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Analysis of the PTO Torque of a Transplanter by Planting Condition

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Abstract

Purpose: This study measured and analyzed the PTO (power take off) torque of a transplanter according to the planting conditions during field operation. **Methods:** A torque measurement system was constructed with torque sensors to measure the torque of a PTO shaft, a measurement device to acquire sensor signals, and a power controller to provide power for a laptop computer. The field operation was conducted at four planting distances (26, 35, 43, and 80 cm) and two planting depths using the transplanter on a field with similar soil conditions. One-way ANOVA with planting distance and Duncan's multiple range test at a significance level of 0.05 were used to analyze the PTO torque. The torque ratio was calculated based on the minimum torque using the average PTO torque measured under each planting condition. **Results:** The average torques on the PTO shaft for planting distances of 26, 35, 43, and 80 cm at a low planting depth were 11.05, 9.07, 7.04, and 3.75 Nm, respectively; the same for planting distances of 26, 35, 43, and 80 cm at a middle planting depth were 12.20, 9.86, 7.94, and 4.32 Nm, respectively. When the planting distance decreased by 43, 35, and 26 cm, the torque ratio at a low planting depth increased by 88, 142, and 195%, respectively. When the planting distance decreased by 43, 35, and 26 cm, the torque ratio at the middle planting depth increased by 84, 128, and 182%, respectively. **Conclusions:** PTO torque fluctuated by planting distance and depth. Moreover, the PTO torque increased for short planting distances. Therefore, farmers should determine the planting conditions of the transplanter by considering the load and durability of the machine. The results of this study provide useful information pertaining to the optimum PTO design of the transplanter considering the field load.

Keywords: Field operation, Planting depth, Planting distance, PTO, Torque, Transplanter

Introduction

Transplanters are used for planting operations of various crops such as beans, corn, cabbage, seeds, and broccoli. The number of transplanters has increased in many countries around the world. The worldwide market for the transplanter in 2013 was $10,650 million dollar, and in 2018 it is expected to reach $15,150 million dollar (KSAM., 2015). The market of the transplanter is expected to increase continuously.

The analysis of the torque on the PTO of a transplanter during field operations is critical for the optimum design of the transplanter. Torque analysis has been studied mostly on agricultural tractors because the agricultural tractor accounts for approximately 86% (243,351 units) of domestic agricultural machinery (Kim et al., 2011a; Kim et al., 2016). Lee et al. (2015) analyzed the PTO severeness of an agricultural tractor during rotary tillage and baler operation. The results showed that the damage of the PTO increased when the ground speed or the PTO

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rotational speed increased. Furthermore, they mentioned that the tractor PTO should be designed by considering the loading of rotary tillage and baler operation. Park et al. (2013) analyzed the load of the driving shafts of a 71-kW agricultural tractor during plow tillage at different gear levels. The sum torque of the front and rear driving axles and fuel consumption were measured and analyzed in terms of gear settings by considering the total tractor working hours and tillage depth during plow tillage. The results showed that fuel efficiency improved with a higher gear set because the higher gear set increased the tillage load but working time decreased. Therefore, the appropriate gear should be selected by considering both field performance and tillage quality during plow tillage. Kim et al. (2011b) analyzed the power requirement of an agricultural tractor for major field operations using a power measurement system. The results showed that rotary tillage required the greatest power among other operations. Kim et al. (1998) measured the transmission loads at the input shaft of a transmission gear box during each operation such as plow tillage, rotary tillage, and transportation operation. The time histories of the measured torque loads were converted into a load spectrum and analyzed with respect to the S-N curve of the shaft material to estimate the partial damages on the transmission. The results showed that the severeness during rotary tillage was approximately 59 times greater than that during plow tillage. There are several studies on the planting devices of the transplanter (Min et al., 2015; Park et al., 2005a; Park et al., 2005b); however, there is no study on the load analysis of the transplanter.

Therefore, the purpose of this study is to measure and analyze the work load of a transplanter during field operation. This study was conducted as follows: 1) development of a torque measurement system, 2) conducting field tests by planting operation condition, 3) analysis of the work torque of the transplanter during field operation.

Materials and Methods

Specification of the transplanter

Table 1 shows the specifications of the transplanter (PF2R, Yanmar, Japan) used in this study. The transplanter had a total mass of 615 kg and dimensions of 3,160 × 1,725 × 1,925 mm (length × width × height). The rated power of the transplanter was 7.1 kW at an engine revolution speed of 3,600 rpm. The transplanter was equipped with a hydro mechanical transmission and composed of two direction-gears and two main-gears.

Torque measurement system

The torque measurement system of the transplanter was constructed with torque sensors (TRS605, FUTEK Co., USA) to measure the torque of a PTO shaft as shown in

Table 1. Specification of the transplanter used in the study

Item			Specification
Length × Width × Height (mm)			3160 × 1725 × 1925
Weight (kg)			615
Engine	Rated power (kW)		7.1 @3600 rpm
Transmission	HMT (hydro mechanical transmission)	Direction gear	Forward, Backward
		Main gear	1st, 2nd

(a) Transplanter (b) Torque sensor installed on the PTO shaft

Figure 1. PTO torque measurement system of transplanter.

Figure 1, a measurement device (NI USB-6212, National instrument., USA) to acquire sensor signals, and a power controller (DP-412, DARDA, Korea) to provide power for a laptop computer. A program to acquire data was developed based on LabVIEW (Version 2011, National Instrument, USA).

Field experiment

An experiment was conducted at four planting distances and two planting depths using the transplanter on a field with similar soil conditions. The field experiment was repeated four times for each operating condition. Four planting distances (26, 35, 43, and 80 cm) were selected as representative planting distances from ten planting distances. Low planting depth (level 1) and middle planting depth (level 5) were selected to analyze the effect on the PTO torque. Gear stage 2 (0.9 m/s) level of the working speed of the transplanter was selected because farmers frequently use the transplanter at a high speed. The planting distance, depth, and work speed was determined through a survey of the transplanter users. The field experiment was conducted at a field in Seobu-ro, Okcheon, Chungbuk Province. It was located at 36°17'44.8" North and 127°33'41.4" East. The cone index (CI), depth, shearing force, moisture content, electric conductivity (EC), and temperature were analyzed following the USDA standard for upland field sites(ASABE., 2011a; ASABE., 2011b). The environmental conditions of the field showed that the average moisture content, average CI, average EC, average shearing force of the soil, average depth, and average temperature were 28.5%, 2,685 kPa, 2.4 dS/m, 20 Nm, 12 cm, and 30.3°C, respectively.

Analysis methods

The PTO torque of a transplanter according to the planting condition was measured, and the values of the average PTO torque and standard deviation along with the maximum and minimum PTO torques were analyzed. One-way ANOVA with planting distance and Duncan's multiple range test at a significance level of 0.05 were used to analyze the PTO torque. The SAS (version 9.4, SAS Institute, Cary, USA) was used for statistical analysis. The ratio was calculated based on the minimum torque using the measured average PTO torque under each planting condition. The torque ratio was used to compare the difference between the PTO torques according to the planting distance.

Results and Discussion

PTO torque during field operation at low planting depth

Figure 2 shows the representative results of the PTO shaft at four different planting distances at low planting depth. The measured torque on the PTO shaft showed regular fluctuation patterns during the planting operation. The PTO torque at the shortest planting distance (26 cm) was approximately three times greater than that at the widest planting distance (80 cm).

In addition, the transplanting duration (preparation + planting) at the shortest planting distance (26 cm) was approximately three times shorter than that at the widest planting distance (80 cm). The results showed that the PTO torque was inversely proportional to the planting distance. The PTO torque was measured frequently with increasing operating speed of planting device and decreasing planting distance.

Table 2 shows the results of torque analysis according to the planting distance at a low planting depth. The average torques on the PTO shaft for the planting distances of 26, 35, 43, and 80 cm at a low planting depth were 11.05, 9.07, 7.04, and 3.75 Nm, respectively, and the maximum torques were 31.59, 28.43, 25.64, and 23.62 Nm, respectively. Therefore, the PTO torque of the transplanter increased when the speed of the planting operation increased. The PTO torque according to the planting distance at low planting depths showed a significant difference ($p < 0.05$). The PTO torque was the highest at the

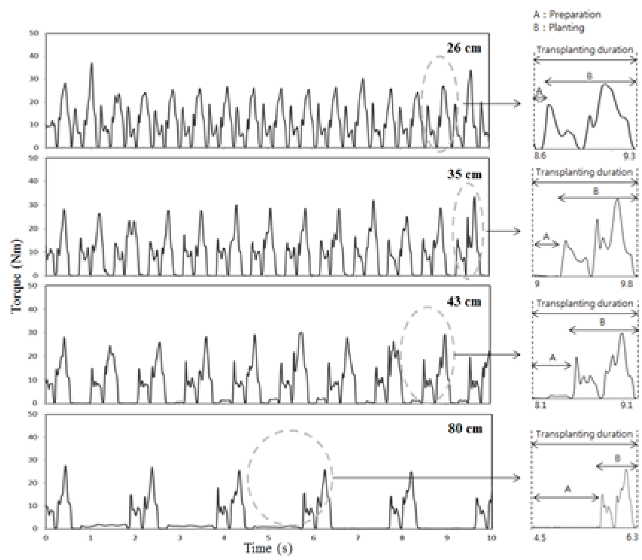

Figure 2. PTO torque of the transplanter according to planting distance at low planting depth.

Table 2. Results of torque analysis according to planting distance at low planting depth (N = 4)

Parameter	26 cm	35 cm	43 cm	80 cm
Min (Nm)	0.18	0.04	0.02	0.01
Avg Std. Dev. (Nm)	11.05 4.16a	9.07 4.91b	7.04 5.97c	3.75 4.42d
Max (Nm)	31.59	28.43	25.64	23.62

[a)]Means with different superscript (a, b, c, d) in each column are significantly different at $p < 0.05$ by Duncan's multiple range

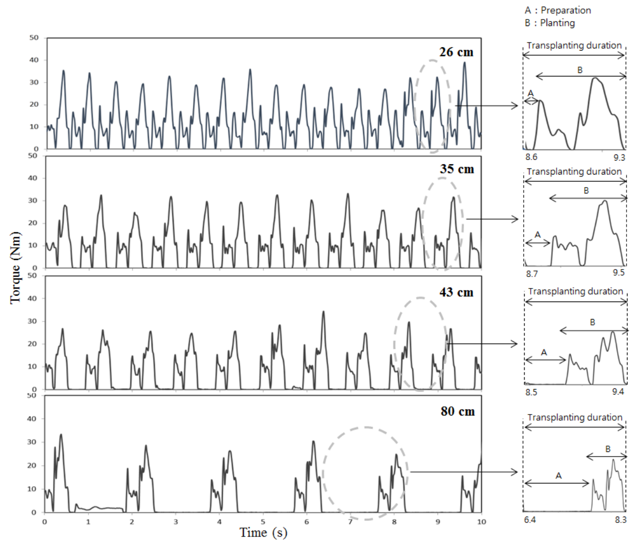

Figure 3. PTO torque of the transplanter according to planting distance at middle planting depth.

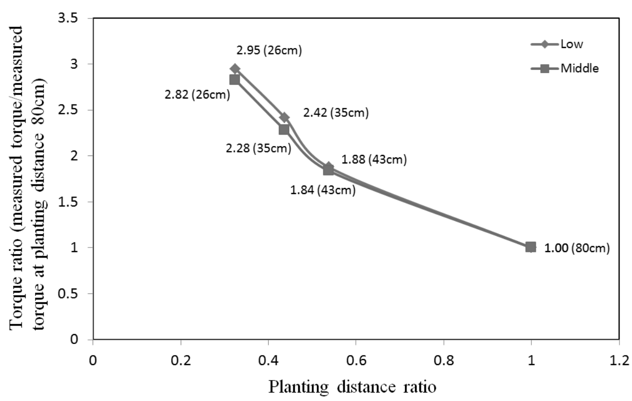

Figure 4. Relation between torque ratio and planting distance ratio in each planting depth.

lowest planting distance (26 cm), which means that the PTO torque increased with decreasing planting distance.

PTO torque during field operation at middle planting depth

Figure 3 shows the representative results of the PTO shaft torque according to four different planting distances at the middle planting depth. The measured torque on the PTO shaft at the middle planting depth showed pattern results similar to those at a low planting depth. Transplanting duration (preparation + planting) at the middle planting depth showed results similar to those at low planting depth. However, the results showed that the PTO torque at the middle planting depth was greater than that at low planting depth.

Table 3 shows the results of torque analysis according to the planting distance at middle planting depth. The average torque on the PTO shaft for planting distances of 26, 35, 43, and 80 cm at the middle planting depth were 12.20, 9.86, 7.94, and 4.32 Nm, respectively; the maximum torques were 29.48, 25.87, 26.08, and 26.13 Nm, respectively. The average torque increased when a short planting distance was selected. The PTO torque according to planting distance at the middle planting depth showed a significant difference ($p < 0.05$). The PTO torque was the highest at the lowest planting distance (26 cm). It showed results similar to those at low planting depth.

Comparison of planting condition

Figure 4 shows the torque ratio according to the planting distance ratio and planting depths (low and middle). The torque ratio was calculated according to the planting distance of 80 cm that has the minimum torque. When the planting distance decreased by 43, 35, and 26 cm, the torque ratio at low planting depths increased by 88, 142, and 195%, respectively. When the planting distance decreased by 43, 35, and 26 cm, the torque ratio at the middle planting depth increased by 84, 128, and 182%, respectively. Therefore, the PTO torque ratio increased with decreasing planting distance. It showed greater torque ratio at low planting depth than the torque ratio at middle planting depth because the PTO torque at the planting distance of 80 cm at the middle planting depth was greater than that at low planting depth.

Table 3. Results of torque analysis according to planting distance at middle planting depth (N = 4)

Parameter	26 cm	35 cm	43 cm	80 cm
Min (Nm)	0.38	0.07	0.02	0.01
Avg Std. Dev. (Nm)	12.20 4.84a	9.86 4.38b	7.94 5.23c	4.23 4.92d
Max (Nm)	29.48	25.87	26.08	26.13

[a]Means with different superscript (a, b, c, d) in each column are significantly different at $p < 0.05$ by Duncan's multiple range

Conclusions

The purpose of this study was to measure and analyze the PTO torque of a transplanter during field operation. First, a torque measurement system was constructed using torque sensors to measure the torque of a PTO shaft, a measurement device was used to acquire sensor signals, and a power controller provided power for a laptop computer. Second, field operation was conducted at four planting distances (26, 35, 43, and 80 cm) using the transplanter on a field with similar soil conditions. Finally, the PTO torque of a transplanter according to the planting condition was statistically analyzed. The average torques on the PTO shaft for planting distances of 26, 35, 43, and 80 cm at low planting depths were 11.05, 9.07, 7.04, and 3.75 Nm, respectively, and the maximum torques were 31.59, 28.43, 25.64, and 23.62 Nm, respectively. The average torques on the PTO shaft for planting distances of 26, 35, 43, and 80 cm at the middle planting depth were 12.20, 9.86, 7.94, and 4.32 Nm, respectively; the maximum torques were 29.48, 25.87, 26.08, and 26.13 Nm, respectively. When the planting distance decreased by 43, 35, and 26 cm, the torque ratio at low planting depths increased by 88, 142, and 195%, respectively. In addition, when the planting distance decreased by 43, 35, and 26 cm, the torque ratio at the middle planting depth increased by 84, 128, and 182%, respectively.

The PTO torque of the transplanter fluctuated according to the planting distance and depth. Moreover, the PTO torque increased for short planting distances. If the planting distance was excessively narrowed for increasing the production, the transplanter was damaged because of excessive torque at the working part. Therefore, farmers should determine the planting conditions of the transplanter by considering the load and durability of the machine.

The results of this study provide useful information for optimum PTO design of the transplanter by considering the field load. In addition, future studies need to provide basic data for the design of the transplanter by considering the working speed and various work conditions.

Conflict of Interest

The authors have no conflicting financial or other interests.

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