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# Comparison of Tillage and Loads Characteristics of Three Types of Rotavators: Rotary-type, Crank-type, and Plow-type

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## Abstract

**Purpose:** This study was conducted to compare tillage and loads characteristics of three types of rotavators in farmland working condition of Korea. **Methods:** Tillage operations using three types of rotavators, i.e. rotary-type, crank-type and plow-type, were carried out in a dry field of Korea. The same prime mover tractor was used for driving three types of rotavators, and under several operational conditions, tillage characteristics such as actual working speed, rotavating depth, rotavating width, actual field capacity, flow of tilled soil, soil inversion ratio, and pulverizing ratio were measured. In addition, loads characteristics like torque and required power of Power Take-Off (PTO) shaft were calculated. **Results:** The average rotavating depth was smaller than the nominal value for all rotavators, and the difference was the greatest in the plow-type rotavator. Nevertheless, the plow-type rotavator showed the largest rotavating depth. The rotavating width was the same as the nominal value of all rotavators. The flow of tilled soil at the same operational conditions was the greatest in the plow-type rotavator and was the smallest in the rotary-type rotavator. In the most commonly used gear conditions of L2 and L3, the average soil pulverizing ratio was the greatest in the rotary-type rotavator, and followed by crank-type and plow-type rotavators in order. In the gear L2 and L3, the plow-type rotavator also had the lowest average soil inversion ratio while the rotary-type and crank-type rotavators had the same soil inversion ratio each other. The average torque and power of PTO shaft in the gear L2 and L3 were the highest in the plow-type rotavator. The load spectra of PTO shaft applying rain flow counting method and Smith-Waston-Topper equation to the measured torque showed that the modified torque amplitude was the greatest in the crank-type rotavator. This may come from the large torque fluctuation of crank-type rotavator during tillage operations. **Conclusions:** The three types of rotavators had different tillage and loads characteristics. The plow-type rotavator had the deepest rotavating depth, the smallest soil inversion ratio, the largest soil pulverizing ratio and required PTO power. Also, the crank-type rotavator showed a large torque fluctuation because of their unique operational mechanism. This study will help the farmers choose a suitable type of rotavator for effective tillage operations.

**Keywords:** Crank-type, Load characteristics, Plow-type, Rotary-type, Tillage characteristics

## Introduction

Plowing and rotavating operations are mainly conducted together for tillage operations in rural areas of Korea (MFAFF, 2006) to save working hours and labor (Myung and Lee, 2009). There are three types of rotavators in Korea: rotary-type, plow-type, and crank-type. Among them, the rotary-type rotavator is the most commonly used one. The rotavating operation of rotary-type is conducted inside the soil by rotating tillage blades mounted on the rotor shaft, so the rotavating depth is shallow and the tillage blades are easy to wear. The plow-type operated by the same mechanism as the rotary-type is used for rotavating deeper soil due to the different blade shape. The crank-type has deep tillage and low traction resistance because of spade-shaped tillage blade. The rotavating depths of plow-type and crank-type

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are generally 300 - 600 mm and rotary-type is 100 - 200 mm. The plow-type and crank-type penetrate deeply into the soil, resulting in better air permeability and moisture content in soils (Varsa et al, 1997; Kim et al, 2001; Yoo et al, 2006). Additionally, the crank-type cut the soil into an aggregate structure which affects crop growth (Cellicorea, 2008).

Most researches have been conducted on the rotary-type rotavator (Lee et al., 2000; Lee et al., 2003; Myung and Lee, 2009; Kim et al., 2011), but there have been very few studies of the crank-type rotavator (NIAE, 2004; Nam et al, 2012) and no studies of the plow-type rotavator. Therefore, comparative studies of tillage and loads characteristics of each type of rotavators in farmland conditions of Korea are needed for effective tillage operations.

## Materials and Methods

### Prime mover tractor and rotavators

The same prime mover tractor was used to drive three different types of rotavators. A view and specifications of the prime mover tractor are shown in Figure 1 and Table 1. The nominal working speed of the tractor at each gear is shown in Table 2.

The rotary-type, crank-type and plow-type, with similar rated power were used for this study. Each rotavator had different types of blade: the rotary-type had 'C'-shaped blades, the plow-type had triangular-shaped blades, and the crank-type had trapezoidal-shaped shovel-type blades. A view and specifications of each rotavator are shown in Figure 2 and Table 3.

### Test site description

The test site was a dry weedy field located in Baekgu-myeon, Gimje-si, Jeollabuk province, Korea (Figure 3). A cone penetrometer (SC900, Spectrum Technology, E

Figure 1. A view of prime mover tractor.

Table 1. Specifications of the prime mover tractor

| Item | | Specification |
|---|---|---|
| Model/Company/Nation | | T623/Tongyang Moolsan/Korea |
| Weight (kN) | | 24.35 |
| Length × Width × Height (mm) | | 3725 × 1840 × 2545 |
| Engine | Rated power (kW) /speed (rpm) | 48 / 2200 |
| PTO | Transmission stage (rotational speed, rpm) | 1 (550), 2 (733) |

Table 2. Nominal working speeds of the prime mover tractor

| Gear | Nominal working speed (km/h) |
|---|---|
| L1 | 0.89 |
| L2 | 1.41 |
| L3 | 2.17 |
| L4 | 2.70 |
| M1 | 2.85 |
| M2 | 4.51 |
| M3 | 6.94 |
| M4 | 8.64 |

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

Figure 2. A view of three types of rotavators.

**Table 3.** Specifications of three types of rotavators

| Item | Specification | | |
|---|---|---|---|
| | Rotary-type | Crank-type | Plow-type |
| Model / Company / Nation | GMR195G / Greenmax / Korea | Prototype / Greenmax / Korea | KING205 / Greenmax / Korea |
| Weight (kN) | 4.41 | 5.78 | 5.88 |
| Nominal rotavating width (mm) | 1950 | 1800 | 2050 |
| Rated power (kW) | 41 | 45 | 45 |
| Nominal rotavating depth (mm) | 120 | 300 | 400 |

**Table 4.** Soil properties of the test site

| Soil texture | Moisture content [d.b.](%) | Cone index by depth (kPa) | | | | | |
|---|---|---|---|---|---|---|---|
| | | Location | 5 cm | 10 cm | 15 cm | 20 cm | 25 cm |
| Loamy sand | Location A: 15.5%<br>Location B: 14.2% | 1 | 210 | 1,158 | 2,528 | 2,492 | 1,825 |
| | | 2 | 140 | 667 | 1,580 | 1,896 | 2,176 |
| | | 3 | 70 | 1,580 | 2,106 | 2,071 | 1,755 |
| | | 4 | 140 | 526 | 1,509 | 1,615 | 2,141 |

**Figure 3.** A view of test site.

Plainfield, USA) that complies with the related standard for the shape (ASAE S313.3, 2009) was used for the measurement of soil strength following standard test method (ASAE EP542, 2009). The measurement spots were randomly selected different four locations, which were scattered in the entire test site and laid on rotavating path. The measurement depths were five points below the surface, i.e. from 50 mm to 250 mm with 50 mm intervals. The ground surface was relatively flat, so the effect of slope was ignored. The moisture content was measured at randomly selected different two locations in the test site using the oven method (ASAE S526.3, 2007). The soil texture was classified by the USDA method.

The measured cone index, moisture content, and soil texture of the test site are shown in Table 4. The soil cone index was in the range of 70 - 2,528 kPa and moisture contents were 15.5% and 14.2% at each location. The soil texture was loamy sand which was comprised of 70.4% sand, 28.7% silt and 0.9% clay.

## Work conditions

The tillage operations were conducted with several tractor gear conditions. The rotary-type and the crank-type performed with L2, L3, L4 and M1 gear conditions while the plow-type conducted with only L2 and L3 gear conditions. It was due to the fact that operating the plow-type with higher gear speed than L3 was hard. The engine speed was fixed to rated one and PTO speed was also fixed to gear 1 throughout the experiment. The actual rotavating distance was 15 m, and the operation was repeated twice for each operational condition.

## Measurement and analysis

To investigate the tillage and load characteristics for each type of rotavators, the speed and torque of the PTO shaft, rotavating depth and width, actual work speed of tractor, pulverizing ratio and inversion ratio of tilled soils were measured. Then the actual field capacity (the rotavating area per unit time), the PTO power, and flow of tilled soil (the volume of tilled soil per unit time) were calculated from the measured data (Nam et al, 2012).

The sampling frequency of the data acquisition system was 600 Hz, which is lager more than 10 times compared to other possible noise source's frequency, and also from 5 point averaging for post process of acquired data, the noise from the engine speed (41.67 Hz), PTO speed (9.17 Hz), and tillage blade's rotational speed (~55Hz) could not disturb the reception of the original signals.

The PTO shaft torque was measured by a torque meter, and PTO speed was calculated by the speed of transmission input shaft and reduction gear ratio of the transmission. A magnetic pick-up sensor mounted on the shaft flange was used for measurement of the speed of transmission input shaft. The PTO power was calculated using PTO shaft torque and speed. The rotavating depth and width were measured with a tapeline, and actual work speed was measured using a GPS installed inside the tractor cap.

The load spectrum of PTO shaft was derived from the measured PTO shaft torque following the processes of the study of Kim et al. (2000). A time history of the measured torque was digitized, and the cycles were counted using the rain flow counting method. The effect of mean torque should be considered to calculate spectrum magnitude because the torque was not completely reversed load. The amplitude of the torque loops was modified using the following Smith-Waston-Topper equation after rain flow counting was performed. The modified torque amplitude from load spectrum is especially important because it is the primary cause of the fatigue failure of components in power transmission path.

$$T = \sqrt{(T_m + T_a)T_a} \tag{1}$$

Where, $T$ : modified torque amplitude
$T_m$ : mean of torque loop
$T_a$ : amplitude of torque loop

The soil pulverizing ratio represents the capability of a rotavator to crush a lump of soil into fine particles. It was defined as the mass of a tilled soil sample smaller than 20 mm in diameter over the total mass of the tilled soil sample. The soil sample was collected from a surface area of 600×300 $mm^2$ into a rotavating depth for each rotavator after tillage operation (NIAE, 2004). The soil inversion ratio represents the capability of the rotavator to turn the inside soil over, and could be measured by comparing the distribution of lime on the soil surface before and after tillage operation. The limed area for the soil inversion ratio was 1700×1700 $mm^2$ (NIAE, 2004).

## Results and Discussion

### Tillage characteristics

Table 5 shows the tillage characteristics measured with each rotavator. Under the same operational condition, the actual working speeds of the crank-type and the plow-type were faster than that of the rotary-type. This came from the skid effect where the spades of the rotavator push the tractor forward. The average rotavating depth of the rotary-type, the crank-type and the plow-type were 111 mm, 251 mm and 280 mm, respectively. The rotavating depth of the plow-type was the largest, and the rotary-type showed the smallest value. Also, the rotary-type rotavator showed the smallest differences between the measured and the nominal rotavating depths because it had mild operational circumstances such as shallow rotavating depth. The rotavating width was the same as the nominal value for all operational

**Table 5.** Tillage characteristics of each rotavator

| Rotavator type | Gear | Actual working speed (km/h) | Rotavatingdepth (mm) | Rotavatingwidth (mm) | Actual field capacity ($m^2$/h) | Flow of tilled soil ($m^3$/h) |
|---|---|---|---|---|---|---|
| Rotary-type | L2 | 1.36 | 120 | 1950 | 2642 | 310.54 |
| | L3 | 2.19 | 105 | 1950 | 4261 | 447.53 |
| | L4 | 2.74 | 110 | 1950 | 5343 | 574.52 |
| | M1 | 2.9 | 110 | 1950 | 5655 | 607.67 |
| Crank-type | L2 | 1.62 | 275 | 1800 | 3069 | 843.98 |
| | L3 | 2.42 | 235 | 1800 | 4589 | 1066.71 |
| | L4 | 2.79 | 240 | 1800 | 5292 | 1257.33 |
| | M1 | 3.01 | 255 | 1800 | 5710 | 1460.06 |
| Plow-type | L2 | 1.46 | 295 | 2050 | 2983 | 881.30 |
| | L3 | 2.46 | 265 | 2050 | 5043 | 1332.40 |

**Table 6.** Soil pulverizing ratio and inversion ratio of each rotavator

| Rotavator type | Gear | Pulverizing ratio (%) | Inversion ratio (%) |
|---|---|---|---|
| Rotary-type | L2 | 98.78 | 100 |
| | L3 | 96.96 | 100 |
| | L4 | 98.80 | 100 |
| | M1 | 97.91 | 90 |
| Crank-type | L2 | 88.04 | 100 |
| | L3 | 92.03 | 100 |
| | L4 | 95.14 | 90 |
| | M1 | 95.13 | 80 |
| Plow-type | L2 | 84.06 | 80 |
| | L3 | 73.64 | 80 |

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

**Figure 4.** A view of pulverized soil using each type of rotavator.

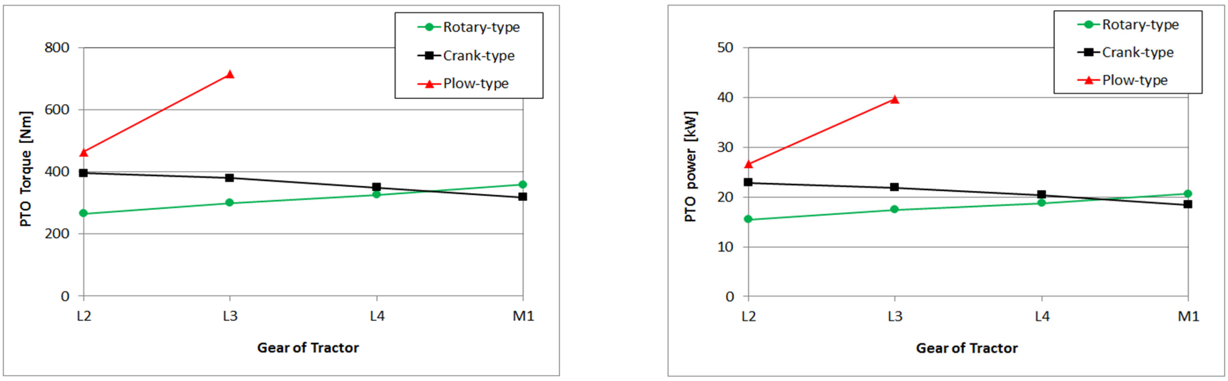
conditions of the rotavators. The flow of tilled soil was the largest in the plow-type rotavator, and followed by the crank-type and rotary-type rotavators in order.

Table 6 shows the other tillage characteristics, i.e. soil pulverizing ratio and inversion ratios, for each rotavator and operational condition. In the most commonly used gear ranges of L2 and L3, the average soil pulverizing ratio of the rotary-type, the crank-type and the plow-type rotavators were 97.87%, 90.04% and 78.85%, respectively. The rotary-type rotavator showed the highest soil pulverizing ratio and followed by the crank-type and plow-type rotavators in order. The soil inversion ratio also showed better performance in the rotary-type rotavator than in the crank-type and plow-type rotavators. Especially, in the gear L2 and L3, the rotary-type and the crank-type rotavators showed 100% of soil inversion ratio while the plow-type rotavator showed 80%. Figure 4 shows the soil pulverized with each type of rotavators.

## PTO loads and power

The average torques and powers of PTO shaft for each type of rotavators are shown in Figure 5. In the most commonly used gear conditions (L2 and L3), the average PTO torque for the rotary-type was 283.22 Nm, for the crank-type was 399.21 Nm, and for the plow-type was 589.16 Nm. The average PTO powers for the rotary-type, crank-type, and plow-type rotavators were 16.48 kW, 22.38 kW and 33.14 kW, respectively. The ratios of the average PTO power with the gear of L2 and L3 to the tractor rated power were 34.33% (the rotary-type), 46.63% (the crank-type) and 69.04% (the plow-type). The plow-type rotavator consumed the greatest power in the tillage operation while the rotary-type rotavator required the lowest power. Comparing to the plow-type rotavator, the use of rotary-type rotavator saved about 25% of the tractor power. The crank-type was ranked in the second place for the PTO torque magnitude and PTO power consumptions.

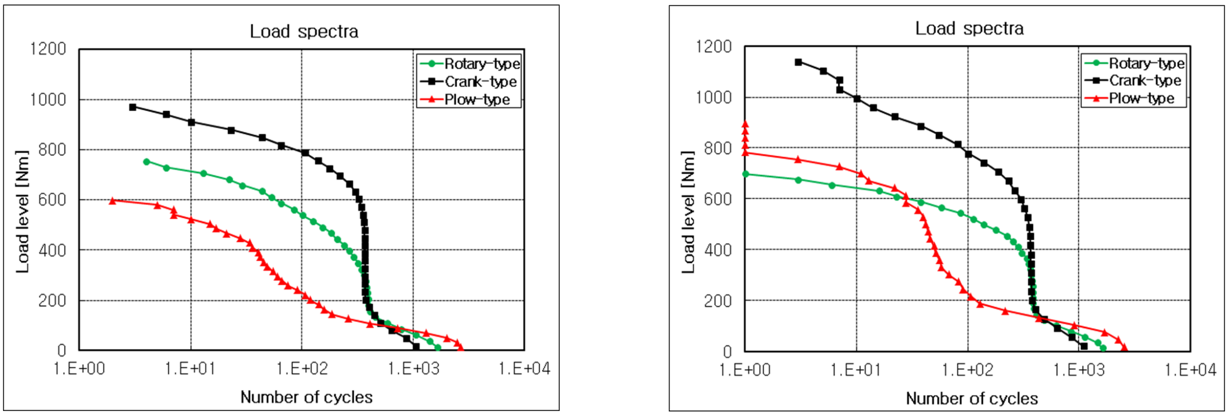
The load spectra of PTO shaft torque with the gear of L2 and L3 are shown in Figure 6. For both gear conditions, the greatest torque amplitude was occurred in the crank-type rotavator. The rotary-type and plow-type rotavators followed next in order. Because of the large torque fluctuation during tillage operation, the crank-type




PTO shaft torque

PTO shaft power

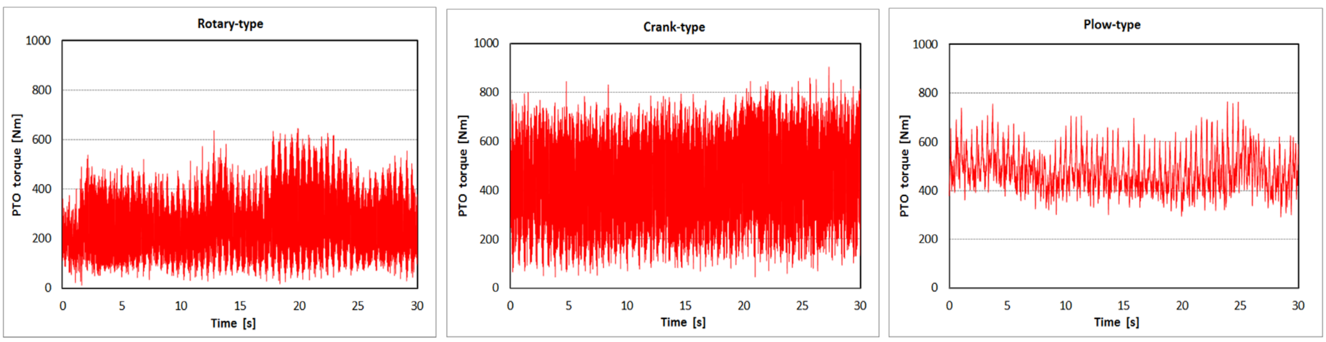
**Figure 5.** Average PTO shaft torque and powers at each rotavator and operational condition.




(a) Gear L2

(b) Gear L3

**Figure 6.** Load spectra of PTO shaft torque at practical gear conditions.




(a) Rotary-type

(b) Crank-type

(c) Plow-type

**Figure 7.** Time histories of PTO shaft torque for three types of rotavators.

rotavator showed the largest torque amplitude despite the medium-sized average torque level. Figure 7 shows the time history of PTO torques with gear L2 of each rotavator. The magnitude and fluctuation of PTO torque with gear L3 of each rotavator showed similar trend as those with gear L2.

## Conclusions

This study was fundamental research to investigate different performance characteristics of three types of rotavators. In this study, tillage operations were conducted using the same prime mover tractor with three types of rotavators of similar rated power. The test site was a dry weedy field located in Baekgu-myeon, Gimje-si, Jeollabuk province, Korea. During the tillage operations, several elements such as actual working speed, rotavating depth, rotavating width, actual field capacity, flow of tilled soil, soil inversion ratio, pulverizing ratio, torque, and required power of PTO shaft were measured and analyzed.

The main findings of this study are as follows:

(1) Under the same operational conditions, the rotary-type rotavator showed the best soil pulverizing ratio, and the crank-type and plow-type rotavators were followed next in order. On the other hand, the rotavating depth and the flow of tilled soil showed reverse tendency from the soil pulverizing ratio, i.e. the highest in the plow-type rotavator and the lowest in the rotary-type rotavator. The rotavating widths were the same with the nominal value for all operational conditions of rotavators. The soil inversion ratios in the gear L2 and L3 were 100% in the rotary-type and crank-type rotavators while 80% in the plow-type rotavator.

(2) In the most commonly used gear conditions (L2 and L3), the average PTO torque and power were the greatest in the plow-type rotavator. The rotary-type rotavator reduced tractor power consumption by 25% compared to the plow-type rotavator.

(3) The modified PTO torque amplitude derived from rain flow counting and Smith-Waston-Topper equation was the greatest in the crank-type rotavator. This came from the large torque fluctuation of crank-type rotavator during tillage operations.

(4) The plow-type rotavator had the deepest rotavating depth, the smallest soil inversion ratio, the largest soil pulverizing ratio and required PTO power. The rotary-type rotavator showed reverse tendency from the plow-type rotavator for all the above parameters. The crank-type rotavator has medium value between the plow-type and rotary-type for the above parameters. The modified PTO torque amplitude, however, was the highest in the crank-type rotavator.

(5) This study found the tillage and loads characteristics of three types of rotavators. Therefore, the findings of this study will help the farmers choose a suitable type of rotavator for effective tillage operations.

## Conflict of Interest

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

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