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Power delivery efficiency of a wheeled tractor at oblique drawbar force

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ABSTRACT

The offset position of an implement creates an oblique drawbar force. This force occurs when the resistance direction of the implement is at a certain angle with respect to the longitudinal axis of the tractor (tractor traction direction). The focus of this study was to demonstrate the dependence of wheeled tractor power delivery efficiency on wheel slippage for central and oblique drawbar forces, both on plowed and unplowed stubble. For this purpose, the travel speed of tractor, wheel slippage, drawbar force and engine speed were measured. Mathematical models were formed using a nonlinear regression analysis, and after that, an algorithm for calculating the power delivery efficiency of wheeled tractors depending on the drawbar force and the angle of the drawbar force was developed. This method allowed us to determine the dependence of the power delivery efficiency on the wheel slippage for different angles of the drawbar force. The highest power delivery efficiency of a tractor is achieved at a central drawbar force (angle of the oblique drawbar force equals zero). Results showed the influence of oblique drawbar force on the power delivery efficiency of the wheeled tractor on soft and loose types of soil. Power delivery efficiency of the tractor on unplowed stubble decreased by 6.7% when the angle of the oblique drawbar force increased to 10 degrees, and by 15.0% when the angle of the oblique drawbar force increased to 20 degrees. On plowed stubble, power delivery efficiency decreased by 10.4% at a 10 degree angle of oblique drawbar force and by 21.9% at an angle of oblique drawbar force of 20 degrees. The importance of properly attaching the implement to the tractor was also confirmed.

1. Introduction

A tractor should overcome the work resistance of an implement using as much engine power as possible with minimum fuel consumption. Transmitting all of the engine power to the implement would be ideal; however, power losses make this impossible in practice. Those losses determine the level of engine power used by the tractor.

The primary purpose of agricultural tractors, especially those in the middle to high power ranges, is to perform drawbar work (Zoz and Grisso, 2003). According to Kathirvel et al. (2001), the ability to provide draft to pull various types of implements is a primary measure of the effectiveness of a tractor. Drawbar work is defined as moving a weight or force over some distance. The tractor's value is measured by the amount of work that can be accomplished and the cost associated with completing the task. Drawbar power is defined as the product of the actual forward velocity and the component of the drawbar force that is in the direction of the actual forward velocity. An ideal tractor would convert all fuel energy into useful work at the drawbar (drawbar power). However, due to power losses, not all fuel energy is converted into useful work (Grisso et al., 2010). In practice, most of the potential energy is lost during the conversion of chemical energy to mechanical energy, along with losses from the engine through the drive-train and finally through the tractive device (Zoz and Grisso, 2003). Literature reports indicate that approximately 20–55% of the available tractor energy is wasted at the tractive device-soil interface. This energy wears out the tires and compacts the soil to a degree that may be detrimental to crop production (Burt et al., 1983).

The combination of traction devices and the performance of the tractor drive-train greatly influence the performance of the tractor. The efficiency of a traction device is defined as the tractive efficiency, and the efficiency of an entire tractor is defined as the power delivery efficiency (Zoz et al., 2002). The efficiency of the traction system, where the traction force is transmitted onto the attached unit through the drawbar, is expressed by the power delivery efficiency of the tractor (Zoz and Grisso, 2003; Nikolić et al., 2007b). Zoz et al. (2002) analyzed the traction performances of

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wheeled and rubber belt tractors. The authors concluded that the power delivery efficiency was the best parameter for estimating and comparing tractor traction performance. The power delivery efficiency represents the ratio between drawbar power and engine power, and is, therefore, suitable for comparing different tractor types with different running systems.

Turner (2005) developed a simple instrumentation system and test procedure for measuring the power delivery efficiency of tractors during agrotechnical operations in the field. The system did not measure standard traction efficiency (on the wheel) but the power delivery efficiency of the tractor (at drawbar). The system also enabled the operator to observe the effects of changes made to the tractor to improve power delivery efficiency and gain benefits from measures undertaken.

Many researchers have focused their attention on evaluating and comparing the performances of tractors based on the power delivery efficiency (PDE). Stokes and Claar (2004) examined the efficiency of 74 front-wheel-assist agricultural tractors produced by three U.S. manufacturers. They confirmed that the power delivery efficiency increased, whereas the slippage decreased on tractors with the center-of-gravity closer to the rear axles of the tractor because more weight was distributed to the rear wheels of the tractor.

Shell et al. (1997) compared the power delivery efficiency and fuel consumption of wheeled and rubber belt tractors of similar power and mass. Six relevant factors were included: tractor configuration (rubber belt tractor and wheeled tractor), soil type (clay and sandy soil), surface (stubble and soil tilled by chisel plow at a depth of 150 mm), engine speed (two values), torque (three values) and net traction ratio (0.3, 0.4 and 0.5).

In all tests, the rubber belt tractor's power delivery efficiency exceeded that of the wheeled tractor by 2.1%. However, this percentage was higher in poor tractive conditions. Turner et al. (1997) conducted a similar research study that involved more tractors from various manufacturers. Two-wheeled tractors with dual wheels on the rear axle and two rubber belt tractors of similar power and mass were compared. Testing was conducted on tilled and untilled clay soil in South Alberta (Canada). It was concluded that for net traction ratios ranging from 0.4 to 0.5, wheeled and rubber belt tractors had almost the same power delivery efficiency. Rubber belt tractors showed their greatest benefit when operated at net traction ratio of 0.6 or higher or in soft or loose soil conditions. Rubber belt tractors of the same weight developed higher traction forces at lower slip values.

Because the majority of agrotechnical operations are performed by implements pulled by a tractor, this study focused on tractor efficiency from the aspect of traction, that is, power transmission through the drawbar (*i.e.*, power delivery efficiency). Losses and lower power delivery efficiency are influenced by three factors that are usually correlated. The first factor is the increase in slippage, which is influenced by the type and condition of the soil surface and the drive wheels, *i.e.*, the tire type and inflation pressure (Al-Hamed et al., 1994; Sümer and Sabanci, 2005; Schreiber and Kutzbah, 2008). Slippage or travel reduction occurs when the horizontal force applied to the soil by a tire or track overcomes the internal shearing strength of the soil, which results in the soil displacing and moving in the opposite direction of the vehicle motion (Turner, 1993). More contact area for the same downward pressure tends to reduce slippage for a given pull. The second factor represents insufficient drive wheel load (ballast), which prevents the realization of tractive forces. Ballast should be added to the tractor before fall tillage operations, which requires more tractor engine power to be transferred to the drawbar (Hanna et al., 2010). Therefore, the addition of ballast will provide just enough traction to transmit power to the ground without excessive wheel slippage. The optimum ballast is a compromise between wheel slippage and motion resistance (Casady, 1997). The third factor represents the way the implement is attached to the tractor. A tractor is properly connected with an implement when the resistance direction of the implement and the longitudinal axis of tractor (tractor traction direction) coincide. Otherwise, eccentric and oblique drawbar forces may occur (Stjelja, 2002). Simikić et al. (2012) concluded that eccentric drawbar force occurs when the tractor traction direction and resistance direction of the implement are parallel. Authors developed mathematical model for the prediction of power delivery efficiency and showed that increased eccentricity at the drawbar reduced power delivery efficiency of the wheeled tractor on the examined soil surfaces.

To select and match tractors with implements, it is necessary to provide information about the capacity of the tractor and the implement and the possible tractor load. Accordingly, draft requirements will vary with the implement size, soil type, speed and depth of operation. Therefore, for effective tractor-implement matching, there is a need to ascertain actual field efficiencies and draft requirements along with other indices of tractive performance (Ahaneku et al., 2011). Field machines such as tractors constitute the major portion of the total costs of mechanized crop production. The proper operation of these machines is essential for profitable agricultural production, and performance data for tractors and implements under different soil conditions are important for farmers, machinery operators and tractor manufacturers alike (Al-Suhaibani et al., 2010). Grisso et al. (2007) also considered the problem of matching tractors with drawn implements. The authors developed and demonstrated the use of spreadsheet-based predictions of tractor performance. Other researchers have also reported the use of graphical methods, templates and software programs for predicting the tractive performance of tractors. The traction model

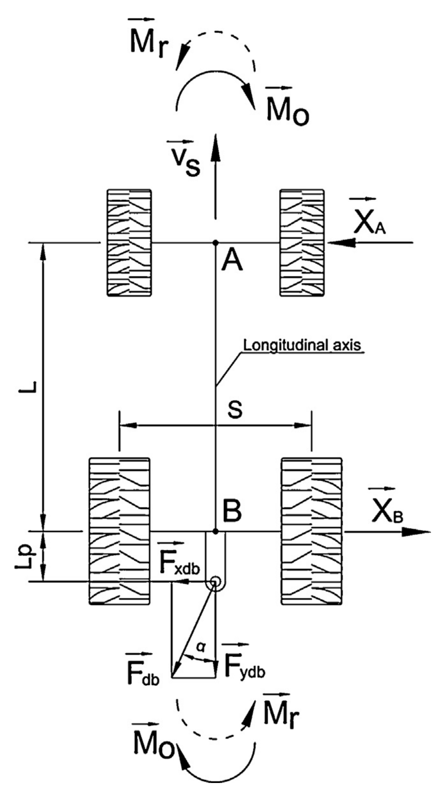

Fig. 1. Oblique offset of a wheeled tractor. Labels: L – wheelbase, L_p – distance between drawbar and tractor's rear axle, S – width of rear wheels track, $\vec{v}_s$ – actual velocity, $\vec{F}_{db}$ – oblique force on the drawbar, α – angle of oblique drawbar force, $\vec{M}_o$ – destabilizing moment, $\vec{M}_r$ – resistance moment, $\vec{X}_A$ – reactive lateral force on front wheels, $\vec{X}_B$ – reactive lateral force on rear wheels, $\vec{F}_{xdb}$ – lateral component of oblique force, $\vec{F}_{ydb}$ – longitudinal component of oblique force.