

Effect of tractor forward speed and type of transmission system on agricultural tractors performance under clay soil condition

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ABSTRACT

This research study was conducted at the Experimental Farm of the University of Gedarif during the season 2016/ 2017 to evaluate the effect of forward speed and type of transmission system on some performance parameters of agricultural tractors. The transmission systems used were the conventional, powershift and a combination of conventional and powershift. The tested parameters were the drawbar power, fuel consumption, field capacity and wheel slippage at three levels of speed of 5, 6 and 7 km/hr. A completely randomized block design with three replications was used to execute the experiment. The results of the experiment showed that, there was a significant difference in the drawbar power between conventional and the other two systems for the speed of 5km/hr, it gave about 20kW lower drawbar power. No significant difference between the three systems for the speeds of 6 and 7 km/hr. For the speed of 5km/hr there was no significant difference ($p \geq 0.05$) between conventional and powershift transmission systems in fuel consumption, while the combination showed the highest fuel consumption. For the speed of 6km/hr the combination showed the lowest fuel consumption. No significant difference between the three systems for the speed of 7km/hr. This referred to the variation of engine revolution per minute and the gear ratio for each type of tractor to achieve the required speeds. Regarding field capacity, there was no significant difference between the powershift and the combination systems at 5km/hr. For the speed of 6km/hr there was no significant difference between the three systems. For the speed of 7km/hr there was a significant difference between the combination and the other two systems. The combination gave the highest field capacity. The statistical analysis illustrated that there was no significant differences ($p \geq 0.05$) between the three tractors for the speed of 5km/hr and 6km/hr. No significant difference between powershift and combination tractors for the speed of 7km/hr, while there was a significant difference between the conventional and the other two systems for the speed of 7km/hr.

INTRODUCTION

A general goal of more energy efficiency encourages the use of tractors with better energy performance. Energy losses in agricultural tractors occur principally in the engine and secondarily in the transmission (Ortiz, 2005). Most field operations are carried out using the conventional small tractors (51-55kW) and the farmers overwhelming performance was Massey Ferguson tractor type particularly the MF-290. The second popular small tractor is Ford type 6000 series and later Newholland (TT75), because of the availability of spare parts and service stations. On the other hand the need for large tractors (134-155kW) for deep plowing, land leveling and pulling large combined implement were appeared for solving the problem of soil compaction, weeds control, land undulation which was lead to the reduction of crop production and machinery performance. The power generated at the engine is transmitted to the wheel drive through the power train (clutch, transmission, and final drive). The selecting gear of transmission can be engaged or disengaged mechanically (manual) or hydraulically by using electrical control modules and actuators (valves) which was called power shift.

Agricultural vehicles are essentially designed to work at low speed while providing large traction forces. Moreover, their ease of moving on uneven soil makes them suitable also for heavy trailers transportation. To ensure the maximum flexibility of use at each speed and to exploit the maximum engine power available in all working conditions, now a days agricultural vehicle are often equipped with a so-called power-shift transmission. This kind of transmission has a large number of available gears (typically from 9 to 30) and this allow to perform a gearshift with no (or at least with a minimum) loss of power from the engine to the driving wheels. Usually, a power-shift transmission is characterized by the presence of two or more- (depending on the number of gears and the overall mechanical architecture of the gearbox) wet-clutches connected to a hydraulic circuit, whose pressure can be regulated by a proportional solenoid valve. Considering the large number of gears available and the fact that an optimal gear-shift needs to manage correctly several control variables, this kind of transmission needs to be properly controlled.

Drawbar power is the useful power that produced by the traction device. It is the product of the net traction force and wheel forward velocity (Belal and Dahab, 1997). It is also defined as the power developed at the hitch of drawbar, and available for pulling, dragging, or similar tractive effort (Fred, 1996). ASAE (1983) reported that, the drawbar power is that power developed through the drive wheels or tracks to move the tractor and implement through or over the crop or soil. Drawbar power is affected by many factors such as speed, draft, engine size and soil type. Belal and Dahab (1997) reported that, the drawbar power is increased as the implement draft is increased, but it is not necessary to have a maximum power at maximum draft force. ASAE (1983) reported that the drawbar performance of tractors depends primarily on engine power, weight distribution on drive wheel, type of hitch, and soil surface. Also Belal and Dahab (1997) stated that the drawbar pull increases as the slip increases but it increases to a certain limit. Hunt (2001) stated that the drawbar power was normally 20 – 23 % less than brake power.

Fuel consumption of agricultural operations is an essential parameter for selecting appropriate machines. It is needed for developing strategies for operating machines under various field conditions. Energy used in agricultural operations depends on many factors such as soil type, soil condition, working depth, speed of operation and hitch geometry (Kepner et al. 1978). On the other hand, Lonnemark (1977) reported that fuel consumption depends upon many factors such as hour of use, size and kind of implement attached, travel speed and soil condition.

Wheel slippage is one of the most important variables in assessing the efficiency of traction and correct operation of the machine. The level of wheel slip serves as a proxy indicator of whether the right combination of tire pressures, tractor weight (ballast) and operating speed are resulting in correct traction for efficient performance and fuel savings. Further, wheel slip can determine the wear and expected lifetime of a tractor's drive train and tires. A wheel slip that is too low may be a sign that the drive train is being strained and excessive weight is being hauled. Conversely, a very high wheel slip suggests that the tires are wearing excessively and wasted rotations are likely wasting fuel. Although there are some differences in opinion regarding the most appropriate wheel slip, several sources suggest that the most optimal wheel slip range is between 8 to 15 percent. The objective of this study was to determine the effect of transmission system type and operating speed on the performance of agricultural tractors under clay soil condition.

MATERIALS AND METHODS

Experimental site:

The study was conducted at the Experimental Farm of the University of Gedarif during summer season of 2016. The soils of the area are heavy dark cracking clays (Hamdoun et. al, 1999). at a soil moisture content of 7.24% and bulk density of 1.4 g/cm³. The climate of the area is semi-arid to high rainfall savanna with hot summer and worm winter. The average temperature in the hottest April or May is 40 – 42°C. The average rainfall is 400–1000 mm which falls mainly during May to October, (July and August receive the highest quantities). The experiment was conducted at a soil moisture content of 7.24% (dry base) and bulk density of 1.4 g/cm³.

Experimental materials:

1. Three types of tractors with different transmission systems were used in this study. The transmission systems were conventional (C), powershift (PS) and combination of conventional and powershift (COMB). Some of the specifications are shown in Table (1).

Table (1) tractors specification

Item	Tractor Transmission type		
	Conventional	Powershift	Combination
Number of cylinders	6	6	6
Power (kW)	134	134	134
Fuel system	Inline	Rotary type	Inline
Front tire dimensions	16.9R28	540/65R28	16.9R28
Rear tire dimensions	20.8R38	650S/65R38	20.8R38

2. A spring pull type Dynamometer (SN2650) was used for measuring the draft force available for the tractors used in this study.
3. A plastic, 50-meters long measuring tape was used for distance measurements.
4. A cylindrical glass gauge was used for the measurement of fuel consumption.
5. Cell-phone stop watch was used to record the time required to determine the speed.
6. An auger for soil sampling for measuring moisture content and bulk density.
7. Mounted chisel plow with (11) shanks and 3m width was used to conduct the experiment of tractor performance parameters.

Experimental procedure:

The tested parameters used to evaluate the research were, drawbar power, fuel consumption, wheel slippage, and field capacity.

Drawbar power:

Two tractors were used to determine the maximum draft. The dynamometer was attached between the two tractors when the tested tractor was loaded by the implement. To evaluate the tested parameters, three different speeds were used, namely, 5, 6 and 7 km/hour.

After determining the speed and the draft at which the tractors were capable to pull the implement, the drawbar power is calculated using the following equation (Hunt, 2001):

$$DBP = \frac{S \times D}{C} \dots\dots\dots (1)$$

Where:

- DBP = Drawbar power (kW)
- S = Travel speed, (km/hr)
- D = Draft, (kN)
- C = Constant (3.6)

Fuel consumption:

- a) The tractor fuel tank was filled at the starting point of the experimental block.
- b) The tractor was moved from the started point to the end (100 m) when plowing.
- c) The time (t) required to cover the distance was recorded and the quantity of fuel (Q) required to fill the tank was measured.
- d) Then the fuel consumption was calculated as follows.

$$F.C = \frac{Q}{t} \dots\dots\dots (2)$$

Where:

- F.C = Fuel consumption (L/h)
- Q = Quantity of consumed fuel required to fill the tank (L)

T = Time (hr)

Wheel slippage:

Tractor wheel slippage was found by determining the number of tire rotations when the tractor travels over a set distance, at the working speed without load then determining the number of rotations while the tractor is under load. Then the slip was determined by the following equation:

$$\text{slip}(\%) = \frac{(\text{No of rotation with load} - \text{No of rotation without load})}{\text{No of rotation with load}} \times 100 \dots \dots \dots (3)$$

Field capacity:

The field capacity was measured by determining the time required to travel (100m) to obtain the speed. Then the field capacity was determined using the formula (Kepner et. al.1978):

$$TFC = \frac{S \times W}{C} \dots \dots \dots (4)$$

Where:

- TFC = Theoretical field capacity (ha/hour)
- S = Operating speed (km/hour)
- W = Implement width (m)
- C = Constant (10)

Experimental design:

The randomized complete block design (RCBD) with four replications (blocks) was used to execute the experiment. The block was (100m x 3m) with 1.5m spacing between blocks. three treatments were tried each with three replications. Analysis of variance was done using (MSTAT) program at 0.05 of probability level and Duncan’s Multiple Range Test (DMRT) to evaluate the different tested parameters.

RESULTS AND DISCUSSION

Drawbar power:

The means of the drawbar for the three speeds were 95.76, 106.10 and 105.10 kW for conventional, powershift and the combination systems, respectively. These values were less than the engine power by about 21%, 20% and 7%. This range was in line with Hunt (2001) for the conventional and powershift systems and over the range for the combination system. This might be attributed to the presence of two transmission systems, powershift for the range and mechanical shift for gear group. The analysis of variance showed that there was a significant difference (p ≥0.05) in the drawbar power between conventional and the other two systems for the speed of 5km/hr, it gave about 20 Kw lower drawbar power. There was no significant difference between the three systems for the speeds of 6 and 7 km/hr (Table. 2).

Table (2): Effect of Speed on drawbar (kW)

Transmission type	Speed (km/hr)
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	5	6	7
Conventional	79.80b	100.80a	106.68a
Powershift	89.04a	106.26a	122.80a
Combination	85.68a	101.85a	127.68a
Mean	84.84	102.97	119.05
C.V	2.86	2.69	9.15
L.S	5.51	6.27	24.69

Where: C.V= Coefficient of Variance, L.S= least Significant Difference

Fuel consumption:

Table. 3 shows that the means of fuel consumption for the three speeds were 22.1, 28.62 and 23.30 L/hr for conventional, powershift and combination systems, respectively. The result of fuel consumption was inline with ASABE (2011) for the combination system and near it for the conventional and powershift. The minimum fuel consumption for the conventional and the combination systems was achieved at a speed of 6 km/hr, while it was at a speed of 7 km/hr for the powershift system. The statistical analysis showed that for the speed of 5km/hr there was no significant difference between conventional and powershift transmission systems. There was a significant difference between the combination system and the other two systems; the combination showed the highest fuel consumption. For the speed of 6km/hr there was a significant difference between the three systems. Here the combination showed the lowest fuel consumption. On the other hand, there was no significant difference ($p \geq 0.05$) between the three systems for the speed of 7km/hr. This referred to the variation of engine revolution per minute and the gear ratio for each type of tractor to achieve the required speeds.

Table (3): Effect of Speed on fuel consumption (L/hour)

Transmission type	Speed (km/hr)		
	5	6	7
Conventional	25.00b	20.00b	21.33a
Powershift	25.03b	35.83a	25.00a
Combination	33.24a	10.00c	26.67a
Mean	27.76	21.94	24.33
C.V	12.85	12.96	9.89
L.S	8.09	6.07	5.45

Field capacity:

Table 4 indicates that the maximum field capacities for conventional and powershift transmission systems were achieved under the speed of 6km/h while it was at 7km/h for the combination system. The statistical analysis demonstrated that for the speed of 5km/hr there was a significant difference between the conventional and the other two systems. At 5km/hr the conventional transmission resulted in the highest field capacity. There was no significant difference between the powershift and the combination systems. For the speed of 6km/hr there was no significant difference between the three systems. For the speed of 7km/hr there was no significant difference between the conventional and powershift while there was a significant difference between the combination and the other two systems. The combination gave the highest field capacity, because less drawbar power is required to achieve the speed of 6km/hr, which was available for each tractor while speed 7km/hr requires highest drawbar power, which was more available for the tractor equipped with the combination system as shown in Fig. 3.

Table (4): Effect of Speed on theoretical field capacity (ha/hr)

Transmission type	Speed (km/hr)		
	5	6	7
Conventional	1.14b	1.44a	1.52b
Powershift	1.27a	1.56a	1.76ab
Combination	1.22a	1.46a	1.82a
Mean	1.21	1.49	1.70
C.V	2.85	3.88	8.88
L.S	0.08	0.13	0.35

Wheel slip:

Table 5 shows that the minimum wheel slip (2% and 4 %) occurred under the 7 km/hr speed for the powershift and combination systems tractors. However, it was found to be 8 % at speed of 5km/hr for the conventional system tractor .The statistical analysis illustrated that there was no significant difference between the three tractors for the speed of 5km/hr and 6km/r. No significant difference between powershift and combination tractors for the speed of 7km/hr, while there was a significant difference between the combination and the other two systems for the speed of 7km/hr. This can be attributed to the fact of availability of more drawbar power for the combination system tractor which requires more wheel slip.

Table (5): Effective of Speed on wheel slippage (%)

Transmission type	Speed			
	(km/hr)	5	6	7
Conventional		8a	10a	10a
Powershift		6a	8a	4b
Combination		10a	10a	2b
Mean		8	9.33	5.33

C.V	28.87	29.01	47.03
L.S	5.24	6.14	5.45

CONCLUSION

From the results of this work endeavor, it can be concluded that, the combination transmission systems gives more power, less fuel consumption, with minimum wheel slip comparing with the other types of transmission systems.

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