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Drawbar performance of a power tiller on a sandy loam soil of the Nadia district of West Bengal

Sujit Hensh[1], Partha Sarathi Chattopadhyay[2], Khokan Das[3]*

[1]*College of Agriculture, Extended Campus of Bidhan Chandra Krishi Viswavidyalaya, Burdwan, West Bengal, India*

[2]*Farm Machinery and Power Department, Faculty of Agricultural Engineering, Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, West Bengal, India*

[3]*John Deere India Private Limited Unit, John Deere Technology Centre Cyber City, Pune, India*

**Corresponding author: s.hensh1986@gmail.com*

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Abstract: A 9.69 kW power tiller's drawbar performance was tested by using a drawbar loading vehicle consisting of a power tiller with a mould board (MB) plough. A spring-loaded dynamometer was attached between the tested power tiller and the loading vehicle to measure the drawbar pull. The drawbar pull was changed from 0.905 kN to 2.232 kN by varying the operating depth of the MB plough. Empirical equations were developed to correlate the drawbar pull to the wheel slip, drawbar power, fuel consumption, and drawbar specific fuel consumption (DBSFC), and one was developed to correlate the drawbar power to the wheel slip. The wheel slip increased exponentially with an increase in the drawbar pull and drawbar power. A maximum wheel slippage of 48.94% was observed at a 2.232 kN drawbar pull and 0.763 kW drawbar power. A second-degree polynomial equation was found to correlate the drawbar pull to the drawbar power, fuel consumption, and DBSFC. The maximum drawbar power was found as 0.763 kW at a 2.02 kN drawbar pull, which was 7.87% of the rated engine power. The fuel consumption increased by 66.93%, and the DBSFC reduced by 10.56% due to the increase of the drawbar pull from 0.905 kN to 2.232 kN. The lowest DBSFC of 2.01 $kg \cdot kWh^{-1}$ was found at a 2.232 kN drawbar pull.

Keywords: drawbar power; drawbar pull; dynamometer; specific fuel consumption; wheel slip

A power tiller is one of the most useful machines for small and marginal farmers and for those who have small land holdings. It is also called a hand tractor, walking tractor, two-wheel tractor and single axle tractor (Paman et al. 2015). It is mainly used to prepare the land in dry and wet conditions (Tewari et al. 2004). Primarily, rotary tines attached to the power tiller are used to serve help with this process (Hensh et al. 2021). Moreover, a mould board plough and cultivator can also be attached to the power tiller to prepare the land. Apart from preparing a seed bed, it can also be used for pumping water, digging potatoes, sowing seeds, spraying pesticides, forming ridges, threshing, harvesting, transporting goods, etc. (Kumar and Kumar 2018). Hence, the use of power tillers is increased daily. In 2005, the annual sales of power tillers in India was only 17 481 units, while in 2015, it reached up to 48 000 units (Ministry of Agriculture 2015). In spite of having several benefits, power tillers have limited use for traction work because the availability of the drawbar power per brake power of the power tiller's engine is very low. The lighter weight and the use of small pneumatic tyres for traction are the main reasons for the low drawbar power (Rasool and Raheman 2018).

Several studies have already been undertaken on a drawbar performance evaluation of power till-

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ers. Alvi and Pandya (1968) evaluated the drawbar performance of a 7.46 kW power tiller. They observed the maximum drawbar power and specific fuel consumption of 1.38 kW and 1.62 kg·kWh^{-1}, respectively at 18% wheel slip. Narang and Varshney (1995) conducted the drawbar performance of a 6.71 kW power tiller on tar roads. A loading car was used for the measurement of the power tiller's draught. They found that the developed drawbar power was 0.855, 1.201 and 2.042 kW in the 2nd low, 3rd low and 1st high gears, respectively, at a wheel slip of 15% without wheel ballast at an engine speed (rpm) of 1 500·min^{-1}. The corresponding values of the specific fuel consumption were 0.83, 0.655 and 0.475 L·kWh^{-1}, respectively. The maximum drawbar pull at a rpm of 1 500·min^{-1} was recorded as 2 110 N at the 3rd low and 1st high gear. Pradhan et al. (2015) investigated the traction and drawbar performance of a power tiller attached to a five tine cultivator and cage wheel in wet and puddle soil. They concluded that, in the wet soil, a maximum drawbar power of 710.56 W was found at a drawbar pull of 1 225 N, whereas, in the puddle soil, a maximum drawbar power of 675.84 W was obtained at a drawbar pull of 1 024 N. Kathirvel et al. (2000) developed a loading car, consisting of a power transmission system and a hydraulic loading system. They evaluated the performance of a 7.46 kW power tiller with the developed loading car. They observed that the drawbar power varied from 0.30 kW to 0.65 kW and 0.20 kW to 0.50 kW in untilled and tilled soil conditions, respectively. The lowest drawbar specific fuel consumption was found as 1.1 kg·kWh^{-1}. Narang and Varshney (2006) evaluated the draught and drawbar performance of an 8.95 kW walking tractor on tilled land. A loading car with three main systems (traction system, hydraulic system and draught indicating system) was used to measure the draught of the tractor. They reported that the drawbar power at a rpm of 1 500·min^{-1} and at the 2nd low and 3rd low gear were 0.286 kW and 0.348 kW, respectively, when the draught was 748.39 and 735.22 N, respectively. The corresponding values of the specific fuel consumption were 2.056 × 10^{-3} and 1.672 × 10^{-3} m^3·kWh^{-1}, respectively.

In the above-mentioned research studies, the drawbar performance of the power tillers was evaluated by using a drawbar loading car, which was very expensive and also consisted of so many complicated systems like a hydraulic system, draught indicating system, etc. So, there was a need to develop a very simple, cost-effective drawbar loading vehicle. Hence, the present study was undertaken to develop a drawbar loading vehicle to evaluate the drawbar performance of a 9.69 kW power tiller on an untilled sandy loam soil and also to develop empirical equations for the prediction of the performance parameters.

MATERIAL AND METHODS

Development of the drawbar loading vehicle. For the power tiller's drawbar performance, a drawbar loading vehicle was developed. It consisted of a power tiller and a two bottom mould board (MB) plough. The rotary tines were removed from the power tiller. Then the MB plough was fixed to the power tiller. The drawbar load was varied by changing the cutting depth of the MB plough. To adjust the cutting depth, a depth control lever with a caster wheel was welded onto the frame of the MB plough. By rotating the lever clockwise and anti-clockwise, the operating depth was increased and decreased, respectively.

Measurement of the drawbar pull and drawbar power. The drawbar pull was measured by a spring-loaded mechanical dynamometer in a range 0–5 kN. The dynamometer was mounted in between the tested power tiller and drawbar the loading vehicle by different types of fixtures: short 'S' clamp, long 'S' clamp, 'U' clamp, 'T' clamp. The experimental set-up is shown in Figure 1. The drawbar power was calculated by multiplying the drawbar pull value by the actual forward speed of the power tiller as given in Equation (1):

$$DBP = D \times V_a \qquad (1)$$

where: DBP – the drawbar power (W); D – the drawbar pull (N); V_a – the actual forward speed (m·s^{-1}).

Measurement of the wheel slip. The wheel slip was calculated by measuring the actual forward speed (V_a) and the theoretical forward speed (V_t). It is expressed as Equations (2–4):

$$S = \left(1 - \frac{V_a}{V_t}\right) \times 100 \qquad (2)$$

$$V_a = \frac{l}{t} \qquad (3)$$

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Figure 1. Test set-up for the power tiller's drawbar performance evaluation

1 – tested power tiller; 2 – drawbar loading vehicle; 3 – spring dynamometer

$$V_t = \frac{\pi d n}{t} \quad (4)$$

where: S – the wheel slip (%); V_a – the actual forward speed ($m \cdot s^{-1}$); V_t – the theoretical forward speed ($m \cdot s^{-1}$); l – the total distance travelled (m); t – the time required to travel distance – l (s); d – the wheel diameter (m); n – the number of wheel rotations to cover distance – l.

Measurement of the fuel consumption. To measure the fuel consumption of the power tiller engine, a graduated glass cylinder with a capacity of 0.3×10^{-3} m^3 was used. The cylinder was fully filled up with diesel fuel and kept aside. At the beginning of each test run, the fuel tank of power tiller was fully filled with diesel fuel up to a particular level. Then, the power tiller was operated for a distance of 50 meters. Due to the fuel consumption of the power tiller engine for the field operation, the fuel level in the fuel tank was lowered by a certain level. The fuel tank was again filled up to the previous level by the fuel kept in the graduated cylinder. The fuel consumption was measured by subtracting the final level from the initial level of the graduated cylinder. The rate of fuel consumption (q) was calculated using the following Equation (5):

$$q = \frac{Q}{t} \times 3\,600 \quad (5)$$

where: q – the fuel consumption rate ($m^3 \cdot h^{-1}$); Q – the quantity of fuel consumed in each test run (m^3); t – the time required to travel a distance of 50 m (s).

Drawbar specific fuel consumption (*DBSFC*). The unit of the *DBSFC* is $kg \cdot kWh^{-1}$. To derive the *DBSFC* value, the fuel consumption rate (q) was first multiplied by the density of the diesel fuel 832 $kg \cdot m^{-3}$ to convert it from $m^3 \cdot h^{-1}$ to $kg \cdot h^{-1}$. Then it was divided by the drawbar power. The Equation (6) to find the *DBSFC* is shown below:

$$DPBSFC = \frac{q \rho}{DBP} \quad (6)$$

where: ρ – the density of fuel ($kg \cdot m^{-3}$); *DBP* – the drawbar power (W).

Experimental method. The experiment was conducted at the Instructional farm of Bidhan Chandra Krishi Viswavidyalaya, Nadia, West Bengal, India. The soil was a sandy loam type. The bulk density, cone index and moisture content of the soil were 1.21 $mg \cdot m^{-3}$, 1.12 MPa and 21.49%. For this experiment, two power tillers were used. For the drawbar performance test, a VST 130 DI power tiller was used (VST Tillers Tractors Ltd., India).

The specifications of the power tiller are given in Table 1, the same specifications were used to make the drawbar loading device. The tested power tiller had a total of six speeds: three low (L1, L2 and L3) and three high (H1, H2 and H3) speed settings. The power tiller was operated at the L2 gear to provide effective and efficient manoeuvrability. The engine speed was set at three quarters of a rpm of 2 $400 \cdot min^{-1}$, i.e. at rpm of 1 $800 \cdot min^{-1}$ at the beginning of each test. During the field experiment, the cutting depth of the MB plough was set at 0 mm, 30 mm, 60 mm, 90 mm, 120 mm, 150 mm and 180 mm. The corresponding drawbar loads (drawbar pull) in the spring dynamometer were 0.905 kN, 1.14 kN, 1.366 kN, 1.578 kN, 1.795 kN, 2.02 kN and 2.232 kN, respectively. At these loading conditions, the fuel consumption, forward speed, wheel slip, drawbar power and *DBSFC* were measured. The power tiller was operated over a distance of 50 m in each test run. Each test was replicated three times.

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Table 1. Specifications of the power tiller

No.	Particulars	Technical details
1	Maximum power	9.69 kW at 2 400·min^{-1}
2	Maximum torque	42 Nm at 1 600·min^{-1}
3	SFC	0.254 kg·kWh^{-1}
4	Dimensions (L×W×H)	2 720 × 865 × 1 210 mm
5	Total weight	405 kg
6	Fuel used	HSD oil
7	Fuel tank capacity	11 L
8	Number of speeds	forward – 6; reverse – 2
9	Tilling width	600 mm (maximum)
10	No. of tynes	18

SFC – specific fuel consumption

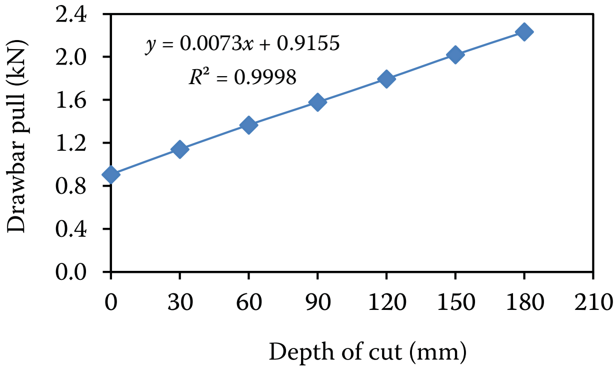

Figure 2. Relationship between the cutting depth and the drawbar pull

RESULTS AND DISCUSSION

Relationship between the drawbar pull and the cutting depth. With an increase in the cutting depth of the MB plough, the drawbar pull increased which is shown in Figure 2. From the linear regression analysis, the R^2 value was found to be 0.99. It showed a good linear correlation between the drawbar pull and the cutting depth.

Relationship between the drawbar pull and the wheel slip. The variation in the wheel slip with the drawbar pull is shown in Figure 3. With an increase in the drawbar pull, the wheel slip also increased. The traction developed at the soil-tyre interaction surface provided the required force to overcome the drawbar pull and rolling resistance. At a higher drawbar pull, the traction of the soil-tyre interaction was not able to supply the required force, which caused an increase in the wheel slippage. The same behaviour of the increasing wheel slippage with the increase in the drawbar pull was also reported by Narang and Varshney (1995), Schreiber and Kutzbach (2008). The wheel slip reached a maximum of 48.94% when the drawbar pull was 2.232 kN at a 180 mm operating depth. A regression analysis was conducted to establish the relationship between the wheel slip and the drawbar pull. An exponential relationship was found between the wheel slip and the drawbar pull. The R^2 value was derived as 0.95, which showed a good correlation between the wheel slip and the drawbar pull. A similar exponential relationship between the wheel slip and drawbar pull was also reported by Narang and Varshney (2006).

Relationship between the drawbar pull and the drawbar power. The relationship between the drawbar pull and the drawbar power is shown in Figure 3. The drawbar power increased from 0.409 kW to a maximum of 0.763 kW due to the increase in the drawbar pull from 0.905 kN to 2.232 kN. Due to the increase in the drawbar pull, more power was required to be delivered to overcome the draught

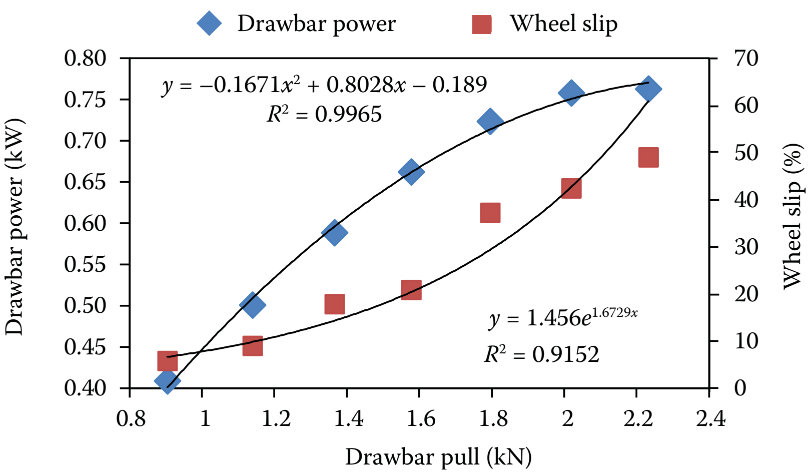

Figure 3. Effect of the drawbar pull on the drawbar power and wheel slip

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that caused the increase in the drawbar power. The same behaviour of the drawbar power with respect to the drawbar pull was also reported by Simikic et al. (2018). The maximum drawbar power was observed to be 0.763 kW, which was 7.87% of the rated engine power. Similar findings were also reported by Kathirvel et al. (2000), Pradhan et al. (2015), Narang and Varshney (2006) and Abrahám et al. (2015). For the prediction of the drawbar power with respect to the drawbar pull, a regression analysis was performed, where it was found that the second-degree polynomial regression equation fitted well with the graph with an R^2 value of 0.99.

Relationship between the drawbar pull and the fuel consumption rate. The effect of the drawbar pull on the engine's fuel consumption rate is shown in Figure 4. The power tiller's fuel consumption rate increased from 1.11×10^{-3} to 1.85×10^{-3} $m^3 \cdot h^{-1}$ with an increase in the drawbar pull from 0.905 kN to 2.232 kN. The increase in the drawbar pull demanded more fuel to be supplied to the engine to produce more engine brake horse power (BHP). Hence, the fuel consumption increased. The test results of the fuel consumption rates were in agreement with the findings of and Tiwari and Varshney (2002); Mandal et al. (2016) and Simikic et al. (2018). A polynomial regression analysis was performed to predict the fuel consumption rate of the power tiller engine at different drawbar loads, where it was found that the second-degree polynomial regression equation with an R^2 value of 0.99 predicted the fuel consumption rate closer to the measured values.

Relationship between the drawbar pull and the *DBSFC*. The effect of the drawbar pull on the DBSFC is shown in Figure 4. It was observed that the *DBSFC* decreased from 2.25 $kg \cdot kWh^{-1}$ to 2.01 $kg \cdot kWh^{-1}$ due to the increase in the drawbar pull from 0.905 kN to 2.232 kN. At a lower drawbar pull range, the fuel consumption was larger when compared to the drawbar power developed, which caused a higher *DBSFC*, whereas at higher drawbar loading conditions, the drawbar power development was more than the fuel consumption. Hence, the *DBSFC* decreased at a higher drawbar pull. This phenomenon of reducing the DBSFC with an increase in the drawbar load was also reported by Simikic et al. (2018). A regression analysis was carried out to develop an equation for the prediction of the *DBSFC* with respect to the drawbar pull, where it was found that the second-degree polynomial regression equation with an R^2 value of 0.92 could predict the dependent parameter (*DBSFC*) satisfactorily.

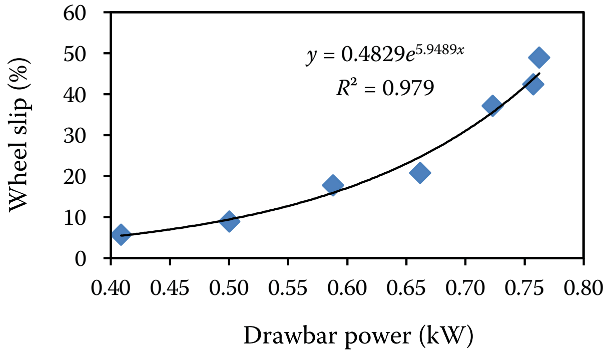

Figure 5. Relationship between the drawbar power and wheel slip

Relationship between the drawbar power and the wheel slip. The wheel slip increased from 5.71% to 48.94% with an increase in the drawbar power from 0.409 kW to 0.763 kW, which is shown in Figure 5. The drawbar power increased to increase the draught. At a higher draught, the resistance force was higher than the developed traction, so the wheel slip also increased. A regression analysis was con-

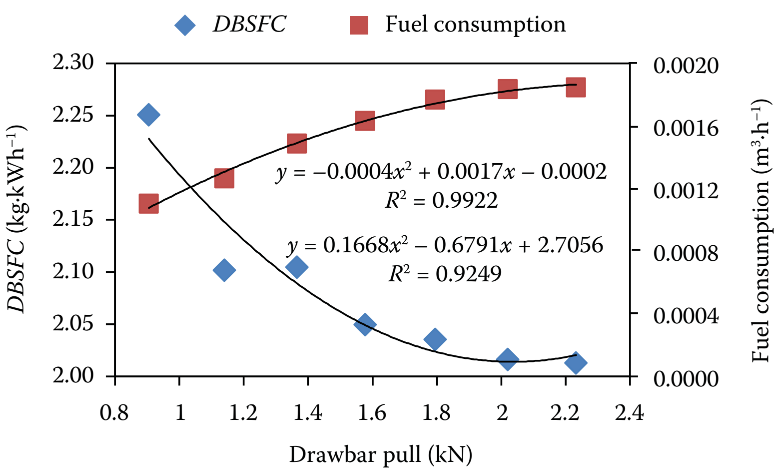

Figure 4. Effect of the drawbar pull on the *DBSFC* and fuel consumption

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ducted to establish the relationship between the drawbar power and the wheel slip. An exponential relationship was found with R^2 value of 0.98. Similar exponential relation between drawbar power and wheel slip was also reported by Narang and Varshney (2006). However, the empirical equations were valid only when the power tiller was operated with the L2 gear and a rpm of 1 800·min^{-1} engine speed setting, and within the drawbar load range of 0.905 kN to 2.232 kN.

CONCLUSION

The test results revealed that the loading vehicle's drawbar pull linearly increased with the operating depth of the MB plough. The wheel slip increased exponentially with an R^2 value of 0.95 with the drawbar pull increase. A maximum wheel slippage of 48.94% was observed at an operating depth of 180 mm when the drawbar pull was 2.232 kN. The drawbar power increased from 0.409 kW to 0.763 kW with an increase in the drawbar pull from 0.905 kN to 2.232 kN. The maximum drawbar power was found to be 7.87% of the rated engine power. The fuel consumption rate increased by 66.93%, and the *DBSFC* decreased by 10.56% when increasing the drawbar pull from 0.905 kN to 2.232 kN. The lowest *DBSFC* of 2.01 kg·kWh^{-1} was recorded at a maximum drawbar pull of 2.232 kN. Second-degree polynomial regression equations with an R^2 value of 0.99, and 0.99 and 0.92 predicted the drawbar power, fuel consumption, and *DBSFC*, respectively, with respect to the drawbar pull. An exponential relationship of the wheel slip with an R^2 value of 0.98 was found for the drawbar power.

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