Turkish Journal of Agriculture - Food Science and Technology, 10(10): 1901-1906, 2022
DOI: https://doi.org/10.24925/turjaf.v10i10.1901-1906.5394

Turkish Journal of Agriculture - Food Science and Technology

Available online, ISSN: 2148-127X | www.agrifoodscience.com | Turkish Science and Technology Publishing (TURSTEP)

Effects of Torque Rise on Lugging Ability of Tractors Equipped with Different Gear Boxes

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ARTICLE INFO

Research Article

Received : 23/07/2022
Accepted : 16/09/2022

ABSTRACT

The objective of this study was to find out the effects of torque rise on lugging ability of tractors. In British terminology, torque rise refers to torque back-up or torque reserve. Torque rise is the amount of torque that the engine can produce above the manufacturers rated amount of torque. It is the percent increase in torque, from rated torque to peak torque. In order to meet the above objective, two tractor reports issued by Nebraska Tractor Test Laboratory were used. Powertrain schemas obtained from three different tractor manufacturers were used and the total transmission ratios from these schemas were calculated. The effect of torque rise on lugging ability of the two tractors with four different gear boxes was studied. From the study, it was concluded that higher torque rise enables the tractor to run in a wide range of torque and the gear box to be chosen should be such that it can match with the engine.

Keywords:
Transmission
Powertrain
Torque back-up
Circumferential wheel force
Forward speed

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Introduction

Tractors are tested according to OECD code 2. Tests eligible for OECD approval includes compulsory and optional tests. Compulsory tests include main power take-off and five extra points for calculating fuel consumption characteristics, hydraulic power and lifting force along with the drawbar power and fuel consumption for unballasted tractors. Bohn et al. (2006) focused on a nonlinear model of a spark-ignited internal combustion engine for the design and simulation of idle speed controllers. The control inputs included the throttle command signal and the spark advance control signal. In terms of output signals, speed of the engine and the torque reserve were used. Adding the torque reserve to the set point for the basic torque ensures that the desired torque reserve is achieved under stationary conditions. Torque rise is a measure of lugging ability of a tractor and as a general rule the more torque rise, the better. Bendjedia et al. (2006) stated that a large torque reserve is required to overcome any load variation. Yet, any information about the level of torque reserve was not revealed. Kim et al. (2005) compared 926 tractors. For the comparison, the parameters such as fuel consumption, tractive coefficient and maximum torque rise were used. They found that the average torque rise was approximately 32.8% in the 1986-1990 period. The lugging ability and torque rise increased steadily for the 30-year period from 1972 through 2002. In the 2001-2002 period, the average torque rise of the tractors in a PTO power range of 37 to 75 kW was 27.7%, which was 18.4% increase in a decade. The tractors with greater PTO power than 187 kW had an average torque rise of 50.8%, being 30.9% increase over the same period.

Goering et al. (1997) developed a total engine performance monitor to display the speed, torque, power, fuel consumption, BSFC and fuel optimization efficiency (FOE). As a result of their study, de Souza and Santa Catarina (1999) concluded that the optimum working curve (OWC) provides the optimum torque-speed relation required for the design of a tractor gear selection indicator. According to Zoz et al. (2002), the ratio of drawbar horsepower to input horsepower (Power Delivery

Efficiency), as a measure of overall tractor performance is a valid parameter for making tractor comparisons. On the contrary, Sessiz et al. (2016) investigated the effects of fuels obtained by mixing canola biodiesel into diesel in different proportions on engine performance and torque rise.

Following Kim et al. (2005), there is no study conducted about the progress in torque rise in tractor engines. It is believed that the torque rise has reached higher values due to developments in engine technologies and new generation engines at present (Renius, 2020). Only the classification made for Torque rise was specified by Keçecioğlu and Gülsoylu (2005) as given in Table 1.

A tractor can be "lugged down" from rated RPM to torque peak RPM without danger of stalling, and easily pull through tough field conditions without changing gears if the tractor has sufficient torque rise. On the other hand, without torque rise, the engine would lose RPM and stall since there would be no available torque back-up as the engine is lugged below rated RPM.

Farmers have to make sure to match the tractor's rated power and torque to the job requirements if they are purchasing for a 4WD tractor. This match of rated power and torque allows the engine to get maximum fuel economy and will not be under or overloaded. The torque rise will then allow the operator to keep consistent speeds or performance if the job requirements abruptly become more demanding (Anonymous, 2009).

Gülsoylu (1995) studied the field performance of tractor-implement combinations used for soil tillage operations and determined the performance theoretically by mathematical models. Four different tractors at different power were used. He evaluated the performance of each tractor with its own gear box. Furthermore, Kim et al. (2001) analyzed the loads acting on the transmission and driving axle of an agricultural tractor during plowing operations in Korea. Some studies conducted in the past about power train in tractors such as Kim et al. (2001). Forward speed and torque parameters were studied in these studies while torque rise related studies were conducted later on. None of the studies included the effect of torque rise on tractor power train along with the use of different gear boxes. Hence, a study was conducted and the objective of this study was to demonstrate the effect of torque rise on lugging ability of tractors equipped with different gear boxes. The circumferential wheel force was assumed to be representing lugging ability of a tractor (Figure 1).

Materials and Method

A typical torque (Nm) and PTO power (kW) for a tractor engine is depicted in Figure 2.

The torque rise is calculated as in the following (Renius, 2020);

$$\text{Torque rise}=\frac{\text{Max. torque - Torque at rated rpm}}{\text{Torque at rated rpm}}\times 100 \qquad (1)$$

Two tractors at similar power used in this study were selected from Nebraska Test Laboratory archive (Anonymous, 2022) and the data for these tractors are tabulated in Table 2.

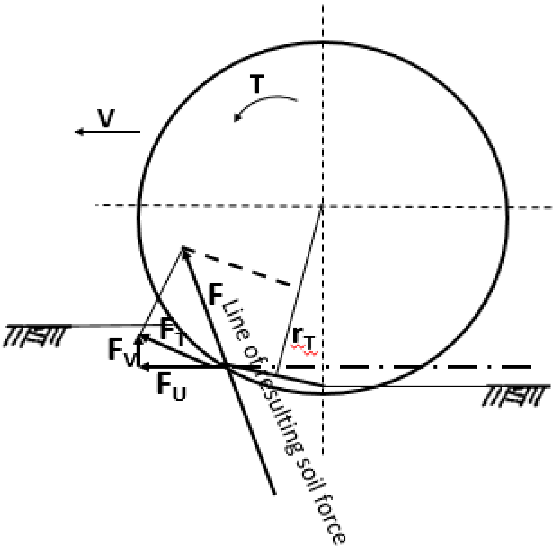

Figure 1. Forces on a tractor tire on soil surface (F_U: circumferential wheel force; V: forward speed; T: torque; F_V: vertical and F_T: resultant soil force, r_T: rolling radius)

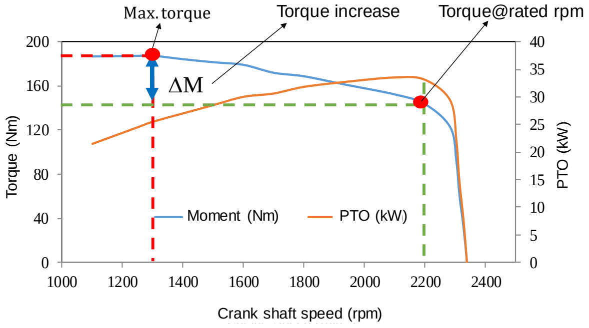

Figure 2. An example of torque and PTO power as a function of engine speed

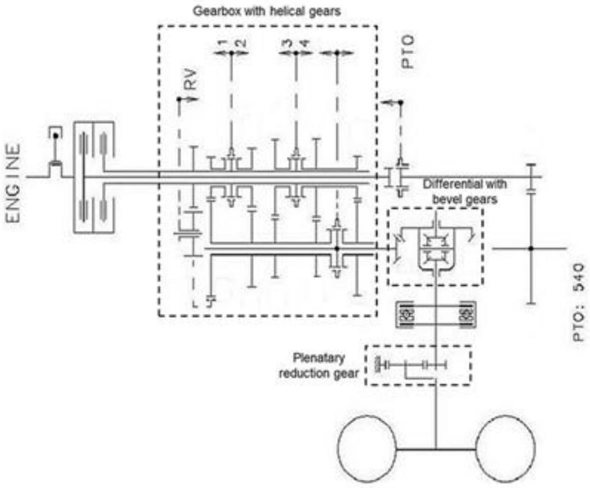

Figure 3. Schematic diagram of powertrain system of a tractor

As seen from Table 2, the maximum power for the two tractors is similar and the difference is 1.67 kW and it is at negligible level but there is a significant difference between the torque rises.

The total circumferential wheel force (Keçecioğlu and Gülsoylu, 2005) was calculated using the equation given below.

$$F_U = \frac{M_M \; i_{total} \; \eta_{trans}}{r_T} \qquad (2)$$

Where;

F_U : total circumferential wheel force (kN)
M_M : crank shaft torque (kNm)
i_{total} : total transmission ratio (-)
η_{trans} : transmission efficiency (-)
r_T : wheel radius (m)

Crank shaft torque values were attained from the tractors' test reports (Anonymous, 2022). Powertrain schemas obtained from three different tractor manufacturers were previously used in a study by Kömekçi (2014) and also used for this study and the total transmission ratios were calculated from the schemas. A typical powertrain schema regardless of transmission ratio is depicted in Figure 3. Gear boxes and total transmission values are given in Table 3. The gear efficiencies were assumed for helical gears, bevel gear and planetary reduction gear as 0.995, 0.93 and 0.98, respectively (Lechner and Naunheimer, 1999; Goering and Hansen, 2004). As an example, the N1 gear efficiency in GB-1 was calculated to be the multiplication of three helical gears, bevel gear and planetary reduction gear and the result is 0.897 (0.995 × 0.995 × 0.995 × 0.93 × 0.98). The other assumption made was the wheel radius of 0.7 m and assumed to be the same for both tractors for comparison purposes.

The forward speed of the tractor at different gear combinations (Keçecioğlu ve Gülsoylu, 2005) was calculated as in the following.

$$V_T = \frac{0{,}377 \; r_T \; n_m}{i_{total}} \qquad (3)$$

Where;

V_T : forward speed of the tractor (km h^{-1})
n_m : crank shaft speed (min^{-1})

As understood from equation 2 and 3, circumferential wheel force is governed by crank shaft torque while crank shaft speed is the main variable that determines the forward speed.

Two tractors and four different gear boxes were coupled separately in order to show the effect of torque rise on lugging ability. Forward speeds of the tractors were calculated for each gear at selected gear box.

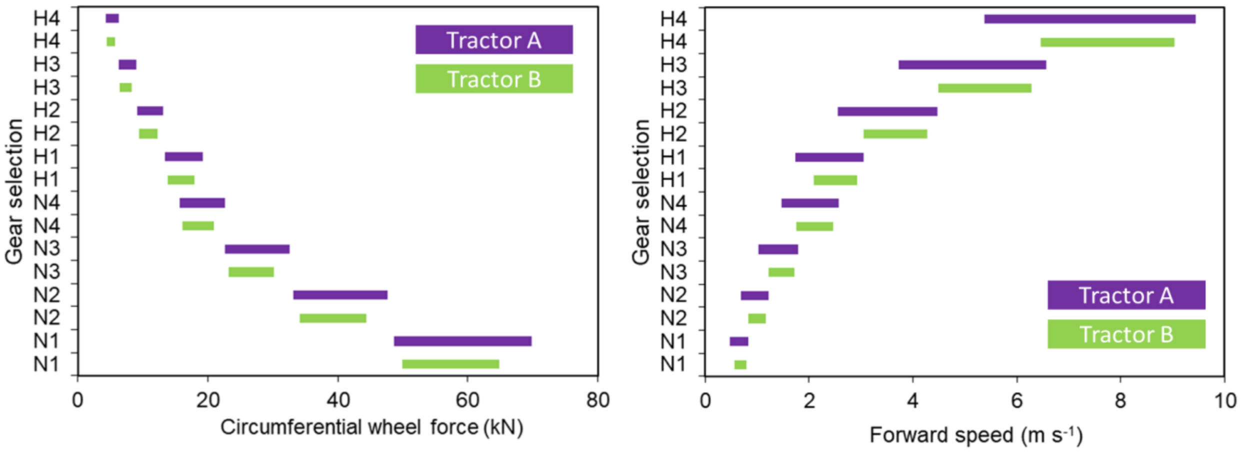

Figure 4. Circumferential wheel force and forward speed at different gear selections for the Gear Box-1 (8+2) as coupled with tractor A and B

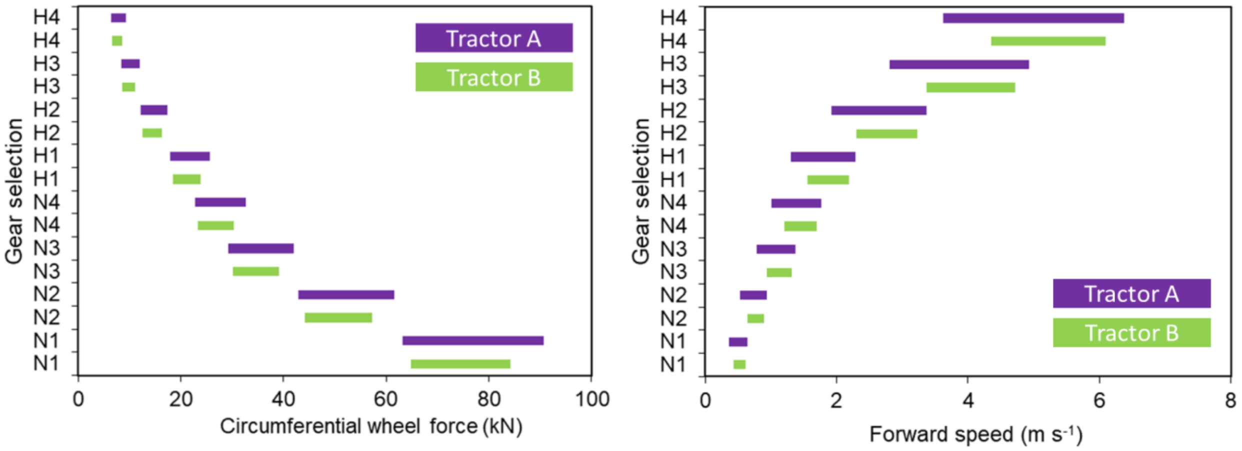

Figure 5. Circumferential wheel force and forward speed at different gear selections for the Gear Box-2 (8+2) as coupled with tractor A and B

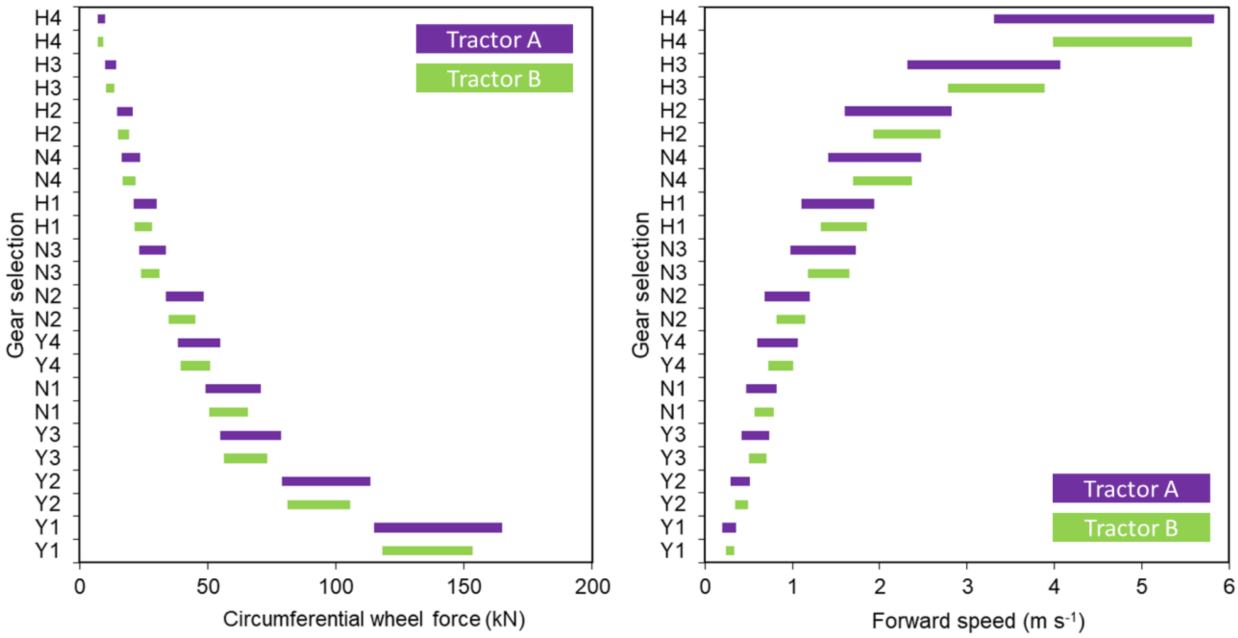

Figure 6. Circumferential wheel force and forward speed at different gear selections for the Gear Box-3 (12+12) as coupled with tractor A and B

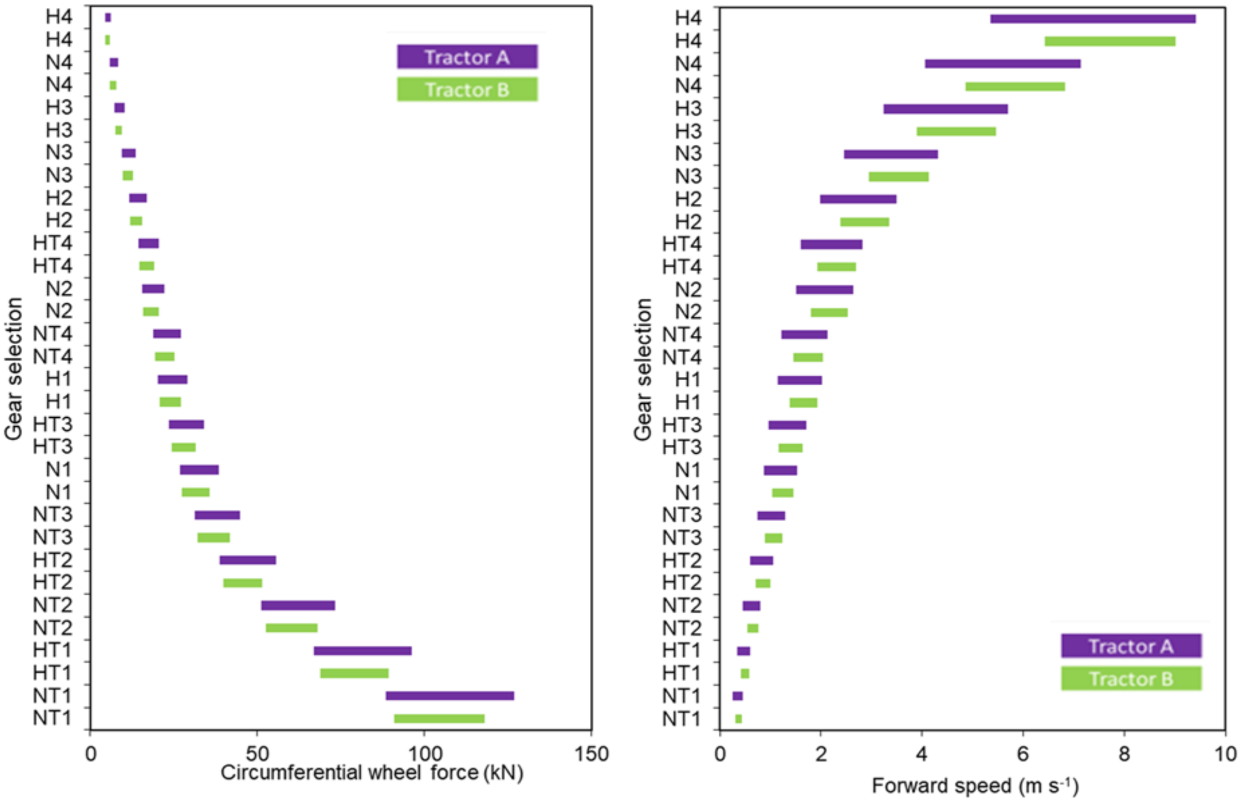

Figure 7. Circumferential wheel force and forward speed at different gear selections for the Gear Box-4 (16+8) as coupled with tractor A and B

Results and Discussion

The circumferential wheel force (kN) and forward speed (ms^{-1}) for two tractors as they are equipped with four different gear boxes are depicted in Figure 4 thru 7. The common points in four figures are such that a wider circumferential wheel force is obtained for the tractor with higher torque rise (Tractor A) with any gear box and at any gear selection. The most important issue to run the tractors effectively is that there should be no gap in terms of circumferential wheel force between two gears in appropriate operating speed. When the evaluations are made from this point of view, the followings can be written:

- For both tractors, there is no force gap between N4 and H1 in GB-1 (8+2) but there is a force gap between all other consecutive gears (Figure 4).
- There is no gap between N3-N4-H1 gears in GB-2 (8+2) in tractor A that has the higher torque rise as compared to tractor B. There is a force gap between all other consecutive gears in terms of circumferential wheel force (Figure 5).
- For tractor B coupled with GB-2 (8+2,) there is a force gap between all sequential gears. This is due to low torque rise as compared to tractor A (Figure 5).
- There is no force gap between the gears of Y3-N1-Y4-N2-N3-H1-N4-H2 in Tractor A with GB-3 (12+12) but there is a force gap between all other consecutive gears (Figure 6).
- The use of tractor B with GB-3 (12+12) results in a force gap between N2-N3 gears unlike Tractor A (Figure 6).
- High torque rises in Tractor A provided a circumferential wheel force such that there is no force gap between any sequential gears with GB-4 (16+8). On the other hand, there are force gaps between three consecutive gears in Tractor B (Figure 7).

The evaluations made for the forward speed of the tractors are as follows:

- Agricultural operations are usually conducted between 4 and 12 km h^{-1} (approximately 1 and 3.3 m s^{-1}) and these operations includes %70 of the total farm operations while transportation related duties consist of % 25 (Keçecioğlu ve Gülsoylu, 2005). The GB-1 provides speeds less than 0.5 ms^{-1} and higher than 8 ms^{-1} for both tractors. But there is no speed gap at any gear and gear box for tractor A.
- For tractor B, there are forward speed gaps at all gears except only between N4-H1 when GB-1 was used (Figure 4).
- Tractor forward speed evaluation for GB-2 indicated that any of the sequential speeds do not overlap for tractor B (Figure 5).
- For gear box GB-4, as a result of increased number of gears, the gaps between sequential gears reduced. It could be stated that the best results for tractor B were obtained when gear box 4 was used (Figure 7). Similarly, Gülsoylu (1995) found that the gaps in circumferential wheel load reduced once the number of gear selection increases.

Table 1. Classification of torque rise

Torque rise (%)	Classification
10-15	Average
15-20	Good
>20	Very good

Table 2. Some characteristics of the engines for the tractors ***(Courtesy of Nebraska Tractor Test Laboratory)***

Engine related data	Tractor A	Tractor B
Maximum torque (Nm)	282 Nm @1249min^{-1}	262 Nm @1500min^{-1}
Nominal torque (Nm)	196 Nm @2197min^{-1}	202 Nm @2102min^{-1}
Maximum power (kW)	47,53 kW @1750min^{-1}	45,86 kW @2022min^{-1}
Appropriate range for rpm	1249 min^{-1}- 2197 min^{-1}	1500 min^{-1}- 2197 min^{-1}
Torque rise (%)	43.6	30.1

Table 3. Gear boxes with gear selections and total transmission ratios

Gear Boxes (GB)											
GB-1; (8+2)*		GB-2; (8+2)*		GB-3; (12+12)*				GB-4; (16+8)*			
Gear	i_{total}**	Gear	i_{total}**	Gear	i_{total}**	Gear	i_{total}**	Gear	i_{total}**	Gear	i_{total}**
N1	175.71 [0.897]	N1	230.58 [0.888]	Y1	415.16 [0.897]	H1	75.50 [0.906]	HT1	243.08 [0.893]	NT1	321.16 [0.906]
N2	120.00 [0.897]	N2	156.59 [0.888]	Y2	285.64 [0.897]	H2	51.94 [0.906]	H1	72.73 [0.902]	N1	96.10 [0.888]
N3	81.81 [0.897]	N3	106.94 [0.888]	Y3	198.14 [0.897]	H3	36.03 [0.906]	HT2	140.28 [0.893]	NT2	185.35 [0.897]
N4	56.84 [0.897]	N4	82.79 [0.888]	Y4	138.32 [0.897]	H4	25.15 [0.906]	H2	41.9 [0.902]	N2	55.4 [0.906]
H1	47.92 [0.906]	H1	64.05 [0.906]	N1	177.75 [0.897]			HT3	85.81 [0.893]	NT3	113.38 [0.893]
H2	37.72 [0.906]	H2	43.49 [0.906]	N2	122.29 [0.897]			H3	25.67 [0.902]	N3	33.92 [0.902]
H3	23.31 [0.906]	H3	29.70 [0.906]	N3	84.83 [0.897]			HT4	51.98 [0.893]	NT4	68.68 [0.893]
H4	15.50 [0.906]	H4	22.99 [0.906]	N4	59.22 [0.897]			H4	15.55 [0.902]	N4	20.55 [0.902]

*Number of forwards + reverse gears; ** The numbers in brackets are the transmission efficiencies of the gears (η_{trans}).

The most suitable operating range of tractor engines is the range of speed at which the maximum torque is obtained and the engine speed range. Specific fuel consumption reaches the lowest values when operating in this rpm and under full load conditions.

Tractor engines with high torque rise can run in a wide torque range. Gear boxes of tractor engines with a wide range of suitable operating speed also work in a wider speed range.

Thus, it is appropriate to prefer tractor engines with a high torque rise and high difference between the rated engine speed and the engine speed at which the maximum torque is obtained. As a result, Tractor A should be preferred if a tractor will be purchased. No gaps occur when different gear boxes were selected and no gaps between forward speeds exits. If tractor B should be chosen, the best selection would be GB-4 with 16 gears.

Once the torque rise values of both tractors were evaluated based on the classification by Keçecioğlu and Gülsoylu (2005), these values are classified as very good. On the other hand, the findings in this study showed that Tractor B with a torque rise of 30.1% cannot meet the requirements of circumferential wheel force with three out of four different gear boxes. Hence, the torque rise value cannot represent the lugging performance of a tractor.

The above findings are also supported with the recommendation by de Souza and Santa Catarina (1999) since they emphasized that tractor gear selection is an important parameter for optimum working.

Conclusions

The following conclusions were drawn from the study conducted:

- As a result of comparison of two tractors with different torque rise it can be stated that the higher the torque rise the better the lugging ability.
- Higher torque rise enables the tractor to run in a wide range of torque.
- The gear box to be chosen for a tractor should be such that it matches with the engine in terms of torque rise and forward speed to obtain the desired lugging performance. Torque rise alone does not represent and give an idea about the performance of a tractor but it will allow the operator to keep consistent speeds.
- When a tractor will be built, the torque rise of the engine must be evaluated with difference gear boxes. This study revealed the information such that a tractor with a torque rise greater than 20% engine may not provide desired performance but it can be brought to an acceptable level with the use of an appropriate gear box.
- The torque rise level along with the number of gear selections are of importance in order to purchase of a tractor.

Acknowledgment

The authors gratefully acknowledge the contribution of Nebraska Tractor Test Laboratory for allowing to use the test reports to carry out this study (The necessary permission to use reports was obtained from Justin GEYER from Nebraska Tractor Test Laboratory, University of Nebraska, Lincoln). We also acknowledgment the help of Private Tractor Manufacturers for providing Powertrain schemas of the tractors.

References

Anonymous 2009. Torque rise explained. Available from: https://www.grainews.ca/news/torque-rise-explained/ [Accessed 15 September 2021]

Anonymous 2022. Tractor test reports. Available from https://tractortestlab.unl.edu/ [Accessed 22 March 2022]

Bendjedia M, Ait-Amirat Y, Walther B, Berthon A. 2006. DSP Implementation of Field Oriented control of Hybrid Stepper Motor. In: Second International Conference on Electrical Systems ICES'06 Oum El Bouaghi, Algeria, 8-10 May 2006, pp 278-281.

Bohn C, Böhme T, Staate A, Manemann P. 2006. A Nonlinear Model for Design and Simulation of Automotive Idle Speed Control Strategies. In: Proceedings of the 2006 American Control Conference Minneapolis, Minnesota, USA, 14-16 June 2006, pp 3272-3277.

De Souza EG, Santa Catarina A. 1999. Optimum working curve for diesel engines. Transactions of the ASAE, 42(3): 559-563.

Goering CE, Newman CR, Stombaugh TS, Mariman NA. 1997. Total engine performance monitor. Applied Engineering in Agriculture, 13(1):27-30.

Goering CE, Hansen AC. 2004. Engine and Tractor Power 4th Edition, American Society of Agricultural and Biological Engineers, 483p.

Gülsoylu E. 1995. A Study on Determination of Optimum Tractor and Tool Combinations Used in Soil Tillage. PhD Dissertation, Institute of Natural and Applied Sciences, Ege University, Bornova, İzmir-Türkiye.

Kim DC, Ryu IH, Kim KU. 2001. Analysis of tractor transmission and driving axle loads. Transactions of the ASAE, 44(4): 751–757

Kim KU, Bashford LL, Sampson BT. 2005. Improvement of tractor performance. Applied Engineering in Agriculture, 21(6): 949−954.

Kömekçi F. 2014. Evaluation of Power Transmission Systems of Some Domestic Tractors from the Point of Multi-Gear Speed Ratios. MSc Thesis, Institute of Natural and Applied Sciences, Ege University, Bornova, İzmir-Türkiye.

Keçecioğlu G, Gülsoylu E. 2005. Tarım Traktörleri, Ege Üniversitesi Ziraat Fakültesi, 232p.

Lechner G, Naunheimer H. 1999. Automotive Transmissions Fundamentals Selection Design and Application, Springer, Germany, 447p.

Renius KTh. 2020. Fundamentals of tractor design. Springer Nature Switzerland.

Sessiz A, Bayhan Y, Sümer SK, Erol O. 2016. Determining The Effects of Canola Biodiesel on Engine Performance and Torque Rise. In: IV Scientific Congress Agricultural Machinery Proceedings Volume 3: Engines. Vehicles. Transport Technologies, Rousse, Bulgaria, 22-25 June 2016, pp 8- 11. ISSN: 1310-3946

Zoz FM, Turner RJ, Shell LR. 2002. Power delivery efficiency: a valid measure of belt and tire tractor performance. Transactions of the ASAE, 45(3): 509–518