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Comparison of Performance Characteristics of Agricultural Tractors

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Abstract: In this study, the relationships between some parameters such as PTO (power take-off) power, engine speed, specific fuel consumption, travel speed, drawbar power, drawbar pull and tractor mass of agricultural tractors were compared. Test reports of tractors according to standard code 2 of Organization for Economic Cooperation and Development (OECD) obtained Nebraska University Tractor Test Laboratory reports were used as material. The statistical relationships between the parameters were investigated which obtained from the test reports. According to the results of regression analysis same results were found both at 85 per cent of the torque obtained in the torque corresponding to maximum power available at rated engine speed and at standard PTO speed for 2 WD and 4 WD tractors. The relations between PTO power and engine speed were found different in working conditions both at 85 per cent of the torque obtained in the torque corresponding to maximum power available at rated engine speed and at standard power take-off speed for 2 WD tractors. Besides, according to the results of regression analysis same results were found at a pull equal to 75 percent of the drawbar pull corresponding to maximum power at rated speed for 2 WD and 4 WD tractors. The relations between drawbar pull and specific fuel consumption were found different in working conditions at a drawbar pull equal to 75 per cent of the pull corresponding to maximum power at rated speed for 2 WD tractors. The overall efficiency (η) of tractors was found on an average of 29.04.

Key words: Drawbar power, performance characteristics, power take-off power, test report, tractor

Tarım Traktörlerinin Performans Karakteristiklerinin Karşılaştırılması

Öz: Bu çalışmada, tarım traktörlerinin PTO (PTO) gücü, motor devri, özgül yakıt tüketimi, ilerleme hızı, çeki gücü, çeki kuvveti ve traktör kütlesi gibi bazı parametreler arasındaki ilişkiler karşılaştırılmıştır. Nebraska Üniversitesi Traktör Test Laboratuvarı raporlarından elde edilen Ekonomik İşbirliği ve Kalkınma Teşkilatı (OECD) standart kod 2'ye göre traktörlerin test raporları materyal olarak kullanılmıştır. Test raporlarından elde edilen parametreler arasındaki istatistiksel ilişkiler araştırılmıştır. Regresyon analizi sonuçlarına göre, 2 WD ve 4 WD traktörler için hem nominal motor devrinde mevcut maksimum güce karşılık gelen torkta elde edilen torkun yüzde 85'inde hem de standart PTO hızında aynı sonuçlar bulundu. PTO gücü ile motor devri arasındaki ilişkiler, hem nominal motor devrinde mevcut maksimum güce karşılık gelen torkta elde edilen torkun yüzde 85'inde hem de 2 WD traktörler için standart PTO hızında çalışma koşullarında farklı bulunmuştur. Ayrıca regresyon analizi sonuçlarına göre 2 WD ve 4 WD traktörler için nominal hızda maksimum güce karşılık gelen çeki demiri çekişinin yüzde 75'ine eşit bir çekmede aynı sonuçlar bulunmuştur. Çeki kuvveti ile özgül yakıt tüketimi arasındaki ilişkiler, 2 WD traktörler için nominal hızda maksimum güce karşılık gelen çekmenin yüzde 75'ine eşit bir çeki kuvveti çalışma koşullarında farklı bulunmuştur. Traktörlerin toplam verimi (η) ortalama 29.04 olarak bulunmuştur.

Anahtar Kelimeler: Çeki gücü, performans karakteristikleri, PTO gücü, test raporu, traktör

1.Introduction

The meaning of the tractor (tracteur) is puller. Previously, tractors were used only in tow works. Later, in accordance with the developments in agriculture and agricultural machinery technique, the structure of the tractor changed significantly. Tractors are at least two axles, wheeled or tracked and are self-propelled. Tractors are used in agricultural and forestry for towing trailers, transporting tools and machines, and pulling or pushing. They are used to run and power the machines while they are moving or stationary (OECD, 2019). In agriculture, tractor is the most fuel-consuming machine. The research indicates that 20–55% of available tractor power is lost in the process of interaction between tires and soil surface. Tire pressure and vertical wheel load are both easily managed parameters, which play a significant role in controlling the slip, the traction force and the fuel consumption of a tractor (Janulevicius and Damanauskas, 2015). A set of standard procedures to be applied by test stations to measure the performance characteristics of agricultural and forestry tractors is called the OECD Tractor Performance Test Code. Using these codes, it has made it possible to follow the same methods and compare the test results in tractor experiments conducted by research and test centers in different countries. Power takes off (PTO) and drawbar performance tests are included in OECD standard Code 2 within the scope of the standard test code numbered one to ten for agricultural and forestry tractors (OECD, 2016). In addition, tractor performance was determined in order to enable the farmer to use the tractor efficiently and to trade properly (Taşbaş *et al*. 2003). Sumer *et al.* (1998) stated that there is a decrease in specific fuel consumption depending on the load applied to the powet take off (PTO). Grisso *et al*. (2004), according to the test reports published by Nebraska Tractor Test Laboratory, stated that specific fuel consumption can be used to compare tractors with different working conditions and different sizes. Downs *et al.* (2006) examined the tests performed at Nebraska Tractor Test Laboratory and reported that the fuel efficiency will be half the fuel efficiency at full power position in 25% loading performed in the PTO test. Gil-Sierra *et al.* (2007) examined the partial loads at different engine speeds at six points according to OECD standard Code 2 and determined the corresponding fuel consumption values. Özgür (2009) found that the specific fuel consumption decreases as the power increases. The most decisive criterion in the selection of tractors is tractor performance. Drawbar power is preferred in comparison and evaluation of tractors. In this regard, it has been reported that the use of PTO performance data would be appropriate to evaluate the performance of agricultural tractors (Başer, 2008). Measured at 75% of the maximum drawbar pull, the power is suitable for heavy duty work such as primary tillage. Average fuel consumption at 75% and 50% loads of the drawbar pull at maximum power can represent tillage and planting operations, respectively, on farms producing grain (small grain). Similarly, the average fuel consumption at the 50% load test of the maximum power drawbar pull can give a good fuel consumption estimate for tractors used in growing crops (Grisso *et al.* 2014). Kabeel *et al.* (2010) studied theoretically and experimentally the performance of spot cooling of a tractor cabinet including a single internal heat source (tested body) by using vortex tube. Kumar (2019) observed that the maximum power output can be increased by the help of ballasting, the output power was found to be more in case of corresponding weight of 50 and 75% equivalent weight of iron ballast compared to liquid ballast.

The drawbar power- is directly proportional to the travel speed and the drawbar pulling force. Parameters affecting the drawbar power of a tractor; the characteristics of the engine, gear level, tires, drawbar, tow hook, ground structure, ground condition, angle of the ground with the horizontal, characteristics of the fuel, tractor additional weights, extra loads coming from the towing equipment to the rear axle and being 2 WD or 4 WD (Arıöz and Güner, 2015). Kocher *et al.* (2017) has developed five different fuel consumption models, which include the parameters of drawbar power, travel speed and engine speed, which are a function of fuel consumption. He developed equations for each model and made statistical analyzes to calculate the estimated fuel consumption. The results obtained were evaluated, and fuel consumption was estimated by applying a single equation for each speed range tested. The aim of this study is to make statistical analysis of the PTO performance and drawbar performance values obtained from experiment reports based on OECD standard Code 2 of standard agricultural tractors and to evaluate the results obtained.

2. Materials and methods

In this study, the test reports of 418 agricultural tractors that were tested between 2004 and 2017 in Nebraska University Tractor Test Laboratory, which were tested according to OECD standard Code 2, were used (NTTL, 2018). Nebraska University Nebraska Tractor Testing Laboratory (NTTL) is the official tractor testing station for the Organization for Economic Cooperation and Development (OECD) in the USA. This independent laboratory is responsible for testing a representative tractor of each model sold in the state of Nebraska. It also tests tractors manufactured in the USA and sold in international markets. The laboratory publishes the results of all tests performed. The 418 tractors used in the research have an internal combustion (diesel) engine. The power of tractors at nominal engine speed varies between 45.50 kW and 356.41 kW. The power average is 142.21 kW. 370 tractors are two-wheel drive (2 WD), 48 are four-wheel drive (4 WD). Distribution of tractors according to their power at nominal engine speed is given in Table 1.

Table 1. Distribution of tractors according to their power at rated engine speed.
Çizelge 1. *Traktörlerin nominal motor devrindeki güçlerine göre dağılımı.*

Power at rated engine speed (P) (kW)	Number of tractors (pieces)	Percentage (%)
50>P	1	0
50≤P<100	152	36
100≤P<150	116	28
150≤P<200	67	16
200≤P<250	55	13
250≤P<300	7	2
300≤P	20	5

In this study, firstly, 418 tractors are grouped as 2 WD and 4 WD according to their technical specifications. After that statistical analysis of 2 WD and 4 WD groups were made. The results of the regression analysis and the variance analysis were evaluated. The overall efficiency (η) of the tractors was calculated using the drawbar power, drawbar pull and specific fuel consumption data obtained from the experiment reports. Relationships between PTO power, engine speed, specific fuel consumption and specific energy parameters were determined at 85% of the torque at the maximum engine power obtained at the nominal engine speed, and at the standard PTO revolution (1000 rpm). The loading at 75% of the drawbar pull force may represent operation with primary tillage such as moludboard and disc plow, chisel, subsoil tool which usually require high power. Therefore, in the drawbar performance test at 75% of the pull at the rated engine speed and at the maximum power, the relationships between the drawbar power, pull force, engine speed, forward speed, specific fuel consumption and tractor mass parameters are determined. The overall efficiency of the tractors has been calculated from the following relation by making use of the draw power and fuel power (Sümer, 2005; Sabancı, 1997; Souza *et al*., 1994).

$$\eta = 100\frac{P_d}{P_f} \qquad (1)$$

$$P_f = \frac{B_e \times H}{3600} \qquad (2)$$

Where: $\eta =$ Total tractor efficiency (%), P_d=Drawbar power (kW), P_f =Fuel power (kW), B_e =Fuel consumption (kg/h), $H =$ Energy value of diesel fuel (=41870 kJ/kg)

Minitab 19 program was used to make statistical analysis in the study. The coefficient of determination (R^2), F value showing the incompatibility test (lack of fit), P (probability) value showing the significance status and estimation equations were found. First order (linear) equation, second order (quadratic) equation and third order (cubic) equations were obtained as estimation equation. The coefficient of determination R^2 shows how much percent of the independent variable explains the change in the dependent variable. It is the ratio of the disclosed change to the total change. The estimation equation is used to estimate the values of the Y dependent variable from the values of the independent variable X. The probability level P value is found to determine whether the model fits the data correctly. The incompatibility test F (lack of fit) tells us whether a regression model is a weak or a strong model of data. When choosing, the highest R^2, the lowest F and the lowest P values are based on.

3. Results and discussion

3.1.Relationship between engine speed and power of PTO at 85% of the torque for maximum engine power, rated engine speed and two WD tractors

When estimation equation, coefficient of determination R^2, incompatibility test F (lack of fit) values and probability level P (probability) values are examined, R^2 values of first, second and third degree equations are very close to each other, lack of fit (F) values were found the same (Table 2). It can be said whether the model is meaningful by looking at the F value and the P value. P value was found to be significant with P <0.001 in the first, second and third degree equations. When we examine the regression values of the first degree equation, the coefficient of determination R^2 = 16.19% was the lowest and P <0.001. The significance of P here may be due to the large number of samples (DF = 370). The low coefficient of determination means that the estimation equation cannot be used, that is, the PTO power cannot be estimated by looking at the engine speed. R^2 = 16.19% means that 16.19% of the total variation in the power take-off power variable can be explained, while 83.81% cannot be explained. The correlation coefficient between the PTO power and engine speed is R = 0.4, and it is desired that the R value be close to 1 in order for the relationship to be strong. The R value close to 1 indicates how much the data fits on a linear curve. As a result of the statistical analysis, the hypothesis of obtaining the PTO power value with the help of engine speed is insufficient. It is known that the power of the PTO increases up to the standard PTO speed or nominal engine speed, and starts to decrease after this speed. Power take off (PTO) power decreased as engine speed increased. In his study, Başer (2008) found that as the engine speed increased, the power of the PTO decreased.

Table 2. Regression analysis values of the relationship between engine speed and power of PTO at 85% of the torque for maximum engine power, rated engine speed and two WD tractors

Çizelge 2. *Maksimum motor gücü, nominal motor devri ve 2 WD traktör için torkun %85'inde motor devri ile PTO gücü arasındaki ilişkinin regresyon analizi değerleri*

Regression Analysis: Power of PTO (P_p) (kW) versus engine speed (n_m)(d/d)				
	((R^2) %)	(F)	P≤	The estimation equations
Linear	16.19	2.08	0.001	$P_p = 621.1 - 0.2343n_m$
Quadratic	16.40	2.08	0.001	$P_p = 2253 - 1.711n_m + 0.000334(n_m)^2$
Cubic	16.60	2.08	0.001	$P_p = 46418 - 61.33n_m + 0.02714(n_m)^2 - 0.000004(n_m)^3$

3.2. Relationship between specific fuel consumption and power of PTO at 85% of the torque for maximum engine power, rated engine speed and two WD tractors

The smallest R^2 and smallest P values were obtained in the first degree equation, the largest R^2 value and the smallest F value were obtained in the third degree estimation equation (Table 3). The first order equation was found to be significant with P <0.001. It would be appropriate to select the first order equation because the coefficient of determination R^2 and lack of fit (F) are close to each other and the P value is the lowest. The reason for the need for second and third degree equations in statistical analysis is usually for raising R^2. The specific fuel consumption decreased as the power of the drive shaft increased. Increasing drive shaft power and thus engine speed reduces specific fuel consumption. When the experiment reports are examined, it is seen that the lowest value of the specific fuel consumption is reached at the point where the maximum power is obtained. Özgür (2009) found in his study that the power decreased with increasing specific fuel consumption. Saral and Avcıoğlu (2002) reported that the specific fuel consumption depends very much on the structure of the engine, and it generally gets the lowest value below and close to the nominal speed .

Table 3. Regression analysis values of the relationship between specific fuel consumption and power of PTO at 85% of the torque for maximum engine power, rated engine speed and two WD tractors

Çizelge 3. *Maksimum motor gücü, nominal motor devri ve iki WD traktör için torkun %85'inde özgül yakıt tüketimi ile PTO gücü arasındaki ilişkinin regresyon analizi değerleri*

Specific fuel consumption (b_e) (kg/kWh) versus PTO power (P_p) (kW)				
	(R^2) (%)	(F)	P≤	The estimation equations
Linear	40.00	6.41	0.001	$b_e = 0.3027 - 0.000343P_p$
Quadratic	41.24	6.30	0.006	$b_e = 0.3221 - 0.000698P_p + 0.000001(P_p)^2$
Cubic	42.39	6.19	0.007	$b_e = 0.3745 - 0.002135P_p + 0.000013(P_p)^2 - 0.000000(P_p)^3$

3.3. Relationship between specific energy and power of PTO at 85% of the torque for maximum engine power, rated engine speed and two WD tractors

When Table 4 is examined, the highest R^2 and the lowest F value are obtained in the third degree equation and the lowest P value is obtained in the first degree equation. First degree equation was found to be significant with P <0.001. The highest R^2, the lowest F and P values are taken into account when choosing. Here, the first degree equation can be chosen because the difference between R^2 and F values is small and the P value is the lowest. Specific energy increased as the PTO power increased.

Table 4. Regression analysis values of the relationship between specific energy and power of PTO at 85% of the torque for maximum engine power, rated engine speed and two WD tractors

Çizelge 4. *Maksimum motor gücü, nominal motor devri ve 2WD traktörler için torkun %85'inde özgül enerji ve PTO gücü arasındaki ilişkinin regresyon analizi değerleri*

Specific energy (E_s) (kWh/L) versus PTO power (P_p) (kW)				
	(R^2) (%)	(F)	P≤	The estimation equations
Linear	43.86	6.86	0.001	$E_s = 2.729 + 0.004170P_p$
Quadratic	44.23	6.84	0.120	$E_s = 2.606 + 0.006417P_p - 0.000009(P_p)^2$
Cubic	45.04	6.76	0.020	$E_s = 2.092 + 0.02049P_p - 0.000127(P_p)^2 + 0.000000(P_p)^3$

3.4. Relationship between engine speed and power of PTO at the standard PTO speed for two WD tractors

When Table 5 is examined, P values are the lowest in the first and third degree equations and are found to be significant with P <0.001. The reason for the P value being P <0.001 may be due to the high number of samples (DF = 370). However, the coefficient of specification R^2 was obtained in the third highest equation and was found 26.41%. It is positive that p values are important, but low coefficients of determination is a negative situation. The low coefficient of determination means that the estimation equation cannot be used, that is, the PTO power cannot be estimated by looking at the engine speed. R^2 = 21.06% means that 21.06% of the total variation in the PTO power variable can be explained, while 78.94% cannot be explained. Looking at the P value, the relationship between engine speed and power take-off is important, but considering the coefficient of determination, the rate of estimation of power take-off by using engine speed is low. The hypothesis of obtaining the power of the PTO with the help of engine speed is insufficient. PTO power decreased as engine speed increased.

Table 5. Regression analysis values of the relationship between engine speed and power of PTO at the standard PTO speed for two WD tractors

Çizelge 5. *İki WD traktör için standart PTO hızında motor devri ile PTO gücü arasındaki ilişkinin regresyon analizi değerleri*

PTO power (P_p) (kW) versus engine speed (n_m) (d/d)				
	(R^2) (%)	(F)	P≤	The estimation equations
Linear	21.06	9.12	0.001	$P_p = 650.1 - 0.2588n_m$
Quadratic	22.14	9.07	0.025	$P_p = 2484 - 2.11n_m + 0.000466(n_m)^2$
Cubic	26.41	8.44	0.001	$P_p = 64073 - 95.51n_m + 0.04759(n_m)^2 - 0.000008(n_m)^3$

3.5. Relationship between specific fuel consumption and power of PTO at the standard PTO speed for two WD tractors

When Table 6 is examined, P values are found to be the lowest and significant with P <0.001 in the first and second order estimation equations. The degree of accuracy of the specific fuel consumption estimated, namely R^2 = 43.86% in the first-order equation, R^2 = 46.89% in the second-order equation and the highest R^2 = 47.22% in the third-degree equation. Determination coefficients are higher than previous data and the representation value of the model is 47.22%. In other words, 47.22% of the specific fuel consumption variation, which is the dependent variable, indicates that it is explained by the power of the PTO, which is the independent variable. Another value indicating the model's ability to represent, the lack of fit value was obtained in the lowest third order equation as F = 5.49. The specific fuel consumption decreased as the power of the PTO increased.

Table 6. Regression analysis values of the relationship between specific fuel consumption and power of PTO at the standard PTO speed for two WD tractors

Çizelge 6. *İki WD traktör için standart PTO hızında özgül yakıt tüketimi ile PTO gücü arasındaki ilişkinin regresyon analizi değerleri*

Specific fuel consumption (b_e) (kg/kWh) versus PTO power (P_p) (kW)				
	(R^2) (%)	(F)	P≤	The estimation equations
Linear	43.86	5.82	0.001	$b_e = 0.2691 - 0.000197P_p$
Quadratic	46.89	5.51	0.001	$b_e = 0.29 - 0.000506P_p + 0.000001(P_p)^2$
Cubic	47.22	5.49	0.133	$b_e = 0.3093 - 0.000931P_p + 0.000004(P_p)^2 - 0.000000(P_p)^3$

3.6. Relationship between specific energy and power of PTO at the standard PTO speed for two WD tractors

When Table 7 is examined, the lowest P values were obtained in the first and second degree equations and were found to be significant with P <0.001. The highest R^2 value was obtained in the third degree equation and the lowest F value was obtained in the second and third degree equations. The highest R^2 value is 48.21. It shows that 48.21% of the specific energy, which is the dependent variable, is explained by the independent variable the PTO power. Specific energy increased as the PTO power increased.

Table 7. Regression analysis values of the relationship between specific energy and power of PTO at the standard PTO speed for two WD tractors

Çizelge 7. *İki WD traktör için standart PTO hızında özgül enerji ve PTO gücü arasındaki ilişkinin regresyon analizi değerleri*

Specific energy (E_s) (kWh/L) versus power of PTO (P_p) (kW)				
	(R^2) (%)	(F)	P≤	The estimation equations
Linear	46.11	6.50	0.001	$E_s = 3.094 + 0.002827P_p$
Quadratic	48.03	6.00	0.001	$E_s = 2.861 + 0.006266P_p - 0.00011(P_p)^2$
Cubic	48.21	6.00	0.265	$E_s = 2.662 + 0.01065P_p - 0.00004(P_p)^2 + 0.000000(P_p)^3$

3.7. Relationship between engine speed and power of PTO at 85% of the torque for maximum engine power, rated engine speed and four WD tractors

The highest R^2 value and the lowest F value were found in the third degree equation (Table 8). The lowest P value was obtained in the first degree equation and it was found to be significant with P <0.001. When choosing, the highest R^2, the lowest F and the lowest P values are taken into consideration. Since the difference between the R^2 and F values obtained here is small and the lowest P value is also in the first degree equation, the first degree equation can be selected as the estimation equation. PTO power has increased as the engine speed has increased. In the analysis of the relationship between the engine speed and the PTO power in 85% of the torque at the maximum engine power obtained at nominal engine speed for two WD tractors, it was found that the PTO power decreased as the engine speed increased. However, in the same analysis for 4 WD tractors, it was found that as the engine speed increases, the power of the PTO increases. This may be due to the compression ratio, weight, gearbox, fuel equipment and motion transmission system differences of the tractors analyzed.

Table 8. Regression analysis values of the relationship between engine speed and power of PTO at 85% of the torque for maximum engine power, rated engine speed and four WD tractors

Çizelge 8. *Maksimum motor gücü, nominal motor devri ve 4 WD traktör için torkun %85'inde motor devri ile PTO gücü arasındaki ilişkinin regresyon analizi değerleri*

PTO power (P_p) (kW) versus engine speed (n_m) (min^{-1})				
	(R^2) (%)	(F)	P≤	The estimation equations
Linear	29.17	4.39	0.001	$P_p = -2408 + 1.242n_m$
Quadratic	29.27	4.62	0.810	$P_p = -23230 + 20.82n_m - .0046(n_m)^2$
Cubic	35.90	4.29	0.043	$P_p = 18169928 - 25629n_m + 12.05(n_m)^2 - 0.00188(n_m)^3$

3.8. Relationship between specific fuel consumption and power of PTO at 85% of the torque for maximum engine power, rated engine speed and four WD tractors

The highest R^2 value and the lowest F value were found in the third degree equation (Table 9). The lowest P value was obtained in the first degree equation and it is significant with P <0.001. The specific fuel consumption decreased as the power of PTO increased. However, after a certain PTO power, specific fuel consumption will begin to increase. It is seen in the test reports that the lowest value of the specific fuel consumption is reached at the point where the maximum power is obtained.

Table 9. Regression analysis values of the relationship between specific fuel consumption and power of PTO at 85% of the torque for maximum engine power, rated engine speed and four WD tractors

Çizelge 9. *Maksimum motor gücü, nominal motor devri ve 4 WD traktör için torkun %85'inde özgül yakıt tüketimi ile PTO gücü arasındaki ilişkinin regresyon analizi değerleri*

Specific fuel consumption (b_e) (kg/kWh) versus PTO power (P_p) (kW)				
	(R^2) (%)	(F)	P≤	The estimation equations
Linear	35.19	24.97	0.001	$b_e = 0.3214 - 0.000253P_p$
Quadratic	36.07	12.69	0.436	$b_e = 0.2448 + 0.000377P_p \quad - 0.000001(P_p)^2$
Cubic	39.45	9.56	0.124	$b_e = -0.5258 + 0.01026P_p - 0.000043(P_p)^2 + 0.000000(P_p)^3$

3.9. Relationship between specific energy and power of PTO at 85% of the torque for maximum engine power, rated engine speed and four WD tractors

When Table 10 is examined, the highest R^2 value and the lowest F value were found in the third degree equation. The lowest P value was obtained in the first degree equation and it is significant with P <0.001. Specific energy increased as the PTO power increased. It is seen in the test reports that the specific energy value increases as the PTO power increases.

Table 10. Regression analysis values of the relationship between specific energy and power of PTO at 85% of the torque for maximum engine power, rated engine speed and four WD tractors
Çizelge 10*. Maksimum motor gücü, nominal motor devri ve 4 WD traktör için torkun %85'inde özgül enerji ve PTO gücü arasındaki ilişkinin regresyon analizi değerleri*

Specific energy (E_s) (kWh/L) versus PTO power (P_p) (kW)				
	(R^2) (%)	(F)	P≤	The estimation equations
Linear	38.17	27.16	0.001	$E_s = 2.431 + 0.003364P_p$
Quadratic	38.17	13.27	0.950	$E_s = 2.323 + 0.00423P_p - 0.000002(P_p)^2$
Cubic	40.45	9.51	0.212	$E_s = 19.95 - 0.2088P_p + 0.000846(P_p)^2 - 0.000001(P_p)^3$

3.10. Relationship between engine speed and power of PTO at the standard PTO speed for four WD tractors

When Table 11 is examined, the highest R^2 and the lowest F value are found in the third degree equation. The lowest P value was obtained in the first degree equation. P value in all equations is P> 0.001. Since the difference between the first order equation and the second order equation in the R2 and F values is small and the lowest P value is in the first order equation, it is appropriate to choose the first order equation. PTO power has increased as the engine speed has increased. In the analysis of the relationship between the engine speed and the PTO power at the standard PTO speed for two WD tractors, it was found that the PTO power decreases as the engine speed increases. However, in the same analysis for 4 WD tractors, it was found that the power of the PTO increased as the engine speed increased. This may be due to the compression ratio, weight, gearbox, fuel equipment and motion transmission system differences of the tractors analyzed.

Table 11. Regression analysis values of the relationship between engine speed and power of PTO at the standard PTO speed for four WD tractors
Çizelge 11. *Dört WD traktörler için standart PTO hızında motor devri ile PTO gücü arasındaki ilişkinin regresyon analizi değerleri*

PTO power (P_p) (kW) versus engine speed (n_m) (min^{-1})				
	(R^2) (%)	(F)	P≤	The estimation equations
Linear	27.14	9.42	0.002	$P_p = -2172 + 1.134n_m$
Quadratic	29.94	9.71	0.290	$P_p = -128924 + 120n_m - 0.0281(n_m)^2$
Cubic	46.97	7.63	0.006	$P_p = 40773862 - 57636n_m + 27.16(n_m)^2 - 0.00426(n_m)^3$

3.11. Relationship between specific fuel consumption and power of PTO at the standard PTO speed for four WD tractors

When Table 12 is examined, the highest R^2 and the lowest F value are obtained in the third degree equation. The lowest P value was obtained in the first degree equation and it was found to be significant with P <0.001. The specific fuel consumption decreased as the power of the PTO increased.

Table 12. Regression analysis values of the relationship between specific fuel consumption and power of PTO at the standard PTO speed for four WD tractors
Çizelge 12. *Dört WD traktör için standart PTO hızında özgül yakıt tüketimi ile PTO gücü arasındaki ilişkinin regresyon analizi değerleri*

Specific fuel consumption (b_e) (kg/kWh) versus PTO power (P_p) (kW)				
	(R^2) (%)	(F)	P≤	The estimation equations
Linear	42.02	28.99	0.001	$b_e = 0.3348 - 0.000302P_p$
Quadratic	42.95	14.68	0.430	$b_e = 0.4597 - 0.001299P_p + 0.000002(P_p)^2$
Cubic	43.41	9.72	0.583	$b_e = -0.344 + 0.00828P_p - 0.00036(P_p)^2 + 0.000000(P_p)^3$

3.12. Relationship between specific energy and power of PTO at the standard PTO speed for four WD tractors

When Table 13 is examined, the highest R^2 and the lowest F value are found in the third degree equation. The lowest P value was obtained in the first degree equation and P <0.001 was found significant. Specific energy increased as the PTO power increased. It is seen in the test reports that the specific energy increases as thePTO power increases.

Table 13. Regression analysis values of the relationship between specific energy and power of PTO at the standard PTO speed for four WD tractors

Çizelge 13. *Dört WD traktör için standart PTO hızında PTO'nun özgül enerjisi ve gücü arasındaki ilişkinin regresyon analizi değerleri*

Specific energy (E_s) (kWh/L) versus PTO power (P_p) (kW)				
	(R^2) (%)	(F)	P≤	The estimation equations
Linear	42.39	29.43	0.001	$E_s = 2.354 + 0.003632P_p$
Quadratic	42.91	14.66	0.553	$E_s = 1.231 + 0.0126P_p - 0.000017(P_p)^2$
Cubic	43.86	9.90	0.428	$E_s = 15.14 - 0.1532P_p + 0.000633(P_p)^2 - 0.000001(P_p)^3$

3.13. Relationship between specific fuel consumption and drawbar power at 75% of the drawbar pull for maximum engine power, rated engine speed and two WD tractors

The highest R^2 and the lowest F value were obtained in the third degree equation (Table 14). P values in all equations were found to be significant with P <0.001. The highest R^2 value is 54.91%. Accordingly, 54.91% of the specific fuel consumption, which is the dependent variable, was explained by the drawbar power, which is the independent variable. It is appropriate to select the first order equation since the specification coefficient R^2, F values are close to each other in all equation types and P values are the same. The specific fuel consumption decreased as the drawbar power increased.

Table 14. Regression analysis values of the relationship between specific fuel consumption and drawbar power at 75% of the drawbar pull for maximum engine power, rated engine speed and two WD tractors

Çizelge 14. *Maksimum motor gücü, nominal motor devri ve iki WD traktör için çeki demiri çekişinin %75'inde özgül yakıt tüketimi ve çeki çubuğu gücü arasındaki ilişkinin regresyon analizi değerleri*

Specific fuel consumption (b_e) (kg/kWh) versus drawbar power (P_d) (kW)				
	(R^2) (%)	(F)	P≤	The estimation equations
Linear	49.90	4.81	0.001	$b_e = 0.4021 - 0.000867P_d$
Quadratic	53.02	4.51	0.001	$b_e = 0.4494 - 0.002030P_d + 0.000006(P_d)^2$
Cubic	54.91	4.33	0.001	$b_e = 0.5399 - 0.005318P_d + 0.000042(P_d)^2 - 0.000000(P_d)^3$

3.14. Relationship between engine speed and drawbar power at 75% of the drawbar pull for maximum engine power, rated engine speed and two WD tractors

When Table 15 is examined, the highest R^2 and the lowest F value were obtained in the first and second order equations. R^2 and F values were found close to each other in all equations. The lowest P value was obtained in the first degree equation and it was found to be significant with P <0.001. As the engine speed increases, the drawbar power decreases.

Table 15. Regression analysis values of the relationship between engine speed and drawbar power at 75% of the drawbar pull for maximum engine power, rated engine speed and two WD tractors

Çizelge 15. *Maksimum motor gücü, nominal motor devri ve iki WD traktör için çeki demiri çekişinin %75'inde motor devri ve çeki gücü arasındaki ilişkinin regresyon analizi değerleri*

Drawbar power (P_d) (kW) versus engine speed (n_m) (min^{-1})				
	(R^2) (%)	(F)	P≤	The estimation equations
Linear	17.99	2.21	0.001	$P_d = 520.2 - 0.1999n_m$
Quadratic	18.34	2.21	0.212	$P_d = 2189 - 1.703n_m + 0.000338(n_m)^2$
Cubic	18.43	2.22	0.522	$P_d = -23272 + 32.5n_m - 0.01496(n_m)^2 + 0.000002(n_m)^3$

3.15. Relationship between tractor mass and drawbar power at 75% of the drawbar pull for maximum engine power, rated engine speed and two WD tractors

When Table 16 is examined, the highest R^2 and the lowest F value are obtained in the third degree equation. P value was found to be significant with P <0.001 in the first, second and third degree equations. The largest R^2 = 89.25%. Considering the highest deetrmination coefficient, 89.25% of the change in drawbar power can be explained by the tractor mass, while 10.75% cannot be explained. According to these results, a strong relationship can be mentioned between the tractor mass and the drawbar power. As the tractor mass increases, its drawbar power has increased.

Table 16. Regression analysis values of the relationship between tractor mass and drawbar power at 75% of the drawbar pull for maximum engine power, rated engine speed and two WD tractors

Çizelge 16. *Maksimum motor gücü, nominal motor devri ve iki WD traktör için çeki demiri çekişinin %75'inde traktör kütlesi ve çeki gücü arasındaki ilişkinin regresyon analizi değerleri*

Drawbar power (P_d) (kW) versus tractor mass (m_t) (kg)				
	(R^2) (%)	(F)	P≤	The estimation equations
Linear	87.67	2.76	0.001	$P_d = -19.37 + 0.01263m_t$
Quadratic	88.93	2.43	0.001	$P_d = 21.6 + 0.002097m_t + 0.000001(m_t)^2$
Cubic	89.25	2.35	0.001	$P_d = 85.58 - 0.0229m_t + 0.000004(m_t)^2 - 0.000000(m_t)^3$

3.16. Relationship between travel speed and drawbar pull at 75% of the drawbar pull for maximum engine power, rated engine speed and two WD tractors

When Table 17 is examined, the highest R^2 and the lowest F value were found in the third degree equation. The lowest P value was obtained in the first degree equation and it was found significant with P <0.001. As the travel speed increases, the drawbar pull decreases. It is seen in the test reports that as the travel speed increases, the drawbar pull decreases.

Table 17. Regression analysis values of the relationship between travel speed and drawbar pull at 75% of the drawbar pull for maximum engine power, rated engine speed and two WD tractors

Çizelge 17. *Maksimum motor gücü, nominal motor devri ve iki WD traktör için çeki kuvvetinin %75'inde ilerleme hızı ve çeki kuvveti arasındaki ilişkinin regresyon analizi değerleri*

Drawbar pull (F_d) (kN) versus travel speed (V_t) (km/h)				
	(R^2) (%)	(F)	P≤	The estimation equations
Linear	4.32	2.21	0.001	$F_d = 59.22 - 2.865V_t$
Quadratic	5.45	2.19	0.005	$F_d = -2.75 + 11.31V_t - 0.7984(V_t)^2$
Cubic	7.44	2.12	0.079	$F_d = -572.9 + 202.6V_t - 21.89(V_t)^2 + 0.7638(V_t)^3$

3.17. Relationship between specific fuel consumption and drawbar pull at 75% of the drawbar pull for maximum engine power, rated engine speed and two WD tractors

When Table 18 is analyzed, the highest R^2 = 10.75% and the lowest F = 2.44 value were obtained in the third degree equation, the lowest P value was obtained in the first and third degree equations and it was found significant with P <0.001. It is a negative situation that the determination coefficients are low. The highest representation value of the model, R^2 = 10.75% and the other representation value, F = 2.44 were found in the third degree equation. The relationship between specific fuel consumption and drawbar pull is important. However, when looking at the highest coefficient of determination; While 10.75% of the change in specific fuel consumption can be explained by the drawbar pull, 89.25% means it cannot be explained. The hypothesis of estimating specific fuel consumption is insufficient depending on the drawbar pull. The specific fuel consumption increased as the drawbar pull increased. However, when the test reports are examined, it is seen that the specific fuel consumption decreases as the drawbar pull increases. The reason for the different results of the analysis is that 4 WD tractors can be reached at a rated engine speed of 7.5 km / h, while 2 WD tractors can be reached at rated speeds above 7.5 km / h (9-10 km / h). In the analysis made for 75% of the drawbar pull from which the nominal engine speed was obtained for two WD tractors, it seems that the specific fuel consumption increases while the drawbar pull increases due to the fact that the distribution is not at 7.5 km / h, but at higher speeds. In addition, the specific fuel consumption may have increased because 2 WD tractors have less ability to hold onto the ground compared to 4 WD tractors. In the study of

Küçüksarıyıldız (2006), 2 WD found that with the increase of drawbar pull on a tractor, the specific fuel consumption decreased. He stated that the specific fuel consumption decreased and the effect of the drawbar pull on the specific fuel consumption was important due to the fact that the increase in the drawbar pull increased the effective engine power.

Table 18. Regression analysis values of the relationship between specific fuel consumption and drawbar pull at 75% of the drawbar pull for maximum engine power, rated engine speed and two WD tractors

Çizelge 18. *Maksimum motor gücü, nominal motor devri ve iki WD traktör için çeki kuvvetinin %75'inde özgül yakıt tüketimi ve çeki kuvveti arasındaki ilişkinin regresyon analizi değerleri*

Specific fuel consumption (b_e) (kg/kWh) versus drawbar pull (F_d) (kN)				
	(R^2) %)	(F)	P≤	The estimation equations
Linear	2.79	2.50	0.001	$b_e = 0.3149 + 0.000475F_d$
Quadratic	3.77	2.65	0.054	$b_e = 0.2892 + 0.001978F_d - 0.000019(F_d)^2$
Cubic	10.75	2.44	0.001	$b_e = 0.1117 + 0.01752F_d - 0.000426(F_d)^2 + 0.000003(F_d)^3$

3.18. Relationship between travel speed and specific fuel consumption at 75% of the drawbar pull for maximum engine power, rated engine speed and two WD tractors

When Table 19 is examined, the highest R^2 value and the lowest F value are obtained in the third degree equation. The lowest P value was obtained in the second degree equation and it was found to be significant with P <0.001. It is a negative situation that the specification coefficients are low. Considering the highest (R^2 = 6.02%) determination coefficient, 6.02% of the change in specific fuel consumption can be explained by the travel speed, while 93.98% cannot be explained. The hypothesis of estimating specific fuel consumption is insufficient depending on the travel speed. However, the results of the analysis were found to be the same. Specific fuel consumption decreased as the travel speed decreased. When the test reports are examined, it is seen that the specific fuel consumption decreases as the speed of travel increases.

Table 19. Regression analysis values of the relationship between travel speed and specific fuel consumption at 75% of the drawbar pull for maximum engine power, rated engine speed and two WD tractors

Çizelge 19. *Maksimum motor gücü, nominal motor devri ve iki WD traktör için çeki kuvvetinin %75'inde ilerleme hızı ve özgül yakıt tüketimi arasındaki ilişkinin regresyon analizi değerleri*

Specific fuel consumption (b_e) (kg/kWh) versus travel speed (V_t) (km/h)				
	(R^2) (%)	(F)	P≤	The estimation equations
Linear	0.23	2.20	0.355	$b_e = 0.3482 - 0.001974V_t$
Quadratic	6.01	2.12	0.001	$b_e = 0.938 - 0.1399V_t + 0.007957(V_t)^2$
Cubic	6.02	2.05	0.861	$b_e = 1.04 - 0.1764V_t + 0.01226(V_t)^2 - 0.000167(V_t)^3$

3.19. Relationship between travel speed and specific fuel consumption at 75% of the drawbar pull for maximum engine power, rated engine speed and four WD tractors

The highest R^2 value was obtained in the third degree equation, the lowest F value and the lowest P value were obtained in the second degree equation (Table 20). P value is high in all equations and P> 0.001 was found. The highest determination coefficient is R^2 = 13.33%. While 13.33% of the change in specific fuel consumption can be explained by the travel speed, 86.67% cannot be explained. The hypothesis of estimating specific fuel consumption is insufficient depending on the travel speed. However, the results of the analysis were found to be the same as the results of the experiment. The specific fuel consumption has decreased as the travel speeed has increased. When the experiment reports are examined, it is seen that the specific fuel consumption decreases as the travel speed increases.

Table 20. Regression analysis values of the relationship between travel speed and specific fuel consumption at 75% of the drawbar pull for maximum engine power, rated engine speed and four WD tractors

Çizelge 20. *Maksimum motor gücü, nominal motor devri ve dört WD traktör için çeki kuvvetinin %75'inde ilerleme hızı ve özgül yakıt tüketimi arasındaki ilişkinin regresyon analizi değerleri*

Specific fuel consumption (b_e) (kg/kWh) versus travel speed (V_t) (km/h)				
	(R^2) (%)	(F)	P≤	The estimation equations
Linear	2.06	10.99	0.330	$b_e = 0.3257 - 0.004832V_t$
Quadratic	13.25	10.02	0.020	$b_e = 2.281 - 0.4584V_t + 0.02621(V_t)^2$
Cubic	13.33	10.38	0.850	$b_e = -0.26 + 0.419V_t - 0.0748(V_t)^2 + 0.00387(V_t)^3$

3.20. Relationship between drawbar pull and specific fuel consumption at 75% of the drawbar pull for maximum engine power, rated engine speed and four WD tractors

When Table 21 is examined, the highest R^2 value and the lowest F value are obtained in the third degree equation. The lowest P value was found as P> 0.001 in the first degree equation. The specific fuel consumption decreased as the drawbar pull increased. When the test reports are examined, it is seen that the specific fuel consumption decreases as the drawbar pull increases.

Table 21. Regression analysis values of the relationship between drawbar pull and specific fuel consumption at 75% of the drawbar pull for maximum engine power, rated engine speed and four WD tractors

Çizelge 21. *Maksimum motor gücü, nominal motor devri ve dört WD traktör için çeki kuvvetinin %75'inde çeki kuvveti ile özgül yakıt tüketimi arasındaki ilişkinin regresyon analizi değerleri*

Specific fuel consumption (b_e) (kg/kWh) versus drawbar pull (F_d) (kN)				
	(R^2) (%)	(F)	P≤	The estimation equations
Linear	17.81	9.75	0.003	$b_e = 0.3237 - 0.000437F_d$
Quadratic	19.28	5.26	0.376	$b_e = 0.2632 + 0.0009F_d - 0.000007(F_d)^2$
Cubic	20.48	3.69	0.425	$b_e = -0.0257 + 0.01066F_d - 0.000114(F_d)^2 + 0.000000(F_d)^3$

3.21.Relationship between travel speed and drawbar pull at 75% of the drawbar pull for maximum engine power, rated engine speed and four WD tractors

The highest R^2 value and the lowest F value were obtained in the third degree equation and the lowest P value was obtained in the second degree equation, and P <0.001 was found significant (Table 22). As the travel speed increases, the drawbar pull decreases. When the test reports are examined, it can be seen that the drawbar pull decreases as the speed of travel.

Table 22. Regression analysis values of the relationship between travel speed and drawbar pull at 75% of the drawbar pull for maximum engine power, rated engine speed and four WD tractors

Çizelge 22. *Maksimum motor gücü, nominal motor devri ve dört WD traktör için çeki kuvvetinin %75'inde ilerleme hızı ve çeki kuvveti arasındaki ilişkinin regresyon analizi değerleri*

Drawbar pull (F_d) (kN) versus travel speed (V_t) (km/h)				
	(R^2) (%)	(F)	P≤	The estimation equations
Linear	1.96	0.90	0.348	$F_d = 131.2 - 4.409V_t$
Quadratic	27.12	15.19	0.001	$F_d = -2659 + 643V_t - 37.4(V_t)^2$
Cubic	27.68	0.34	0.566	$F_d = 4006 - 1664V_t + 228.2(V_t)^2 - 10.17(V_t)^3$

3.22. Relationship between tractor mass and drawbar power at 75% of the drawbar pull for maximum engine power, rated engine speed and four WD tractors

While the highest R^2 value was obtained in the third degree equation, the lowest F value was obtained in the second degree equation and the lowest P value was obtained in the first degree equation (Table 23). P value was found to be significant with P <0.001. The coefficient of determination was found to be the highest R^2 = 82.27%. Considering the highest coefficient of determination, 82.27% of the change in drawbar power can be explained by the mass of the tractor, while 17.73% means it cannot be explained. According to these results, a strong relationship can be mentioned between the tractor mass and the drawbar power. As the tractor mass increases, its drawbar power has increased.

Table 23. Regression analysis values of the relationship between tractor mass and drawbar power at 75% of the drawbar pull for maximum engine power, rated engine speed and four WD tractors

Çizelge 23. *Maksimum motor gücü, nominal motor devri ve dört WD traktör için çeki kuvvetinin %75'inde traktör kütlesi ve çeki gücü arasındaki ilişkinin regresyon analizi değerleri*

Drawbar power (P_d) (kW) versus tractor mass (m_t) (kg)				
	(R^2) (%)	(F)	P≤	The estimation equations
Linear	81.56	4.73	0.001	$P_d = -83.25 + 0.01536m_t$
Quadratic	82.25	4.68	0.200	$P_d = -309.7 + 0.03762m_t - 0.000001(m_t)^2$
Cubic	82.27	4.83	0.812	$P_d = -20 - 0.0051m_t + 0.000002(m_t)^2 - 0.000000(m_t)^3$

3.23. Relationship between engine speed and drawbar power at 75% of the drawbar pull for maximum engine power, rated engine speed and four WD tractors

The highest R^2 value and the lowest P value were obtained in the third degree equation. P value was found to be P> 0.001 in all equations (Table 24). The lowest F value was obtained in the first degree equation. As the engine speed increases, the drawbar power decreases. When the test reports are examined, it is seen that the drawbar power decreases as the engine speed increases.

Table 24. Regression analysis values of the relationship between engine speed and drawbar power at 75% of the drawbar pull for maximum engine power, rated engine speed and four WD tractors

Çizelge 24. *Maksimum motor gücü, nominal motor devri ve dört WD traktör için çeki kuvvetinin %75'inde motor devri ve çeki gücü arasındaki ilişkinin regresyon analizi değerleri*

Drawbar power (P_d) (kW) versus engine speed (n_m) (min^{-1})				
	(R^2) (%)	(F)	P≤	The estimation equations
Linear	2.68	1.24	0.272	$P_d = 476.2 - 0.1195n_m$
Quadratic	19.78	5.54	0.007	$P_d = -7344 + 7.536n_m - 0.001868(n_m)^2$
Cubic	28.28	5.77	0.002	$P_d = 150617 - 219.5n_m + 0.1065(n_m)^2 - 0.000017(n_m)^3$

3.24. Relationship between specific fuel consumption and drawbar power at 75% of the drawbar pull for maximum engine power, rated engine speed and four WD tractors

The highest R^2 value and the lowest F value were obtained in the third degree equation and the lowest P value was obtained in the first and second degree equations, and it was found significant with P = 0.001 (Table 25). The specific fuel consumption decreased as the drawbar power increased. When the test reports are examined, it is seen that the specific fuel consumption decreases as the drawbar power increases.

Table 25. Regression analysis values of the relationship between specific fuel consumption and drawbar power at 75% of the drawbar pull for maximum engine power, rated engine speed and four WD tractors

Çizelge 25. *Maksimum motor gücü, nominal motor devri ve dört WD traktör için çeki kuvvetinin %75'inde özgül yakıt tüketimi ve çeki gücü arasındaki ilişkinin regresyon analizi değerleri*

Specific fuel consumption (b_e) (kg/kWh) versus drawbar power (P_d) (kW)				
	(R^2) (%)	(F)	P≤	The estimation equations
Linear	23.43	13.77	0.001	$b_e = 0.3289 - 0.000205P_d$
Quadratic	28.45	8.75	0.001	$b_e = 0.2195 + 0.000792P_d - 0.000002(P_d)^2$
Cubic	29.53	3.00	0.002	$b_e = -0.0282 + 0.004247P_d - 0.000018(P_d)^2 + 0.000000(P_d)^3$

3.2. Tractor overall efficiency

Tractor overall efficiencies were calculated for all tractors analyzed in the study. The arithmetic mean of tractor overall efficiency (η) was found as 29.04. When the tractor overall efficiency is analyzed, it is seen that there is an inverse proportion between the tractor overall efficiency and the specific fuel consumption. In general, specific fuel consumption decreases as the overall efficiency of the tractor increases. The inverse relationship between the overall efficiency of the tractor and the specific fuel consumption is an expected result.

4. Conclusions

Statistical analysis for two WD tractors both at 85% of the torque at the maximum engine power at rated engine speed and for parameters at the standard PTO speed gave the same results. Statistical analysis for four WD tractors both at 85% of the torque at the maximum engine power at rated engine speed and for parameters at the standard PTO speed gave the same results. According to the results of statistical analysis for both WD tractors at 85% of the maximum engine power torque at nominal engine speed and at the standard PTO speed, it was found that as the engine speed increases, the PTO power decreases. According to the results of the statistical analysis performed at 75% of the drawbar pull at the rated engine speed at maximum power for two WD tractors, it was found that the specific fuel consumption increased as the drawbar pull increased. The arithmetic mean of tractors overall efficiency (η) was found as 29.04.

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