Original Article | Journal of Biosystems Engineering

J. of Biosystems Eng. 37(3):140-147. (2012. 6)
http://dx.doi.org/10.5307/JBE.2012.37.3.140

eISSN : 2234-1862
pISSN : 1738-1266

Comparison of Work Performance of Crank-type and Rotary-type Rotavators in Korean Farmland Conditions

Ju-Seok Nam[1], Dae-Sig Kang[2], Young-Sun Kang[3], Kyeong-Uk Kim[4], Dae-Cheol Kim[5]*

[1,4]*Department of Biosystems and Biomaterials Science and Engineering, Seoul National University, Seoul, Korea,* [2]*Greenmax Co., LTD., Incheon, Korea,* [3]*Tongyang Moolsan Co., LTD., Gongju, Korea,* [5]*Department of Bio-Industrial Machinery Engineering, Chonbuk National University, Jeonju, Korea*

Received: April 23th, 2012; Revised: June 20th, 2012; Accepted: June 21th, 2012

Abstract

Purpose: This study was conducted to understand the work performance of crank-type rotavators and compare them with those of rotary-type rotavators in Korean farmland conditions. **Methods:** Tillage operations were carried out using both rotavators with the same nominal rotavating width and rated power. During the operations, PTO speed and torque, actual work speed, and rotavating width and depth were measured. To evaluate work performance, pulverizing ratio, inversion ratio, and specific volumetric tilled soil were calculated and compared for each rotavator. **Results:** It is found that the crank-type rotavator has better specific volumetric tilled soil performance and deep tillage, while the pulverizing ratio is worse. **Conclusions:** Crank-type and rotary type rotavator have diffenent properties each other in several work performances. It's important, therefore, to choose a suitable type of rotavator that satisfy the farmer's requirements in accordance with the condition of field and the purpose of tillage operation.

Keywords: Crank-type, Farmland, Rotavator, Rotary-type, Work performance

Introduction

The repeated cultivation of land without fallow periods could cause damage such as poor nutrient levels in soil in rice fields or farms. Tillage operations using rotavator can reduce this side effect by improving soil drainage and air permeability, and by developing a preferred environment for helpful microorganisms (RDA, 2004).

Generally, there are two types of rotavators, one is a rotary- type-rotavator that representatively has 'C' or 'L' shaped tillage blades and 100 to 200 mm of rotavating depth. Because of a shallow rotavating depth, this type of rotavator doesn't appropriate for burying organic matters such as rice straw and several kinds of vine especially needed for Korean farmland where typically have double or triple cropping conditions. The other type of rotavator, i.e. crank-type rotavator, use equally spaced several spades as tillage blades that represent a slider of crank-slider mechanism and has a deeper rotavating depth necessary for burying organic matters. Spade operations of crank-type rotavator make it possible for the spades to penetrate deeply into the soil and easily override obstacles in the field, resulting in better operational safety, air permeability and drainage of tilled soil (Cellicorea, 2008). Therefore, it's expected that usage of crank-type rotavator has a good effect on improving crop growth in Korean farmland as similar to the study of deep tillage in Indian farmland (Vittal et al., 1983).

There were several researches about rotary-type rotavator in the country (Lee et al., 2000; Lee et al., 2003; Myung and Lee, 2009) and internationally (Ghosh, 1967; Beeny and Khoo, 1970; Salokhe et al., 1993). They include a study of the effect of several parameters such as blade

***Corresponding author:** Dae-Cheol Kim
Tel: +82-63-270-2590; **Fax:** +82-63-270-2620
E-mail: dckim12@jbnu.ac.kr

type, forward speed, number of passes, tillage depth and rotational speed of rotor shaft on operational characteristics like power or torque requirement. However there were almost no published papers studied about crank-type rotavator. In the country, just one paper exists that conducted a field test of crank- type rotavator in four different sites (NIAE, 2004).

This study was conducted to understand the work performance of crank-type rotavator in Korean farmland conditions, by tilling using crank and rotary-type of rotavators with same rated power and nominal rotavating width and by comparing the important performance parameters from the two rotavators.

Materials and Methods

Test equipments

The rotavators were powered by the same tractor to produce similar working conditions. Table 1 and Figure 1 show the specifications and configuration of the tractor used as the prime mover.

Table 2 and Figure 2 show the specifications and configurations of the test rotavators. 'C' shaped blades that require less power and torque compared to 'L' shaped blades (Beeny and Khoo, 1970; Salokhe et al., 1993) were used for the rotary-type rotavator.

Test site description

The test site was a rectangular weedy field located in Useong-myeon, Gongju-si, Korea (Figure 3). A cone penetrometer (SC 900, Spectrum Technology, E Plainfield, USA) that complies with the related standard for shape (ASAE S313.3, 2009) was used for the measurement of soil strength using a regulated test method (ASAE EP542, 2009). We measured the soil strength at different 4 locations correspond to the apexes of 10 meters square in the middle of test field, and measurement plots were 6 points below the surface at depths of 50 mm to 300 mm at 50 mm intervals. The moisture content was measured at

Figure 1. A view of the prime mover tractor.

(a) Rotary-type (b) Crank-type

Figure 2. A view of rotary- and crank-types of rotavators.

Table 1 Specifications of prime mover tractor

Item		Specification
Model/Company/Nation		T720S/Tongyang Moolsan/Korea
Weight (kN)		30.20
Length×Width×Height (mm)		4047×1970×2600
Engine	Rated power (kW) / speed (rpm)	53/2500
PTO	Transmission stage (rotational speed, rpm)	1 (563 rpm), 2 (799 rpm)

Table 2 Specifications of rotavators used for this study

Item	Specification	
	Rotary-type rotavator	Crank-type rotavator
Model/Company/Nation	GMR205HL/Greenmax/Korea	TORO2000/FLAC/Italy
Weight (kN)	5.20	8.60
Nominal rotavating width (mm)	2,000	2,000
Rated power (kW)	52	52
Nominal rotavating depth (mm)	120	350

Figure 3. A view of the experimental plot.

two different locations of 10 meters distance in the center of test field using the oven method (ASAE S526.3, 2007), and soil texture was classified by the USDA method. The cone index, moisture content, and soil texture of test site are shown in Table 3. Cone index was in the range of 526-3,089 kPa, and moisture contents were 14.1% and 16.3% at each location. Soil texture was loamy sand which is comprised of 8.4% of gravel, 82.6% of sand, 8.6% of silt, and 0.4% of clay.

Work conditions

The tillage operations have been conducted under specific gear conditions, as shown in Table 4, that represent gear ranges used in practice by many farmers for the rotary-type rotavator, and served as a reference for several possible gear ranges for the crank-type rotavator, which currently lacks experienced users. The most commonly used gear conditions of crank-type rotavator are LL3/2 and LL4/2. In the tractor gear range of LL1 to LL4, continuous work was not possible at the lower PTO gear due to stalling of the tractor engine for the crank-type rotavator. Engine speed was fixed to a rated one and the actual working distance was in the range of 10-25 m at each operation.

Measurement and analysis

For the purpose of this study, rotational speed and torque of the PTO shaft, rotavating depth and width, working speed of tractor, pulverizing ratio and inversion ratio of tilled soils were measured for both rotavators. Then the field capacity (the rotavating area per unit time), the specific volumetric tilled soil (the volume of tilled soil per unit time and power) and the PTO power were calculated from the measured data. Figure 4 is a view of the actual tillage operations of both rotavators.

The PTO torque was measured by a torque transducer comprised of a slip ring and strain gauge, and PTO speed was measured by a proximity sensor mounted on the flange of the slip ring case. Then, consumed power of the PTO shaft was calculated by:

Table 3 Soil properties of the experimental plot

Soil texture	Moisture content [d.b.] (%)	Cone index by depth (kPa)						
		Location	5 cm	10 cm	15 cm	20 cm	25 cm	30 cm
Loamy Sand	Location A: 16.3 Location B: 14.1	1	596	1,544	1,931	3,089	2,492	2,036
		2	983	983	1,123	2,041	1,790	1,615
		3	877	1,334	2,844	2,879	1,474	2,738
		4	526	1,720	2,106	2,036	2,106	1,685

Table 4 Gear of each rotavator operation

Rotavator type	Gear of Tractor/PTO	Rated working speed (km/h)
Rotary-type	L1/1	2.21
	L2/1	2.78
Crank-type	LL1/2	0.86
	LL2/2	1.08
	LL3/2	1.46
	LL4/2	1.92
	L1/1	2.21
	L1/2	2.21

(a) Rotary-type (b) Crank-type

Figure 4. Rotavator operations.

$$P=\frac{2\pi}{60000} \quad (1)$$

where P is the PTO power [kW], T is the PTO torque [Nm] and N is the PTO speed [rpm].

Rotavating depth and width were measured with a tapeline at the center of the working distance, and actual working speed was calculated using the actual travel distance and the time required for the operation by:

$$V=\frac{L}{t_r} \quad (2)$$

where V is the actual working speed [m/s], L is the rotavating distance [m] and tr is the required time [s].

The field capacity was derived from rotavating width and actual working speed by:

$$F=W\times V \quad (3)$$

where F is the field capacity [m^2/s] and W is the rotavating width [m].

The volume of tilled soil (the flow of tilled soil) was calculated using the rotavating width, rotavating depth and actual working speed by:

$$U=W\times H\times V \quad (4)$$

where U is the flow of tilled soil [m^3/s] and H is the rotavating depth [m].

The pulverizing ratio represents the capability of a rotavator to crush a lump of soil into a fine particle. It was defined as the mass of a soil sample smaller than 20 mm in diameter over the total mass of the soil sample as expressed in Eq. (5). The soil sample was collected from an 600×300 mm^2 area into the rotavating depth of each rotavator after tillage operation (NIAE, 2004). The soil sample size was classified using a 20 mm square sieve as shown in Figure 5.

Figure 5. A sieve used for separating soil particles smaller than 20 mm in diameter.

$$PR=\frac{m_a}{m_t}\times 100 \quad (5)$$

where PR is the pulverizing ratio, m_t is the total mass of the soil sample [kg] and m_a is the mass of the soil sample smaller than 2 cm in diameter [kg].

The soil inversion ratio represents the capability of the rotavator to turn the soil over, and could be measured by comparing the distribution of lime on the soil surface before and after tillage operation as expressed in Eq. (6). The limed area was 1700×1700 mm^2 (NIAE, 2004).

$$SIE=\frac{A_b-A_a}{A_b}\times 100 \quad (6)$$

where SIE is the soil inversion ratio, A_b is the limed area before rotavating [m^2] and A_a is the limed area after rotavating [m^2].

Results and Discussion

Rotavating speed, rotavating depth and width, field capacity, and flow of tilled soil

Table 5 shows the tillage characteristics related to the measured and calculated results of each rotavator. The rotavating depth and width were 130 mm and 2,070 mm, respectively, for the rotary-type rotavator; and 250-280 mm and 1,920 mm, respectively, for the depth and width of the crank- type rotavator. The measured rotavating depth and width were larger than the nominal value for the rotary-type rotavator, but smaller than nominal value for the crank-type rotavator. For the rotavating depth, the differences between measured and nominal values were larger for the crank-type rotavator, which showed a maximum of 100 mm. During the tillage operation, the crank-type rotavator may have had a large amount of friction against the soil because of its unique operational characteristics such as the shoveling effect of the spade type tillage blade, so it can be expected that the fluctuation of the rotavating depth would be larger for the crank-type rotavator in accordance with deviations in soil strength.

The actual working speed was lower than nominal for most work conditions of both rotavators, and showed a slip of 4-23%, except for tractor gears LL1 and L1 of the crank- type rotavator. The exceptions may have come from the skid effect where the spades of the rotavator push the tractor forward.

The actual field capacity improved as the actual working speed increased for both rotavators. The volume of tilled soil, however, was changed irregularly according to the rotavating depth, rotavating width, and actual working speed.

PTO power and torque

Power ratio (consumed PTO power over rated power of the tractor) and PTO torque were plotted. Figure 6 and 7 show a graph for both rotavators, and Table 6 shows the measured results for all work conditions.

In the most commonly used gear conditions (L1/1 and L2/1 for the rotary-type rotavator and LL3/2 and LL4/2 for the crank-type), the average power and torque of the PTO shaft were 37.5 kW and 760 Nm, respectively, for the rotary-type rotavator; and 35 kW and 465 Nm, respectively, for the crank-type. Standard deviation of PTO power and torque were larger in the crank-type rotavator than in the rotary-type, which could come from the unique operational characteristics of the crank-type rotavator as mentioned above. The specific volumetric tilled soil increased as the actual working speed was higher for both rotavators, but it could decrease over certain actual working speed values since consumed power is generally proportional to the square of the actual working speed (ASAE D497.7, 2011). At the same gear condition L1/1, the crank-type rotavator had larger specific volumetric tilled soil than the rotary-type. Considering some deviations in soil strength and unexpected effects, the power and torque values of each gear conditions generally follow the known trends (Ghosh, 1967; Salokhe et al., 1993); the torque proportional to working speed and inversely proportional to PTO speed, the power proportional to working speed.

Table 5 Work performance of rotavators measured at the experimental plot

Rotavator type	Gear of Tractor/PTO	Actual working speed (km/h)	Rotavating depth (mm)	Rotavating width (mm)	Actual field capacity (ha/h)	Volume of tilled soil (m3/h)
Rotary-type	L1/1	1.91	130	2,070	0.40	513.98
	L2/1	2.35	130	2,070	0.49	632.39
Crank-type	LL1/2	0.98	250	1,920	0.19	470.40
	LL2/2	0.84	250	1,920	0.16	403.20
	LL3/2	1.38	280	1,920	0.27	741.89
	LL4/2	1.69	280	1,920	0.32	908.54
	L1/1	2.30	260	1,920	0.44	1148.16
	L1/2	1.92	250	1,920	0.37	921.60

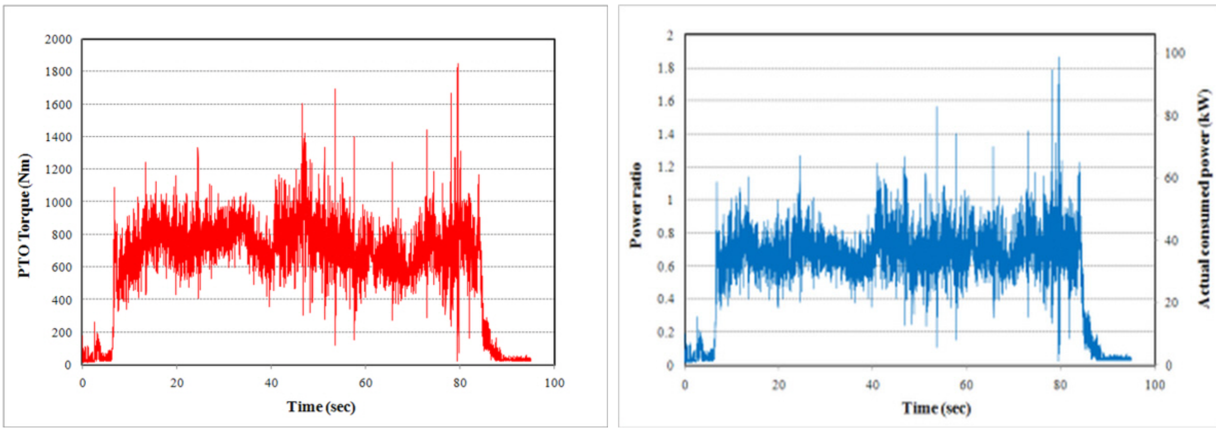

Figure 6. PTO power and torque transmitted to rotary-type rotavator with gear L1/1.

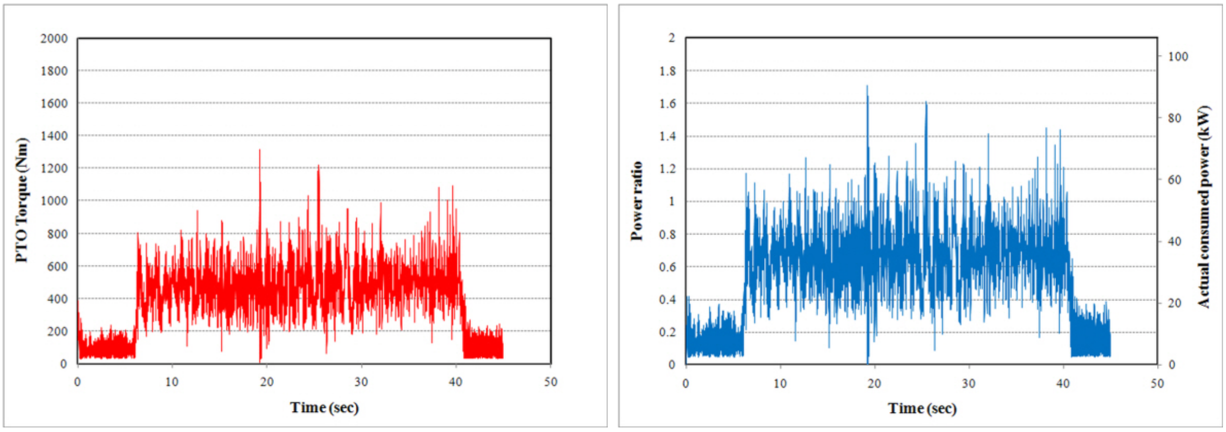

Figure 7. PTO power and torque transmitted to the crank-type rotavator with gear LL4/2.

Table 6 PTO output power and torque during rotavating operations

Rotavator type	Gear of Tractor/PTO	PTO output power (kW)	PTO output torque (Nm)	Specific volumetric tilled soil (m^3/kWh)
Rotary-type	L1/1	36.75 ± 6.96	741.93 ± 146.95	13.98
	L2/1	38.30 ± 6.65	778.42 ± 142.05	16.51
Crank-type	LL1/2	24.92 ± 12.90	321.18 ± 169.32	18.87
	LL2/2	24.61 ± 13.43	314.21 ± 174.52	16.38
	LL3/2	34.41 ± 14.08	445.08 ± 186.29	20.00
	LL4/2	35.62 ± 10.51	485.01 ± 145.29	25.51
	L1/1	34.10 ± 10.27	629.21 ± 189.73	33.67
	L1/2	37.33 ± 11.66	561.52 ± 176.19	24.69

The pulverizing ratio and soil inversion ratio

Table 7 shows the pulverizing ratio and inversion ratio of both rotavators. The rotary-type rotavator has a better pulverizing ratio in the 83-91% range than the crank-type which shows 57-80% range of pulverizing ratio (Figure 8). Also, the pulverizing ratio improved as the PTO speed increased and the actual working speed decreased within the same type of rotavator. The inversion ratio didn't show meaningful difference between both rotavators; there was a 100% inversion ratio in all cases except for the crank-type rotavator with gear L1/1.

Table 7 Pulverizing and inversion ratios by rotary- and crank-type rotavators

Rotavator type	Gear of Tractor/PTO	Pulverizing ratio (%)	Inversion ratio (%)
Rotary-type	L1/1	91.51	100
	L2/1	83.44	100
Crank-type	LL1/2	76.44	100
	LL2/2	80.48	100
	LL3/2	75.72	100
	LL4/2	64.09	100
	L1/1	57.58	80
	L1/2	62.17	100

(a) Rotary-type (b) Crank-type

Figure 8. Soil pulverized by different rotavator types.

Conclusions

In this study, tillage operation was conducted using crank- and rotary-type rotavators that had the same nominal rotavating width and rated power. The test site was a weedy field located in Useong-myeon, Gongju-si, Korea, and the soil texture was loamy sand.

The field was tilled using the both rotavators on the same prime mover tractor under several gear conditions. The most commonly used gear ranges by Korean farmers are L1/1 and L2/1 for rotary-type rotavators, and LL3/2 and LL4/2 for crank-type rotavators. During rotavating, several elements such as PTO speed and torque, rotavating depth and width, actual working speed, field capacity, specific volumetric tilled soil, pulverizing ratio and inversion ratio were measured and analyzed.

The main findings of this study are as follows;

(1) The rotavating depth and width of rotary-type rotavator were 130 mm and 2,070 mm, respectively, while 250- 280 mm and 1,920 mm, respectively, for the crank- type rotavator. Crank-type rotavator has deeper rotavating depth than rotary-type.

(2) PTO power and torque fluctuation during rotavating were larger in the crank-type rotavator. This may be from the unique operational characteristics of the crank-type rotavator. Average PTO torque, however, was smaller in the crank-type rotavator in the practice gear ranges.

(3) For each rotavator, the actual field capacity increased as the actual working speed increased, while the volume of tilled soil was changed irregularly according to the rotavating depth, rotavating width and actual working speed, resulting in larger values in the crank-type rotavator at the same gear condition of L1/1 and at the most commonly used gear ranges. The specific volumetric tilled soil was also larger in crank-type rotavators.

(4) The pulverizing ratio was better in the rotary-type rotavator while inversion ratio didn't show meaningful differences between both rotavators.

(5) The crank-type rotavator is good in the aspect of low power consumption and deep tillage available even though the pulverizing effect is not good but they are acceptable.

Conflict of Interest

No potential conflict of interest relevant to this article was reported.

Acknowledgement

This work was supported by the Center for IT Convertgence Agricultural Machinery (ITAM) grant (No. RO9-5) funded by the Ministry of Knowledge and Economy, Korea.

References

ASAE standards, 2007. S526.3 SEP2007: Soil and water terminology. St. Joseph, MI:ASAE.

ASAE standards, 2009. EP542 FEB1999: Procedures for using and reporting data obtained with the soil cone penetrometer. St. Joseph, MI:ASAE.

ASAE standards, 2009. S313.3 FEB1999: Soil cone penetrometer. St. Joseph, MI:ASAE.

ASAE standards, 2011. D497.7 MAR2011: Agricultural machinery management data. St. Joseph, MI:ASAE.

Beeny, J. M and D. C. P. Khoo. 1970. Preliminary investigations into the performance of different shaped blades for the rotary tillage of wet rice soil. Journal of Agricultural Engineering Research 15(1):27-33.

Cellicorea. 2008. Application of crank-type rotavator. Available at: www.cellicorea.com.

Ghosh, B. N. 1967. The power requirement of a rotary cultivator. Journal of Agricultural Engineering Research 12(1):5-12.

Lee, H. D., Kim, K. D., Oh, J. J., Kim, C. S., Kim, S. H and K. Y. Na. 2003. Development of rotary for reducing power requirement at a farm tractor rotary tilling: development of device for preventing alien substance from being wound and for preventing soil adherence. Journal of Biosystems Engineering 4:295-304 (In Korean, with English abstract).

Lee, S. K., Kim, S. T and J. K. Woo. 2000. Tillage characteristics of the single-edged rotary blade. Journal of Biosystems Engineering 25(5):269-378 (In Korean, with English abstract).

Myung, B. S and H. D. Lee. 2009. Research on the actual condition of rotary tilling & rotary power requirement in the central area. Journal of Korean Society of Industrial Application 12(2):79-83 (In Korean, with English abstract).

NIAE. 2004: Experimental and research report. Suwon: NIAE (In Korean).

RDA. 2004: Newly developed agricultural machinery: for rice cultivation. Suwon: RDA (In Korean).

Salokhe, V. M., Miah, M. H and M. Hoki. 1993. Effect of blade type on power requirement and puddling quality of a rotavator in wet clay soil. Journal of Terramechanics 30(5):337-350.

Vittal, K. P. R, Vijayalakshmi, K and U. M. B. Rao. 1983. Effect of deep tillage on dryland crop production in red soils of india. Soil & Tillage Research 3:377-384.