09^{e}$ ± 0.07 | $6.73^{a}$ ± 0.04 | $5.36^{d}$ ± 0.03 | $5.83^{c}$ ± 0.01 |
| 10 | $7.45^{b}$ ± 0.07 | $5.72^{f}$ ± 0.05 | $5.95^{e}$ ± 0.05 | $7.52^{a}$ ± 0.04 | $6.27^{d}$ ± 0.04 | $6.75^{c}$ ± 0.04 |
| 15 | $8.44^{b}$ ± 0.01 | $6.73^{f}$ ± 0.06 | $6.90^{e}$ ± 0.07 | $8.52^{a}$ ± 0.04 | $7.45^{d}$ ± 0.04 | $7.82^{c}$ ± 0.05 |
| 20 | $9.52^{b}$ ± 0.04 | $7.79^{f}$ ± 0.03 | $8.02^{e}$ ± 0.03 | $9.63^{a}$ ± 0.02 | $8.73^{d}$ ± 0.02 | $9.00^{c}$ ± 0.03 |
| 25 | $10.55^{b}$ ± 0.03 | $9.00^{f}$ ± 0.02 | $9.08^{e}$ ± 0.01 | $10.74^{a}$ ± 0.04 | $9.96^{d}$ ± 0.03 | $10.08^{c}$ ± 0.03 |
| 30 | $11.66^{b}$ ± 0.07 | $10.17^{e}$ ± 0.10 | $10.21^{e}$ ± 0.03 | $11.96^{a}$ ± 0.04 | $11.15^{d}$ ± 0.02 | $11.38^{c}$ ± 0.19 |
| 35 | $12.92^{b}$ ± 0.01 | $11.34^{e}$ ± 0.05 | $11.30^{e}$ ± 0.01 | $13.28^{a}$ ± 0.07 | $12.43^{d}$ ± 0.04 | $12.54^{c}$ ± 0.09 |
| 40 | $14.33^{b}$ ± 0.12 | $12.70^{d}$ ± 0.02 | $12.53^{d}$ ± 0.09 | $14.50^{a}$ ± 0.12 | $13.80^{c}$ ± 0.06 | $13.63^{c}$ ± 0.06 |
| 45 | $15.38^{b}$ ± 0.06 | $13.93^{e}$ ± 0.08 | $13.78^{f}$ ± 0.04 | $15.68^{a}$ ± 0.09 | $15.02^{c}$ ± 0.08 | $14.92^{d}$ ± 0.10 |
| 50 | $16.50^{b}$ ± 0.14 | $15.09^{d}$ ± 0.04 | $15.07^{e}$ ± 0.10 | $16.83^{a}$ ± 0.03 | $16.23^{c}$ ± 0.05 | $16.21^{c}$ ± 0.10 |

Table 3. Regression equations for PTO torque and fuel consumption.

| Tractor | PTO Torque | | Fuel Consumption | |
|---|---|---|---|---|
| | 540 | 750 | 540 | 750 |
| JD | PT = 88.652 L - 0.093 | PT = 63.747 L - 0.12 | FC = 1.1222 L + 5.165 | FC = 1.152 L + 5.203 |
| | $R^2$ = 1 | $R^2$ = 1 | $R^2$ = 0.997 | $R^2$ = 0.997 |
| MF | PT = 88.659 L - 0.693 | PT = 63.607 L + 0.6 | FC = 1.1648 L + 3.315 | FC = 1.2311 L + 3.870 |
| | $R^2$ = 1 | $R^2$ = 1 | $R^2$ = 0.998 | $R^2$ = 0.999 |
| NH | PT = 88.552 L + 0.026 | PT = 63.719 L + 0.007 | FC = 1.1134 L + 3.669 | FC = 1.1608 L + 4.431 |
| | $R^2$ = 1 | $R^2$ = 1 | $R^2$ = 0.997 | $R^2$ = 0.999 |

FC: Fuel Consumption, PT: PTO Torque, L: Load , $R^2$: Coefficents of Determinaton

The cooling water temperature ranges were 79-87 ºC, 63-77 ºC and 66-72 ºC, respectively, for the JD 5625, MF 3085, and NH TD85. During the tests, no obvious variations were observed between the two PTO speeds in terms of cooling water temperature (Figure 4). The small differences among the cooling water temperature levels and tendencies 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. According to the variance analysis (Table 4), it was determined that the effects of tractor difference, PTO shaft speed, and dynamometer loads were statistically significant ($P<0.01$) on all measured characteristics. This held true both for individual effects of the independent variables as well as the effect of the interactions of these variables. The results of Duncan's Multiple Range Test ($\alpha=0.05$) are given in Table 2 for the fuel consumption only.

The variations in torque values were proportional to the increases at the load steps applied to the PTO in all tractors (Figure 2). This is expected since power is a function of both speed and torque. Therefore, increasing the power while keeping the PTO speed constant causes an increase in the torque. Torque curves for 540 and 750 rpm overlapped in each case because the PTO speeds were constant (Figure 2).

Fuel consumption difference between the two PTO operations of JD 5625 was quite lower than those of other tractors. The MF 3085 and NH TD85 had similar fuel consumptions in 540 and 750 rpm operations. The JD 5625, however, has slightly higher fuel consumption. This is probably because the JD 5625 tractor drives the PTO shaft at a higher engine speed (2400 rpm) than the other two tractors. Fuel consumption values measured in this study agree with tractor PTO tests carried out by TAMTEST (Directorate of Agricultural Equipment and Machinery Test Center, Turkey). For instance, according to the test report of the NH TD85 at 540 rpm, fuel consumption and specific fuel consumption were reported to be 13.77 L $h^{-1}$ and 249 g $kW^{-1}h^{-1}$ at 46.5 kW partial load (Taşbaş et al., 2003), which are close to those (13.78 L $h^{-1}$) obtained at 45 kW partial load in this study (Table 2).

The lowest and highest exhaust gas temperatures at 540 and 750 rpm for JD 5625 were 237-440 ºC and 229-447 ºC, respectively. Exhaust temperature ranges were 267-562 ºC and 276-562 ºC for the MF 3085, and 248-548 ºC and 267-548 ºC for the NH TD85.

The cooling water temperatures of the engines varied between 79-87 ºC, 63-77 ºC and 66-72 ºC, 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. The 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 4). It may be because of the fact that the exhaust gas temperatures of this tractor are slightly higher than those of the other tractors.

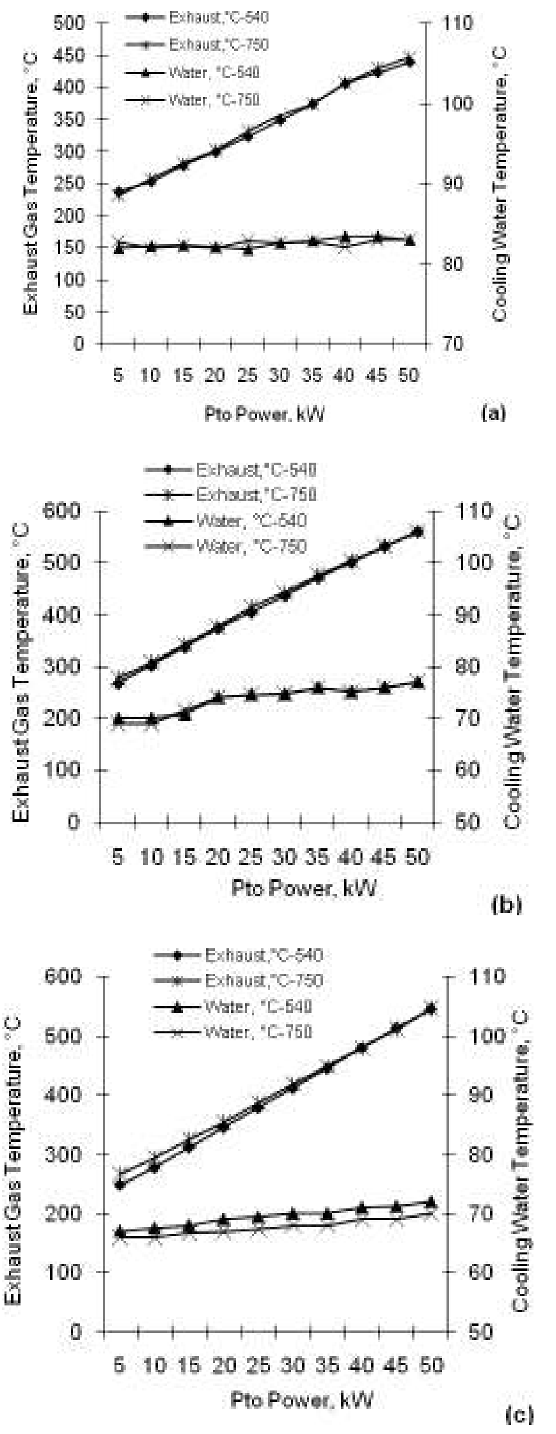


Figure 4 - Exhaust gas and cooling water temperatures depending on the loads applied to the tractor PTO at 540 and 750 rpm operations *(a) JD 5625, (b) MF 3085, (c) NH TD85.*

Table 4. Summary of variance analysis table for all dependent variables.

| Dependent Variable | Source of Variation | Df | F Value |
|---|---|---|---|
| Torque | Factor A | 2 | 0.23$^{ns}$ |
| | Factor B | 1 | 543677.83** |
| | Factor C | 9 | 619985.05** |
| | A x B | 2 | 0.14$^{ns}$ |
| | A x C | 18 | 1.00$^{ns}$ |
| | B x C | 9 | 16580.27** |
| | A x B x C | 18 | 1.60$^{ns}$ |
| | Error | 120 | - |
| Fuel Consumption | Factor A | 2 | 6991.79** |
| | Factor B | 1 | 5595.77** |
| | Factor C | 9 | 53811.26** |
| | A x B | 2 | 727.15** |
| | A x C | 18 | 20.95** |
| | B x C | 9 | 26.74** |
| | A x B x C | 18 | 2.19** |
| | Error | 120 | - |
| Spec. Fuel Consumption | Factor A | 2 | 9096.02** |
| | Factor B | 1 | 4437.04** |
| | Factor C | 9 | 91742.70** |
| | A x B | 2 | 661.96** |
| | A x C | 18 | 1102.85** |
| | B x C | 9 | 195.28** |
| | A x B x C | 18 | 37.41** |
| | Error | 120 | - |
| Exhaust Temp. | Factor A | 2 | 258459.96** |
| | Factor B | 1 | 2664.47** |
| | Factor C | 9 | 338747.75** |
| | A x B | 2 | 132.91** |
| | A x C | 18 | 3195.93** |
| | B x C | 9 | 105.99** |
| | A x B x C | 18 | 119.34** |
| | Error | 120 | - |
| Water Temp. | Factor A | 2 | 2457.71** |
| | Factor B | 1 | 1.70$^{ns}$ |
| | Factor C | 9 | 65.14** |
| | A x B | 2 | 26.48** |
| | A x C | 18 | 23.56** |
| | B x C | 9 | 1.12$^{ns}$ |
| | A x B x C | 18 | 1.67* |
| | Error | 120 | - |

Asterisks (*, **) denote significances at $P<0,05$ and $P<0,01$ respectively. ns: not significant, Factor A: tractors, Factor B: PTO operations, Factor C: load steps

The 750 rpm operation may be an alternative to 540 rpm operation up to loads of 50 kW for these three tractors. Recently, the use of 750 rpm PTO speed has become widespread for many PTO-driven machines. Farmers have preferred this operation because it allows working with bigger working width. Subsequently, a research in field conditions needs to be done to determine the level of mentioned advantage of various PTO-driven machines.

## 4. CONCLUSIONS

The measured torque varied proportionally by the increase in the load steps applied to the PTO, and the torque values for 540 and 750 operations (at load steps of 5-50 kW) were found to be between 88 Nm-888 Nm and 63 Nm-638 Nm, respectively. Specific fuel consumption decreased with power increase for 540 and 750 operations in each tractor. However, fuel consumption increased under the same conditions. Specific fuel consumption in 540 operation was lower compared to 750 rpm in all tractors. Fuel consumption difference between two PTO operations in the JD 5625 was quite lower than those of other tractors. The MF 3085 and NH TD85 tractors have similar fuel consumption in 540 and 750 operations. The JD 5625 tractor, however, has slightly higher fuel consumption. This is probably because tractors drive the PTO operations at different engine speeds and have different engine characteristics. Exhaust gas temperature values of the engines in 540 and 750 operations are very close in all three tractors, since the engine run at equal throttle position in both operations. During the tests, no obvious variations were observed in the cooling water temperatures of the engines between PTO speeds of 540 and 750 rpm. The small differences among the cooling water temperature levels in the tractors are probably caused by differences in the cooling system thermostats. According to the variance analysis, the individual effect of tractor brand, type of PTO, and dynamometer as well as the interaction of these variables had a significant effect on all measured characteristics ($P<0.01$). Overall, the study supports a conclusion that the 750 rpm PTO operation for many PTO-driven machines can be an alternative to 540 rpm operation up to maximum PTO loads of tractors.

## 5. ACKNOWLEDGMENTS

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