



The Impact of a Centrifugal Pump in the Fuel Consumption of Agricultural Tractors with Different Nominal Capacities Driven with 540 and 540e PTO Options

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ABSTRACT

In this study examined that PTO power and torque values, tractor hourly fuel consumption and tractor specific fuel consumption of three tractors with different nominal loads driven with a 540 and 540E min-1 power take-off (PTO) and a centrifugal pump with a reduction gear.

A 150 mm intake line with 1/4 transmission system driven with a PTO, horizontal shaft snail type centrifugal gear pump with 125 mm nominal diameter with outlet line was used in the study. The pump was driven by three different power tractors (New Holland TD65D, TD90D and TD110D) under laboratory conditions with 540 and 540E PTO options. The pump was operated at constant shaft speed (2160 min⁻¹) during all tests.

PTO torque, PTO power, fuel consumption and specific fuel consumption parameters were determined for both PTO applications in the experiments. The pump operations in all three tractor revealed that there was no change in PTO torque values as a result of experiments carried out with 540 and 540E rpm while the values fuel consumption in the 540E rpm application (14% for TD110D tractor, 34% for the TD90D tractor, 11% for the TD65D tractor) and specific fuel consumption (17% for the TD110D tractor, 36% for the TD90D tractor, 13% for the TD65D tractor) were less than the values in the 540 rpm application. This is the result of the application of different engine speeds for the two PTOs.

Taking all parameters into account, it has been concluded that the 540E application provides certain advantages in terms of fuel consumption for many tools and machines operated with PTO compared to the 540 application. According to this result, the 540E application is proposed as an important alternative to the 540 application for tools and machines of similar capacity and specifications used in this study.

1. Introduction

Power and energy resources are necessary to operate tools, machines and facilities used in agricultural activities. The most important component of the irrigation pumping unit, which has a significant share in the activities carried out to increase agricultural production, is the pumping unit. At the top of the operating

expenses that constitute 85% of the total inputs in irrigation pumping plants is energy input (Çalışır, 2007).

Nowadays, pumping plants (pump) are usually driven with electric energy. Where electrical energy is not available, fixed or mobile thermal motors are used. When mobile thermal engines are mentioned, the first thing that comes to mind is tractors.

The power generated in the tractor engine is known as drive, hydraulic and PTO power. The power obtained should be sufficient to meet the needs of the agricultural equipments and machines used with the tractor. Otherwise, more energy will be needed to complete the process. The tractor will need to consume more fuel in order to meet this energy. Carrying out

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agricultural activities by a tractor with a wide working range and low fuel consumption is prioritized.

It is necessary that the torque, the number of revolutions and the power values required by PTO driven engines to perform their normal functions and be used efficiently must be provided by the PTO. Although each of the agricultural machines driven by tractor PTO is designed taking into account the standard PTO speed, they require different levels of torque and power values to be able to operate effectively. Operating machines with very low torque requirements in the standard cycle with the same engine drive consumes unnecessary energy and therefore causes high fuel consumption (Atal, 2006).

Tractors were initially manufactured with only 540 rpm PTO. Subsequently, tractors were developed that can provide a number of revolutions in different standards such as 750 and 1000 rpm. The new generation tractors are equipped with 540E and 1000E rpm, also known as economical PTO revolutions, as well as standard revolutions of 540 and 1000 rpm. Transmission systems, which can achieve the same number of spindle revolutions at lower engine revolutions, have been developed for this purpose.

The difference in engine speeds that enable the 540 and 540E applications result in savings in terms of tractor fuel consumption. However, the level of savings that may arise between these two applications needs to

be known for different loading and operating conditions (Sumer et al., 2010a).

The objective of this study was to determine the differences between 540 and 540E options on PTO driven a centrifugal pump operation. For this purpose PTO power and torque values, fuel consumption and specific fuel consumption of three tractors with different nominal loads driven with a 540 and 540E d/d PTO and a centrifugal pump with a reduction gear were examined in this study. Experiments have been carried out in a laboratory to determine the differences between 540 and 540E applications for this purpose.

2. Materials and Methods

Material

The experiments were carried out in the laboratory of S.Ü. Agricultural Engineering and Technology Engineering Department of the Faculty of Agriculture. A 150 mm intake line with 1/4 transmission system driven with a PTO, horizontal shaft snail type centrifugal gearmotor pump with 125 mm nominal diameter with outlet line was used in the experiments. The test pump was operated by three agricultural tractors: New Holland TD65D, New Holland TD90D and New Holland TD110D.

Some technical features of the tractors used in the experiments are given in Table 1

Table 1

Some technical features of the agricultural tractors used in the experiments

TRACTOR	NEW HOLLAND	NEW HOLLAND	NEW HOLLAND
Model	TD 65 D	TD 90 D	TD 110 D
Maximum Power (HP)	65	88	110
No. of cylinders / Aspiration (unit)	3 / Turbo Inter-cooler	4 / Turbo Inter-cooler	4 / Turbo Inter-cooler
Cylinder Volume (L)	2,9	3,9	3,9
Maximum Torque (Nm)	261	358	430
Engine speed Obtained with Maximum Torque (rpm)	1400	1400	1400
PTO revolution (rpm)	540-540E	540-540E	540-540E
Engine speed & 540 rpm PTO revolution (rpm)	2199	2199	2199
Engine speed & 540E rpm PTO revolution (rpm)	1535	1535	1535

Method

The experiments were initiated after preliminary preparations and calibration were completed. The engine was run idle for 10 minutes to reach operating temperature before the values were taken. The tractors were operated at 540 and 540E (PTO) applications while the pump was kept at 2160 rpm during the experiments.

The measurements were made at seven different flow rates of the pump for which the flow rate was adjusted with an electromagnetic flowmeter (Model: S-MAG 100-125, Working range: 1-440 m³ / h). The measurements were started after the pump entered the regime.

The engine speeds (n_m ; min⁻¹) of the tractors were determined from the tractor speed indicator, PTO speed (n_{PTO} ; min⁻¹) and torque (M; (Nm) torquemeter (brand: Datumelectronics, measurement range: 0-1800 Nm,

540/1000 min^{-1}) and fuel consumption (B, L/h for tractors) were measured simultaneously with the fuel meter (Aquametro brand, digital display, 4-20 mA output value, 1-80 L/h measurement range) in this study. Measurements were measured at seven separate flows (Q , m^3h^{-1}) and at least one minute with a torque meter with hundreds with at least eight repetitions with a fuel meter.

Tractor power output (N_{PTO} ; kW), specific fuel consumption (L/kWh) and load ratio (YO%) were calculated with the following equations. N_a , the tractor indicates the nominal power.

$$N_{\text{PTO}} = (n \cdot M) / 9550$$

$$b_c = B / N_{\text{PTO}}$$

$$\text{YO} = ((N_{\text{PTO}} \cdot 1,36) / N_a) \cdot 100$$

Statistical analyzes were performed using the Tukey method in Minitab 16 package program.

3. Findings and Discussion

Torque and Power

The pump was driven by the tractor with a fixed PTO speed (540 rpm). Therefore, the pump shaft torque and the pump shaft power values were the same for all three tractors for the 540 and 540E PTO applications. For this reason, the flow-torque and flow-power variation values of 540 rpm PTO combination is given in Figure 1 and the flow-power variation of 540E rpm PTO is given in Figure 2.

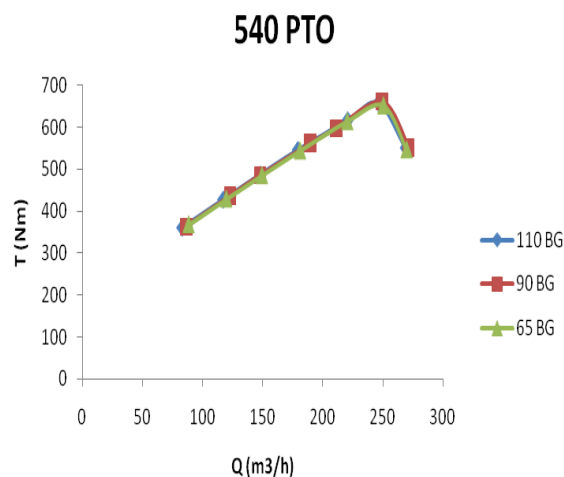
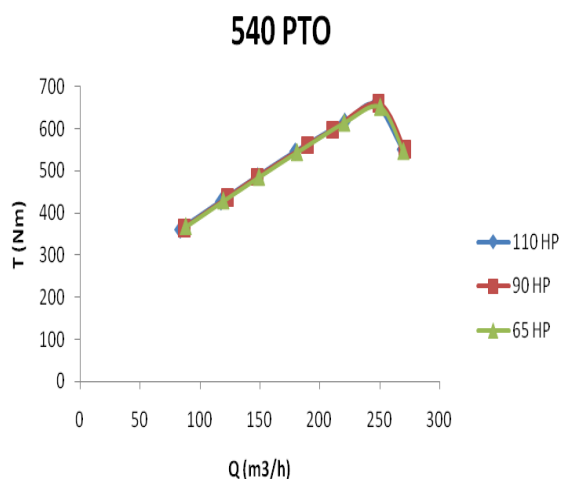


Figure 1

Flow-torque variations at 540 PTO of different tractors

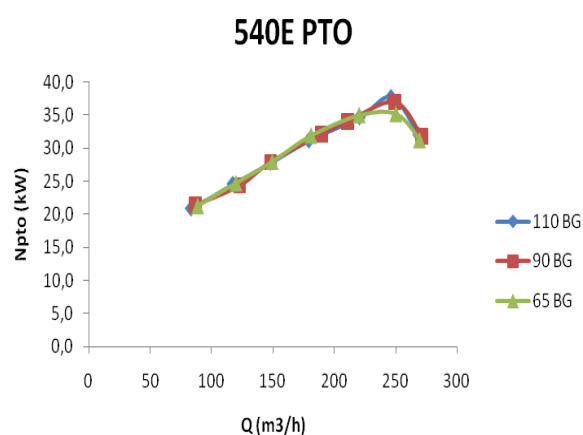
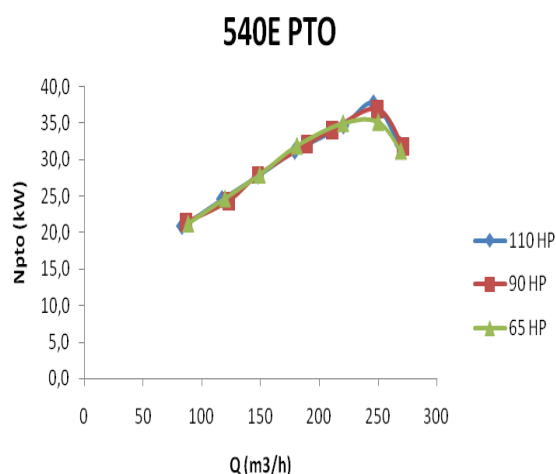


Figure 2

Flow rate-power variations of different tractors at 540E PTO

An examination of Figure 1 and Figure 2 reveal that the torque values and power changes of the flow rate function are coincide and the graphs are similar to each other in three tractors. The reason for this is that the

PTO rpm, which is one of the two basic components of the PTO power in all experiments, was kept constant during all the experiments. The drop in the torque and power after a point despite the increase in pump power can be attributed to the pump being a mixed flow pump. An examination of Figure 2, the power drop in the 65 HP tractor is due to the inability of the tractor to produce the power that the pump needs after a point.

Fuel Consumption

The relationship between tractor power, hourly fuel consumption and flow rate in both 540 and 540E PTO applications is shown in Figure 3 and Figure 4, respectively. The statistical analysis results are given in Table 2.

Table 2

Hourly fuel consumption statistical analysis results

Source	DF	MS	F
Tractor	2	38,453	16,24**
PTO	1	109,646	46,32**
TractorxPTO	2	16,032	6,27**
Error	120	2,367	
Total	125		

**P<0.01

Tractor/Pto	540	540E	Average
TD110D	10,569±1,477 ^B	9,237±1,546 ^{BC}	9,903±1,639 ^B
TD90D	12,888±1,659 ^A	9,610±1,474 ^{BC}	11,249±2,270 ^A
TD65D	9,891±1,574 ^{BC}	8,904±1,492 ^C	9,398±1,595 ^B
Average	11,116±2,016 ^A	9,250±1,508 ^B	10,183±2,005

The statistical difference does not matter between the averages shown with the same letters.

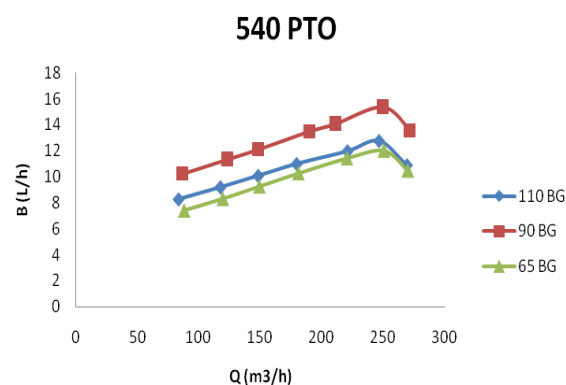
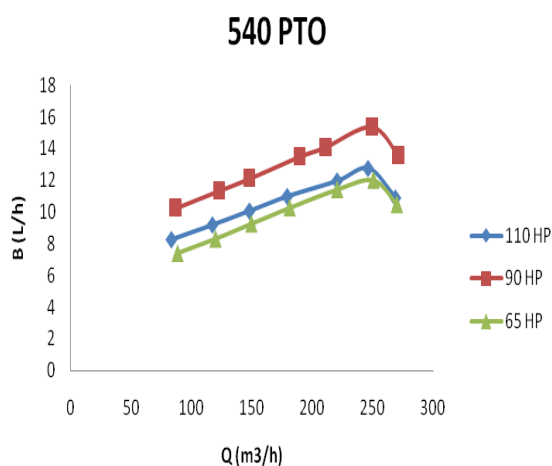


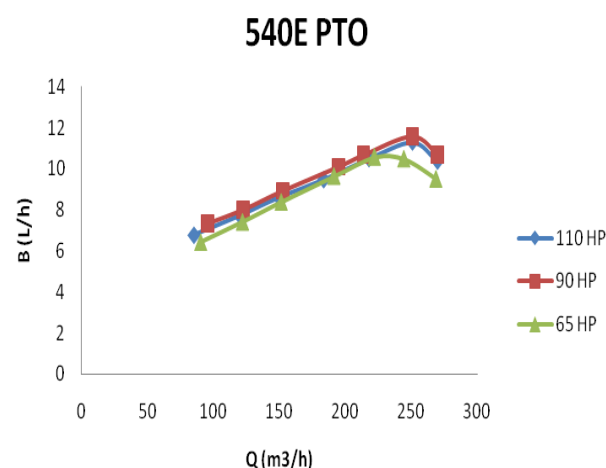
Figure 3

Relation of flow- fuel consumption at 540 PTO speed of different power tractors

When Figure 3 is examined, it is seen that, in the 540 PTO application, the flow rate of fuel consumption rises to 250 m³h⁻¹ and decreases after this value. This is due to the fact that the pump is a mixed flow pump, as explained above and requires a lower torque after a flow rate of 250 m³h⁻¹ at constant speed. This decrease in torque requirement also causes the consumption of fuel to decrease.

The most noteworthy point here is that the TD90D tractor consumes more fuel per unit time than the TD110D tractor at the same flow rates. It can be asserted that although the same engine was used in both tractors, the TD110D tractor was powered by a fuel pump and other technical adjustments.

Although the same moto-run is used on both tractors, it is thought that technological changes made in the TD110D tractor (fuel pump, pressure, compression ratios, etc.).



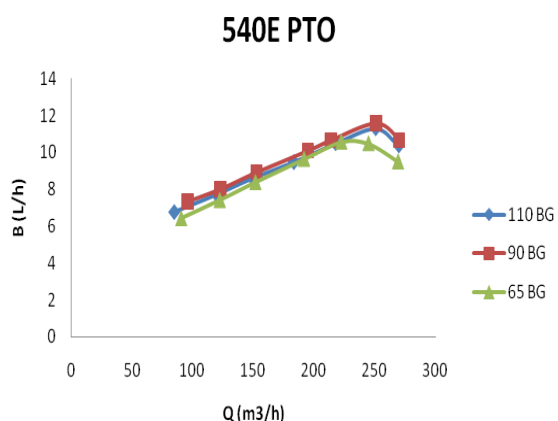


Figure 4

Relation of flow- fuel consumption at 540E PTO cycle of different tractors

When Figure 4 is examined, it is seen that the relation of flow- fuel consumption in the application of 540E rpm PTO is also in accordance with the flow-torque curve given in Figure 1. However, the difference between the curves is not as great as in the 540 rpm PTO application. This can be attributed to the fact that the 540 rpm PTO application is 37.5% higher than the 540E rpm PTO application. While the 540 rpm PTO cycle operates with an engine at 2199 min^{-1} , the 540E PTO rpm operates at 1535 min^{-1} .

In the analysis of Table 2, the variance analysis results showed that the effect of the tractor PTO on the hourly fuel consumption was significant ($P < 0.01$).

The torque values of all three tractors vary depending on the increase in load steps applied to the PTO. In other words, increasing the power value while keeping the PTO speed constant leads to an increase in the moment value. The torque curves for the 540 and 540E rpm processes in each tractor are coincident. The reason for this is that although PTO speeds are fixed for both operations the engine speed is different (Sumer et al., 2010b).

The fuel consumption changes of the TD65D, TD90D and TD110D tractors at 540 and 540E PTO speeds are given in Figures 5, 6 and 7, respectively.

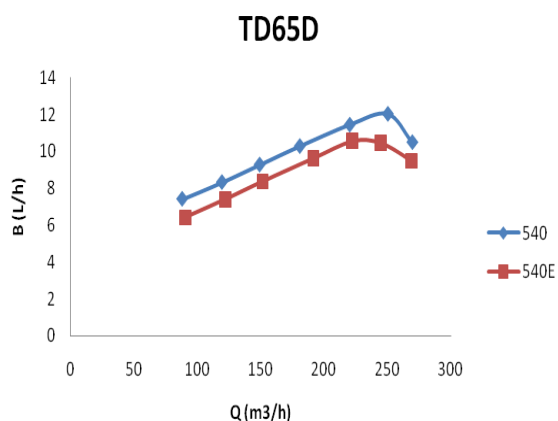


Figure 5

Relation of the flow-hourly fuel consumption of the TD65D tractor at 540 and 540E PTO cycles

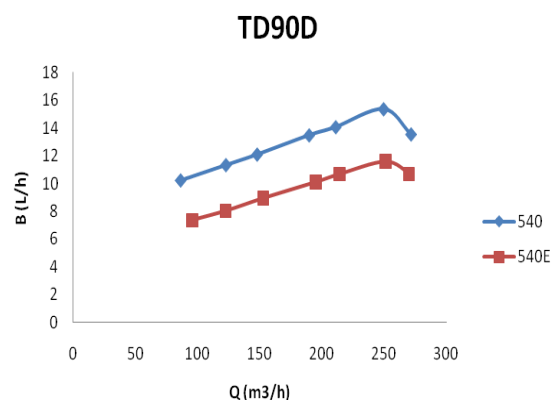


Figure 6

Relation of the flow- fuel consumption of the TD90D tractor at 540 and 540E PTO cycles

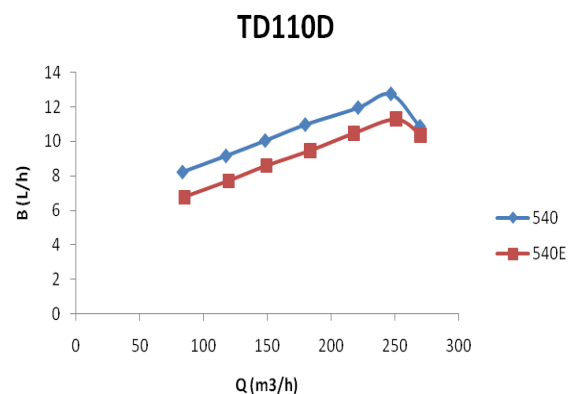


Figure 7

Relation of the flow-hourly fuel consumption of the TD110D tractor at 540 and 540E PTO cycles

An examination of Figure 5, Figure 6 and Figure 7 reveals that all three tractors consume more fuel in the 540 PTO application per unit time than the 540E PTO application under the same flow conditions. This can be attributed to the fact that the engine speed (2199 min^{-1}) of the 540 PTO application is higher by 37.5% than the engine speed (1535 min^{-1}) of the 540E PTO application, as explained above.

The 540E application has a 30% lower fuel consumption on average than the 540 application. As the loads increase, the fuel consumption difference between the two applications increases. This difference stems from the fact that the 540E rpm PTO transmission is achieved at 1715 min^{-1} engine speed and the 540 rpm PTO transmission at 2200 min^{-1} engine speed (Atal, 2006, Özgür, 2009, Sumer et al., 2010b).

Similarly; Atal 2006 determined that the 540E d / min application had lower fuel consumption values than the 540 d / min application, depending on the load. This difference in fuel consumption is about 30%

on average, which means that the difference is due to the 540E rpm tail spindle being delivered at 1715 rpm engine speed and 540 rpm tail spindle output at 2200 rpm engine speed. Sumer et al. 2010b have come to the conclusion that the 540E PTO is advantageous in terms of fuel consumption especially when they are installed by hand. In 2009, the authors noted that significant increases in hourly fuel consumption due to increased tractor tailpipe load were reduced at similar rates in specific fuel consumption.

However, the greatest difference in fuel consumption in the 540 application was determined in the TD90D tractor while the least difference was observed in the TD65D tractor.

When Figure 5 (TD65D) and Figure 7 (TD110D) are examined, the higher the engine power, the higher the fuel consumption is compared to the 540E PTO application in the constant debide 540 PTO application.

An examination of Figure 5 (TD65D) and Figure 7 (TD110D) reveals that as the engine power increases the 540 PTO application has a higher hourly fuel consumption in fixed flow compared to the 540E PTO application. Figure 6 (TD90D) and Figure 7 (TD110D) indicate that compared to the TD110D engine, TD90D engine power has a higher hourly fuel consumption at fixed flow in the 540 PTO application compared to the 540E PTO application. The reason for this is that, as emphasized earlier, the same engine is used in both tractors but the difference is generated with the technological interventions in the TD110D engine.

The reason for this is that, as emphasized earlier, technological changes in the TD110D tractor (fuel pump, pressurizer, compression ratios, etc.) are considered to be due to the same engine used in both tractors.

The relationship between tractor power-load ratio-fuel consumption in 540 PTO and 540E PTO applications of the tractors is given in Figure 8 and Figure 9.

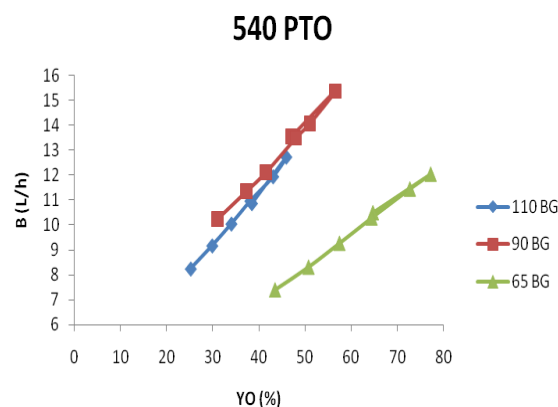
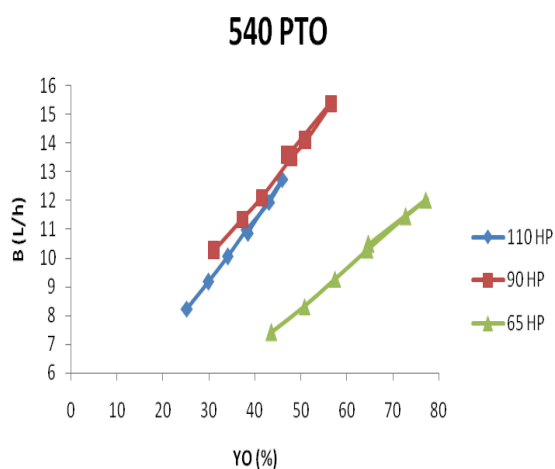


Figure 8

Relation of Tractor load ratio- fuel consumption of different power tractors at 540 PTO

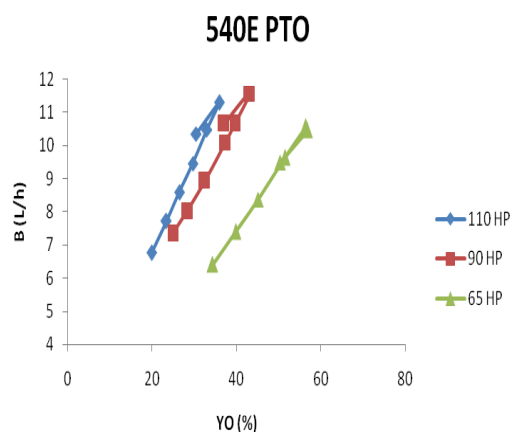


Figure 9

Relation of Tractor load ratio- fuel consumption of different power tractors at 540E PTO

An examination of Figures 8 and 9 indicates that the fuel consumption value increases as the load ratio (relative to the maximum load value) increases with respect to the tractor load ratio - fuel consumption in

the 540 and 540E PTO applications of different power tractors. Depending on the load, however, the increase in fuel consumption varies from small to large compared to the tractor power. So while the smallest increase is in the TD65D tractor, the biggest increase is in the TD110D tractor. What is noteworthy here is that in the 540 PTO application, the highest fuel consumption at the same load value occurs in the TD90D tractor while the highest fuel consumption at the same load value occurs in the TD110D tractor in the 540E PTO application.

The reason for this may be that the TD90D tractor's fuel consumption difference in the 540 and 540E rpm PTO applications is more than the fuel consumption difference in the 540 and 540E rpm PTO applications of the TD110D tractor.

Specific Fuel Consumption

As a result of the experiment, the relationship between tractor power, flow rate and specific fuel consumption in both 540 and 540E PTO applications is shown in Figure 10 and Figure 11 respectively. Statistical analysis results are given in table 3.

Table 3

Specific fuel consumption statistical analysis results

	DF	MS	F
Tractor	2	0,045030	165,36**
PTO	1	0,150006	550,87**
TractorxPTO	2	0,019241	70,66**
Error	120	0,000272	
Total	125		

**P<0.01

TRAC-TÖR/PTO	540	540E	Average
TD110D	0,3630±0,02159 B	0,3111±0,00959 DE	0,3371±0,03097 B
TD90D	0,4416±0,02903 A	0,3238±0,01144 CD	0,3827±0,06345 A
TD65D	0,3379±0,00986 C	0,3192±0,02024 E	0,3463±1,595 C
Average	0,3808±0,04934 A	0,3118±0,01289 B	0,3463±0,0499 O

The statistical difference does not matter between the averages shown with the same letters.

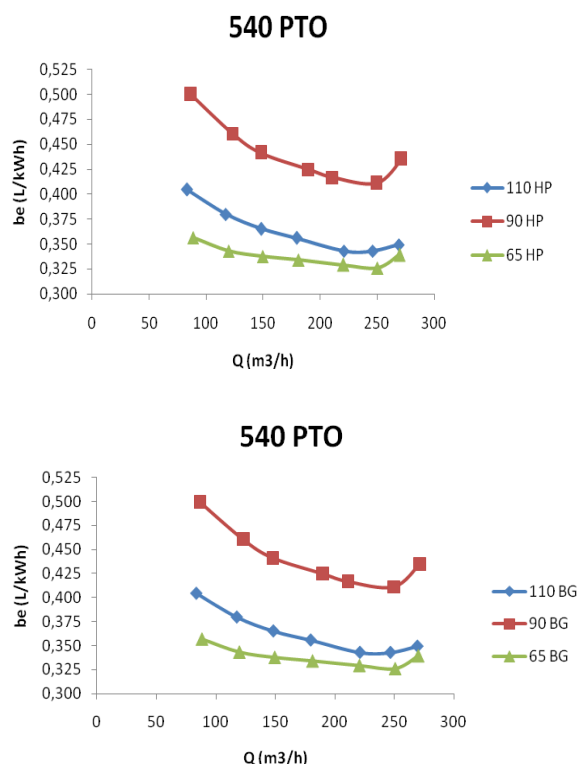


Figure 10.

Relation of flow-specific fuel consumption at 540 PTO option of different power tractors

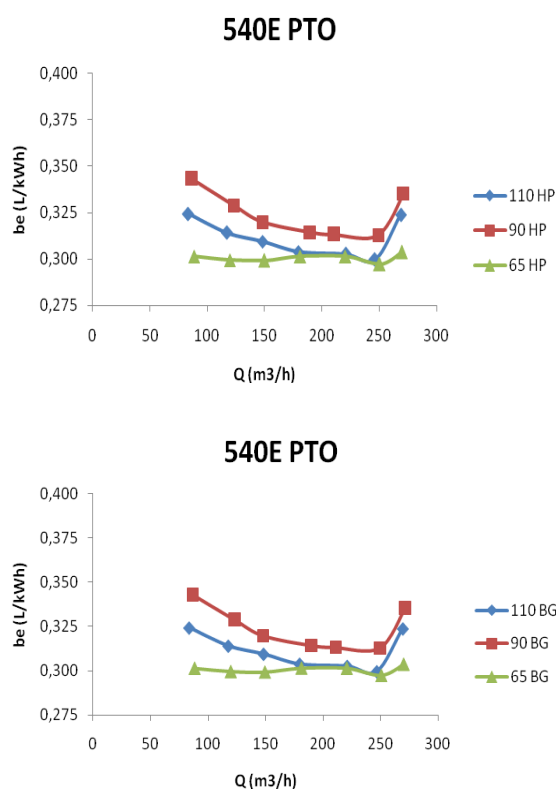


Figure 11

Relation of flow-specific fuel consumption at 540E PTO cycles of different power tractors

An examination of Figure 10 reveals that as the flow rate increases in the 540 PTO application, the specific fuel consumption values drop until a certain point (approx. 250 m³ / h) and then suddenly rise. Specific fuel consumption values at all flow rates were observed from small to large in 65, 110 and 90 HP tractors, respectively.

In the analysis of Table 3, the results of the variance analysis showed that the effect on the specific fuel consumption of the tractor PTO engine was significant ($P < 0.01$).

As a result of the step-by-step loading of three tractors with a PTO dynamometer, the specific fuel consumption decreased as the load increased in all three tractors (Sumer et al., 2010b).

Similarly, Sumer et al. In 2010b, they found that the three tractors in the study performed a step-by-step loading with a PTO dynamometer and the specific fuel consumption decreased as the load increased in all three tractors.

When Figure 11 is examined, it is seen that in the 540E PTO application and all flow values have similar relationships with the 540 PTO application in specific fuel consumption values. However, the difference between the specific fuel consumption values of the tractor powers in the 540E PTO application was on a lower level. It can be asserted that this is related to the severity of the fuel consumption values corresponding to tractor engine speeds.

The most noteworthy point that is revealed both figures are studied together is that the specific fuel consumption value of the TD90D tractor was higher than that of the TD110D tractor at the same flow rates. The reason for this is that the fuel consumption value of the TD90D tractor is higher than the hourly fuel consumption value of the TD110D tractor.

Specific fuel consumption changes manifested by the flow rate dependent 540 and 540E PTO applications of the TD65D, TD90D and TD110D tractors are given in Figure 12, Figure 13 and Figure 14, respectively

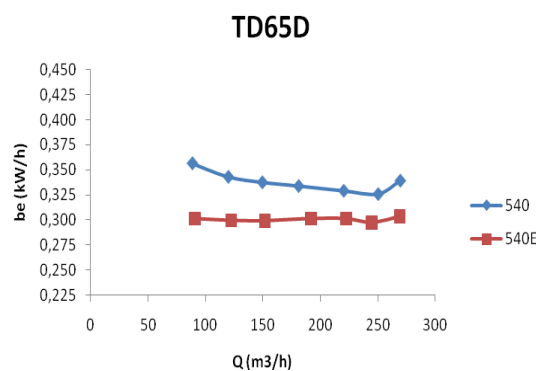


Figure 12

Relation of flow-specific fuel consumption at 540 and 540E PTO cycles of the TD65D tractor

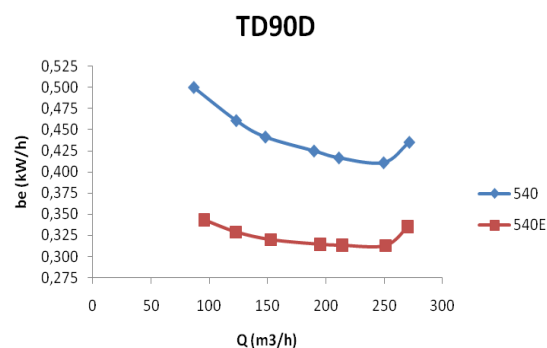


Figure 13

Relation of the flow-specific fuel consumption of the TD90D tractor in the 540 and 540E PTO cycles

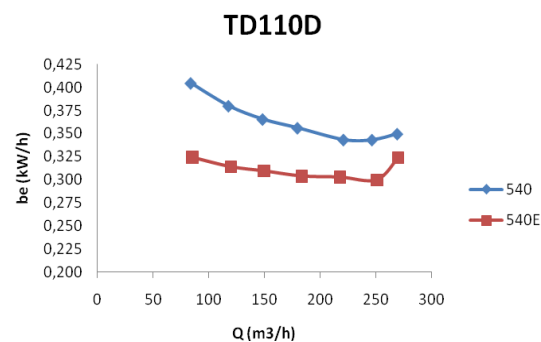


Figure 14

Relation of the flow-specific fuel consumption at 540 and 540E PTO cycles of the TD110D tractor

When Figure 12, Figure 13 and Figure 14 are examined, it is seen that the specific fuel consumption values of 540 PTO application are higher than those of 540E PTO application under the same flow conditions in all three tractors. This may be attributed to the fact that the engine speed of the 540 PTO application is higher than the engine speed of the 540E PTO application. Furthermore, the biggest difference in the maximum specific fuel consumption was noted in the TD90D tractor in the 540 application compared to the

540E PTO application and the least difference was observed in the TD650D tractor.

When Figure 12 (TD65D) and Figure 14 (TD110D) are examined, it is seen that as the engine power increases, the specific fuel consumption values are higher in the 540 PTO application than in the 540E PTO application. When Figure 13 (TD90D) and Figure 14 (TD110D) are examined, it is observed that the specific fuel consumption values are higher in the TD90D tractor compared to the TD110D tractor in both the 540 PTO application and the 540E PTO application. The reason for this is that, as emphasized earlier, the same engine is used in both tractors but the difference is generated with the technological interventions in the TD110D engine.

4. Conclusions and Recommendations

At the same flow rates, the hourly fuel consumption in 540E PTO cycle is 13-22%, 30-40% and 7-15% less than in the TD110D, TD90D and TD65D tractors than the hourly fuel consumption in the 540 PTO cycle, respectively.

In all three tractors, both the 540 PTO and the 540E PTO increase the load ratio, resulting in increased fuel consumption. Increases due to load factor are more in the 540 PTO application than in 540E PTO application.

Operating the TD65D, TD90D and TD110D tractors in the 540E PTO mode resulted in a much lower specific fuel consumption than in the 540 PTO mode.

Agricultural tools and machines operating on the tractor's tail spindle must not be driven by tractors capable of producing much more power than necessary. It is more economical to operate PTO driven machines standard (540 rpm) spindle revolving tools and machines with 540E rpm rather than 540 rpm.

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