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Torque and power demand of agricultural equipment activated by power take-off

Demanda de torque e potência de implementos agrícolas acionados pela tomada de potência

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Abstract

The agricultural tractor is the main mobile energy source in rural companies, with power take-off being one of the most important uses of the energy produced by the engine. This study evaluates the torque and power demand required to activate active parts of agricultural equipment through tractor power take-off in different working conditions. For this, a boom sprayer, an atomizer, a rotary hoe, and a rotary ditcher were used. The experimental design for the sprayers was completely randomized, with working pressures of 150, 240, and 310 kPa for the boom sprayer and flow rates of 11.5, 13.0, and 22.0 L min h^{-1} for the atomizer. The randomized block experimental design, in a bi-factorial design (3 x 2), was used for the rotary hoe and rotary ditcher, with three speeds (2.10; 2.60 and 3.10 km h^{-1}) and two soil conditions for the rotary hoe (one harrowing and two harrowings) and two working depths for the rotary ditcher (0.10 m and 0.20 m). Torque and power values were obtained using a torque indicator installed between the power take-off and the universal joint shaft, which links the tractor to the equipment. From the data obtained, it was concluded that the boom sprayer demanded the highest torque and power at the highest working pressure. The rotary ditcher increased torque and power demand as speed and working depth increased.

Additional keywords: mechanized field operation; pulverization; soil preparation; torque indicator.

Resumo

O trator agrícola é a principal fonte de energia móvel nas empresas rurais, sendo a tomada de potência uma das mais importantes formas de utilização da energia produzida pelo motor. O objetivo deste trabalho foi avaliar a demanda de torque e potência necessária para acionar órgãos ativos de implementos agrícolas por meio da tomada de potência de tratores, em diferentes condições de trabalho. Para isso, foram utilizados um pulverizador de barras, um atomizador, uma enxada rotativa e uma valetadora rotativa. O delineamento experimental, para os pulverizadores, foi inteiramente casualizado, com pressões de trabalho para o pulverizador de barras (150; 240 e 310 kPa) e vazões para o atomizador (11,5; 13,0 e 22,0 L min^{-1}). O delineamento experimental, para a valetadora e enxada rotativa, foi de blocos ao acaso, em esquema bifatorial 3 x 2, sendo três velocidades (2,10; 2,60 e 3,10 km h^{-1}) e duas condições de solo para a enxada rotativa (uma gradagem e duas gradagens) e duas profundidades de trabalho para a valetadora rotativa (0,10 m e 0,20 m). Os valores de torque e potência foram coletados com o uso de um torciômetro, instalado entre a tomada de potência e a árvore com junta cardânica, que une o trator ao implemento. A partir dos dados obtidos, concluiu-se que a maior demanda de torque e potência do pulverizador de barras ocorre na maior pressão de trabalho. A demanda de torque e potência da valetadora rotativa aumenta conforme aumenta a velocidade e a profundidade de trabalho.

Palavras-chave adicionais: conjuntos mecanizados; preparo do solo; pulverização; torciômetro.

Introduction

After the emergence and popularization of the agricultural tractor in rural companies, hand tools and animal traction used in agriculture are being replaced by agricultural machines and implements driven and/or pulled by tractors. This evolution significantly reduced the physical effort and fatigue of workers, besides increasing the production capacity.

Although the largest collections of normative texts and test data address the topic of agricultural tractors (Mialhe, 1996), there is still a lack of information on performance and data related to the torque and power demand of agricultural machines and implements. According to Veit et al. (2016), the joint evaluation of a tractor is complex and time-consuming. Garay et al. (2013) affirmed that the main interest of consumers is related to the acquisition of machines properly adjusted to their reality, so that they are fully aware of technical specifications.

Thus, studies that indicate the power demand of agricultural machines and implements under different working conditions are necessary. According to Márquez (2012), experiments involving mechanized assemblies address traction demand, hydraulic lift system, hydraulic oil flow and pressure, and torque and power demand on power take-off (PTO).

The available torque in the PTO shaft is used to draw energy to active parts of agricultural machinery and implements and can be measured through a torque indicator. Fiorese et al. (2015) defined torque indicators as torque transducers, which allow torque measurement (torque moment). The most used are those in which the deformation of the torsion bar is measured by a strain gauge bridge connected to a set of slip rings and brushes (Mialhe, 1996).

In order to generate more information on the performance of agricultural machines and implements, this study evaluates the torque and power demand by active parts of agricultural implements mounted on the tractor through power take-off in different working conditions.

Material and methods

The study was conducted in two locations. In the experimental area of the Federal University of Santa Maria, municipality of Santa Maria, Rio Grande do Sul state, Brazil, the following two implements for phytosanitary treatment were evaluated: a boom sprayer and an atomizer. In a commercial crop of grains in the municipality of Restinga Seca, Rio Grande do Sul state, where the predominant soil is classified as Bruno-Acinzentado Alítico úmbrico (Embrapa, 2006), two implements for soil preparation were evaluated: a rotary hoe and a rotary ditcher.

The experimental design for boom sprayers was completely randomized, with working pressures of 150, 240, and 310 kPa for the boom sprayer and flow rates of 11.5, 13.0, and 22.0 L min h^{-1} for the atomizer. The randomized block experimental design, in a bifactorial design (3 x 2), was used for the rotary hoe and rotary ditcher, with three working speeds (2.10; 2.60 and 3.10 km h^{-1}) for both implements, two soil conditions for the rotary hoe (one harrowing and two harrowings) and two working depths for the rotary ditcher (0.10 m and 0.20 m).

For the experiments with the boom sprayer and atomizer, the Massey Ferguson tractor, model MF 6713R Dyna-4, 4x2 with auxiliary front wheel drive (FWD), six cylinders, AGCO Power engine, displaced volume of 4,400 cm^3, and engine power of 99.3 kW (135.0 hp) was used. The New Holland tractor, model T7.175 SPS, 4x2 FWD, New Holland NEF™ engine, six cylinders, displaced volume of 6,700 cm^3, and engine power of 104 kW (141.4 hp) was used to activate the implements for soil preparation. According to manufacturer information, both tractors have standardized PTOs with six and 21 gear teeth and angular speed of 540 and 1,000 rpm with electro-hydraulic system.

The boom sprayer is made by the Jacto brand, model FALCON - AM/14/75/MF/4U, series 9.900, equipped with a pump of the same brand, model JP-75, with maximum flow of 75 L min^{-1} at 540 rpm and 29 spray nozzles, model XP 015, spaced 0.50 m between nozzles, totaling 14 m of working width. The atomizer is made by the Jacto brand, model AJ-401-LH, equipped with a centrifugal pump with capacity of 120 L min^{-1}, main turbine with 3,630 rpm at 540 rpm of PTO, high density polyethylene tank with capacity of 400 L, and 18-hole nozzle in the main turbine for low volume application.

Torque and power demand were evaluated statically using the conditions "without water" in the tank and with "circulating" water as variables and application with the following three working pressures: 150, 240, and 310 kPa for the boom sprayer; and conditions "without water" in the tank and with "circulating" water as variables and application with the following flow rates: 11.5; 13.0, and 22.0 L min^{-1} for the atomizer. Thus, the experiments were conducted in a completely randomized design with five treatments and four replicates. The value used as a result of each replicate, for both boom sprayers, was the arithmetic mean of 60 torque readings.

The rotary hoe is made by the brand MEC-RUL, model ER 275, with 2.75 m of effective width, height-adjusting sliders, single transmission gear with only one speed, and adjustable rear cover. This implement consists of 66 L-type universal blades alternately distributed in 11 flanges.

The area where the experiment was conducted had been cultivated with common oats (*Avena sativa L.*), which were harvested and had their crop residues baled. After baling, half the area underwent one harrowing and the remainder underwent two harrowings using a leveling harrow made by the Tatu brand with 36 discs spaced 0.18 m between them. The expressions "one harrowing" and "two harrowings" define the soil condition variable of the experiment. The rotary hoe was adjusted to reach a working depth of up to 0.15 m.

The torque and power demand of the rotary hoe was evaluated with the following three working speeds: 2.10, 2.60, and 3.10 km h^{-1}, besides two soil conditions: soil with one harrowing, with the mobilized depth of 0.06 m and with two harrowings, with the mobilized depth of 0.09 m. Thus, the experiment was conducted in a randomized block design with seven treatments and four replicates.

The rotary ditcher is made by the brand AGRIMEC, model VA75, with a rotor surrounded by 20 L-type universal blades arranged alternately, giving a width of 0.10 m to the ditches. The equipment has height-adjusting sliders and single transmission gear, i.e., one working rotation.

The experiment area had been cultivated with intercropping of common oats (*Avena sativa L.*) and ryegrass (*Lolium multiflorum*) for beef cattle grazing. The equipment was adjusted to reach depths of 0.10 and 0.20 m, which comprised the depth variable. Data were collected in plots of length defined by the time of one minute of effective operation of the mechanized field operation. Thus, the value used as a result of the plot consisted of the arithmetic mean of a total of 60 torque readings.

The data of all experiments were collected using a calibrated Datum® torque indicator, model 310TSP, with capacity of 1,800 N m installed between the PTO and the universal joint shaft, which links the tractor to the equipment. From the data of rotation and torque available in the power take-off (PTO), obtained through the torque indicator, power values demanded by the implements from the PTO were obtained through Equation 1, described by Mialhe (1996).

$$Ppto = \frac{2\pi \times T \times n}{60{,}000} \quad (1)$$

Wherein:
Ppto - Mean power in PTO (kW);
T - Mean torque in PTO (N m);
n - Mean angular speed of PTO (rpm).

Data acquisition and storage occurred instantly through the Torquelog® software installed on a portable microcomputer. This software allows electronic communication with the torque indicator and generates a text file, which can be exported to electronic spreadsheets. The results were tabulated and submitted to analysis of variance. Means were compared using the Tukey test at 5% error probability using the SISVAR statistical program (Ferreira, 2011).

Results and discussion

Interaction between working speeds and depths was observed for the rotary ditcher and for the boom sprayer and atomizer in the working pressure and flow rate evaluation, respectively (Table 1). Interaction was not observed for the rotary hoe between speeds and working conditions (Table 1).

Table 1 - Summary of variance analysis with torque (N m) and power (kW) values for the evaluated agricultural implements: sprayer, atomizer sprayer, rotary hoe and trencher*.*

Sources of variation	Freedom degree	Mean squares	
		Torque	Power
Sprayer			
Working pressure	4	78.98	0.25
Error	3	0.39	0.001
Fc		198	186
CV (%)		3.83	3.95
Mean		16.49	0.93
Atomizer sprayer			
Vazão da calda	4	70	0.22
Error	3	0.22	0.0006
Fc		315	339
CV (%)		0.27	0.26
Mean		174	9.86
Rotary hoe			
Speed (S)	2	123320	394
Soil condition (C)	1	3.63	0.011
S x C	2	152	0.487
Error	15	1351	4.31
Fc (S x C)		0.487	0.488
CV (%)		5.90	5.90
Mean		622	35.22
Rotary ditcher			
Speed (S)	2	48660	155
Depth (D)	1	44507	142
S x D	2	2900	9.27
Error	15	414	1.32
Fc (S x D)		7.002	7.015
CV (%)		8.64	8.63
Mean		235	13.31

*Differ statistically by F test ($\rho \leq 0.05$).

The boom sprayer showed increased torque and power demand when operated at the highest working pressure (310 kPa), not differing from the pressure of 240 kPa (Table 2). The lowest torque demand was observed when the sprayer operated without water in the tank (Table 2). Ferreira et al. (2007) affirmed that a correct working pressure is fundamental for uniform application, considering that it influences the flow and the angle formed by the spray jet. Thus, adjustment of the torque requirement of the implement results in improved application quality.

Table 2 - Torque and power required to drive sprayer and atomizer sprayer pump through tractor power take-off for working conditions.

Working conditions	Sprayer		Working conditions	Atomizer sprayer	
	Torque (N m)	Power (kW)		Torque (N.m)	Power (kW)
Without water	9.45^{d*}	0.53^{d}	Without water	167.12^{c}	9.44^{c}
Circulating water	14.80^{c}	0.83^{c}	Circulating water	176.97^{a}	10.00^{a}
150 kPa	18.51^{b}	1.04^{b}	11.5 L min^{-1}	176.30^{ab}	9.97^{ab}
240 kPa	19.64^{ab}	1.11^{ab}	13.0 L min^{-1}	175.58^{b}	9.93^{b}
310 kPa	20.05^{a}	1.13^{a}	22.0 L min^{-1}	176.37^{ab}	9.97^{ab}

*Means followed by the same letter in the column do not differ between each other by Tukey test ($\rho \leq 0.05$).

The atomizer had a higher torque demand when operated with water circulating in the tank, not differing from the lowest and the highest flow rates evaluated (Table 2). As with the boom sprayer, the lowest torque demand occurred when the atomizer operated without water (Table 2). For Garcia et al. (2005), it is extremely important to know the capacity of the machines to select the power and equipment to perform agricultural operations in the adequate time, avoiding additional costs with oversized machines, which is common in some rural companies.

According to Andriolo (2017), rotary hoes are implements that allow incorporating non-commercialized crop residues and weeds uncontrolled in the previous crop to the soil. In addition, according to the author, it is recommended to adjust the working speed according to the torque demand and the amount of material to be incorporated into the soil. In these operations the tractor is commonly subjected to increased wheel slippage, fuel consumption, and traction effort because of the rigorous working conditions to which it is submitted (Salvador et al., 2008; Sichocki et al., 2013).

The absence of interaction between the parameters speed and soil conditions may have occurred due to the soil characteristics in the experimental area, as the crop residues of common oats (*Avena sativa L.*) had been baled, i.e., the soil was without vegetation cover. In addition, the first harrowing operation resulted in the initial decompaction of the soil, which may also have influenced the very low torque and power demand even with increasing working speeds. Moreover, small variations in the speeds studied can also influence results.

When interaction between factors for the rotary ditcher was analyzed, the highest torque and power demand was observed for the highest working speed (3.10 km h^{-1}) (Table 3). Furlani et al. (2008), when evaluating a seeder, also observed an increase in the tractive force and power in the bar as the speed of the mechanized field operation increased. When evaluating the interaction between depth and working speed of the rotary ditcher, higher torque and power demand by the motor was observed at the depth of 0.20 m when compared to 0.10 m for all speeds evaluated (Table 3). Depth increase contributed to increase the torque demand and reduce the effective field capacity (Machado et al., 2015).

Table 3 - Torque and power required to drive the rotary trencher blade rotor through tractor power take-off for two depths and three working speeds.

Working speed (km h^{-1})	Torque		Power	
	0.10 m	0.20 m	0.10 m	0.20 m
2.10	134.74^{bB*}	188.66^{cA}	7.61^{bB}	10.66^{cA}
2.60	163.65^{bB}	291.81^{bA}	9.25^{bB}	16.49^{bA}
3.10	278.94^{bB}	355.25^{aA}	15.76^{aB}	20.08^{aA}

*Means followed by the same lowercase letter in the column and uppercase in the row for each variable do not differ between each other by Tukey test ($\rho \leq 0.05$).

In addition, it is pertinent to emphasize that the torque of the tractor engine was measured in the PTO. Therefore, torque and power values necessary for the displacement of the mechanized field operation, traction, hydraulic system, and remote and reserve control valves were not considered to overcome possible engine overloads, which should be considered to size the mechanized field operation.

Conclusions

The highest torque and power demand by the boom sprayer occurs at the highest working pressure. For the atomizer, increased flow does not increase torque and power.

Torque and power demand of the rotary ditcher increases as speed and working depth increase.

For the sprayer and atomizer, it is recommended to adapt the torque and power demand in order to improve application quality. For equipment intended for soil preparation, it is recommended to adjust the working speed according to the torque demand and the amount of material to be incorporated into the soil.

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