

Tillage Characteristics Estimation of Crank-type and Rotary-type Rotavators by Motion Analysis of Tillage Blades

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Abstract

Purpose: This study has been conducted to investigate the applicability of motion analysis of tillage blade for estimation of tillage characteristics of crank-type and rotary-type rotavators. **Methods:** The interrelation between tillage traces from motion analysis and field test results including rotavating depth, pulverizing ratio and inversion ratio at the same work conditions were analyzed for both crank-type and rotary-type rotavators. The work conditions include working speed of prime mover tractor and PTO speed of rotavators. For the motion analysis, joint conditions of main connecting component were specified considering the actual working mechanism of rotavator. **Results:** There were important correlations for the trend between motion analysis and field test results. **Conclusions:** Although further study is needed for applying motion analysis to estimate the accurate tillage related parameters such as rotavating depth, the soil pulverizing ratio and inversion ratio, it could be used to compare the tillage characteristics of various rotavators quickly and simply.

Keywords: Crank-type, Motion analysis, Rotary-type, Rotavator, Tillage blades, Tillage characteristics

Introduction

In Korea, the mechanization rate of farm work is continuously increasing every year. Among these, 99% of tillage operation depends on machine, especially rotavator and tractor which have good tillage and pulverizing performances as well as fast working speed (RDA, 2011).

Most of the rotavators currently supplied to domestic market are rotary-type which using 'C' or 'L' shaped tillage blades to rotavate the soil in a circular trace. Since the rotavating work is conducted at subsurface soil, tillage blades could be worn out or broken by foreign matter such as gravel (Choi et al., 1993), and they have shallow rotavating depth of 100-200 mm. In contrast, crank-type rotavator has equally spaced several spades as tillage blade that enable deeper tillage of 300-400 mm depth,

and it has advantage of less abrasion and more safe against the failure by obstacles because of their shovelling-like operational mechanism (Cellicore, 2008). Also, crank-type rotavator is suitable for Korean farm working style which is the way of conducting only one time of tillage operation without separating plowing and rotavating work for the saving of work hours and labor (Lee et al., 2000).

In Korea, there have been many studies on work characteristics of rotary-type rotavator (Lee et al., 2000; Lee et al., 2003; Myung and Lee, 2009; Kim et al., 2011), but there are almost no published papers about crank-type rotavator (NIAE, 2004) and also there is little actual applied experience in Korean soil conditions. The understanding of work characteristics of crank-type rotavator should be preceded to develop crank type rotavator that is suitable for Korean soil conditions. Actual field test is reliable method to investigate work characteristics of certain type of rotavator at a fixed operational condition. It needs, however, many times and cost as well as large manpower, so more simple method is needed to verify work characteristics of a

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rotavator quickly and easily.

In this study, the comparative analysis between motion analysis of tillage blade and actual field test results at the same work conditions have been conducted to investigate the applicability of motion analysis to estimate tillage characteristics of crank-type and rotary-type rotavators.

Prime mover tractor for the operation of each rotavator was T720s model of Tongyang Moolsan, and its specifications are shown in Table 2. Rated working speed of T720s for each tractor gear is shown in Table 3. Commonly used gear conditions by Korean farmers are L1/1 and L2/1 (tractor/PTO) for rotary-type rotavator, and LL3/2 and LL4/2 for crank-type rotavator.

Materials and Methods

Test equipments

Rotary-type and crank-type rotavators with same nominal rotavating width and rated power were selected. 'C' shaped tillage blades which require less power and torque compared to 'L' shaped blades (Beeny & Khoo, 1970; Salokhe et al., 1993) were used for the rotary-type rotavator. Configurations and specifications of each rotavator are shown in Figure 1 and Table 1, respectively.

3D Model and motion analysis

Commercial softwares were used to construct 3D rotavator model and to analyze tillage characteristics of each rotavator. Pro Engineer (R5.0, PTC, USA) and CATIA (V6, Dassault Systems, France), and RecurDyn (V7R5, Functionbay, Korea) were used for modeling and analysis, respectively. 3D model for each rotavator is shown in Figure 2. Information about component size and material property were reflected to the models. For motion analysis, joint conditions of main connecting component were specified considering



Figure 1. A view of rotary and crank type of rotavators.

Table 1. Specifications of rotavators used for the study

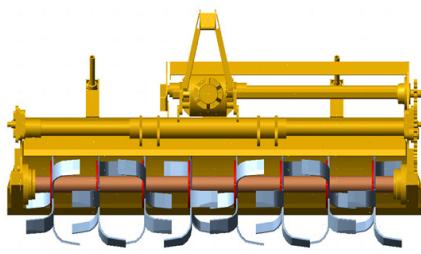
Item	Specification	
	Rotary-type rotavator	Crank-type rotavator
Model/Company/Nation	GMR205HL/Greenmax/Korea	TORO2000/FLAC/Italy
Weight (kN)	5.2	8.6
Nominal rotavating width (mm)	2,000	2,000
Rated power (kW)	52	52
Nominal rotavating depth (mm)	120	350

Table 2. Specifications of tractor used as prime mover

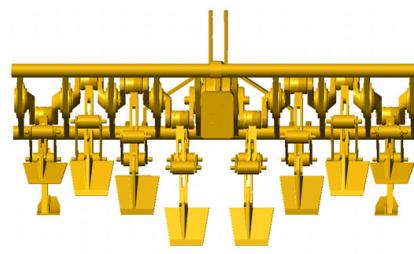
Item	Specification
Model/Company/Nation	T720S/Tongyang Moolsan/Korea
Weight (kN)	30.20
Length × Width × Height (mm)	4047×1970×2600
Engine	Rated power (kW)/speed (rpm)
PTO	Transmission stage (rotational speed, rpm) 1 (563 rpm), 2 (799 rpm)

Table 3. Rated working speed for each tractor gear of T720s

Gear of Tractor	Rated working speed (km/h)
LL1	0.86
LL2	1.08
LL3	1.46
LL4	1.92
L1	2.21
L2	2.78

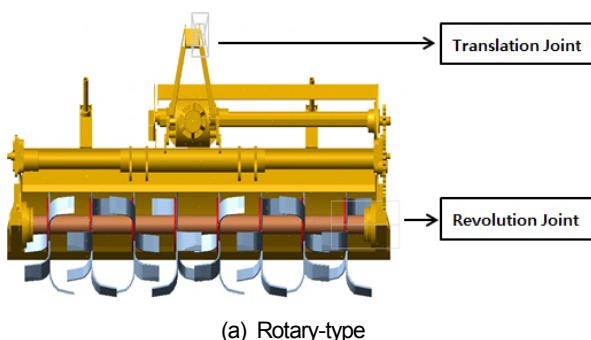


(a) Rotary-type

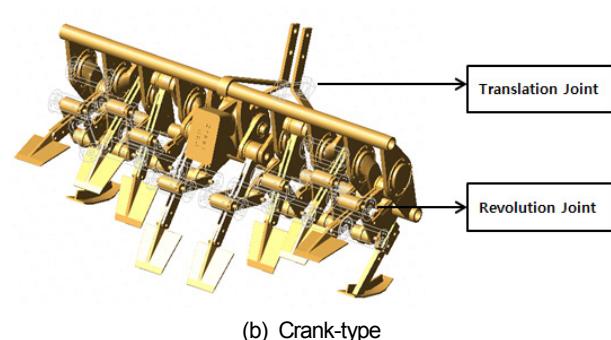


(b) Crank-type

Figure 2. 3D model of each rotavator.



(a) Rotary-type



(b) Crank-type

Figure 3. Joint configuration of each rotavator.

the actual working mechanism of rotavator as shown in Figure 3. At a fixed tractor and PTO gear condition, rated working speed and PTO speed were simulated from translation joint and revolution joint, respectively, and then tillage blades had a certain moving trajectory according to structural link of each part. The output of motion analysis is the edge trace of tillage blade.

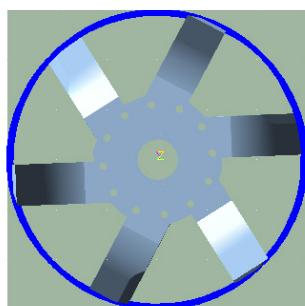
Field test

Field test using the same models of rotavator and tractor had been conducted in a Korean loamy sand soil (Nam et al., 2012). The actual working speed, rotavating depth, rotavating width, actual field capacity, volume of tilled soil, PTO output power and torque, soil inversion ratio and pulverizing ratio were measured at various tractor

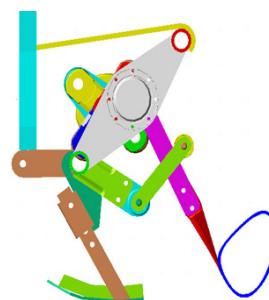
and PTO gear conditions shown in Table 4. Among field test results, only the actual working speed, rotavating depth, soil inversion ratio and pulverizing ratio were used for the purpose of this study. The pulverizing ratio represents the capability of a rotavator to crush a lump of soil into a fine particle. It was defined as the mass of a soil sample smaller than 20 mm in diameter over the total mass of the soil sample. The soil inversion ratio represents the capability of the rotavator to turn the soil over, and could be calculated by the limed area on the soil surface before and after tillage operation. Soil inversion ratio and pulverizing ratio are important indices representing tillage characteristics of rotavator, and the larger value means the better tillage characteristics.

Table 4. Gear shift combination of tractor and PTO used to field test

Rotavator type	Gear of Tractor/PTO
Rotary-type	L1/1
	L2/1
	LL1/2
	LL2/2
Crank-type	LL3/2
	LL4/2
	L1/1
	L1/2

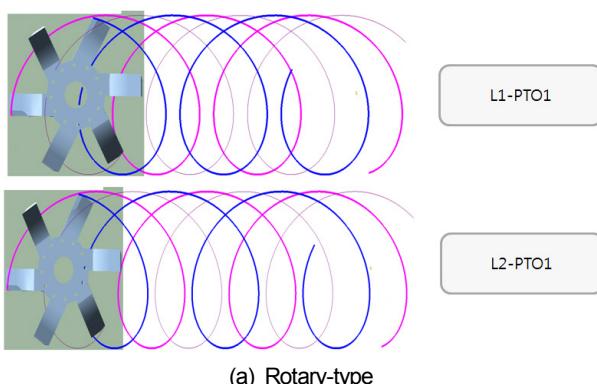


(a) Rotary-type



(b) Crank-type

Figure 4. Traces at the end of tillage blades for stationary rotavator.



(a) Rotary-type

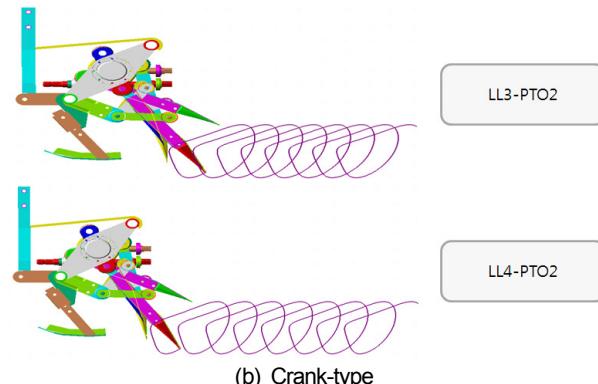


Figure 5. Traces at the end of tillage blades at the commonly used gear conditions.

Results and Discussion

Tillage trace of each rotavator

Trace of a tillage blade edge for stationary rotavator is shown in Figure 4. All tillage blades of rotary-type rotavator are mounted on a rotor shaft with a fixed interval and rotate following the revolution of rotor shaft. Spade shaped tillage blades of crank-type rotavator, by comparison, are connected to links of crank mechanism and move following the motion of links. According to their distinguishing operational mechanism, rotary-type rotavator shows circular

shaped trace with rotor shaft as the center of a circle (MIFAFF, 2002) while crank-type rotavator shows ellipse-like trace by crank mechanism of tillage blades.

Trace of a tillage blade at the commonly used gear conditions is shown in Figure 5. Due to their structural configurations, a half of tillage blades that face the same direction have the same working sections for the rotary-type rotavator, and each blade has different working section for a crank-type rotavator. The shapes of tilled soil slice for each rotavator is shown in Figure 6.

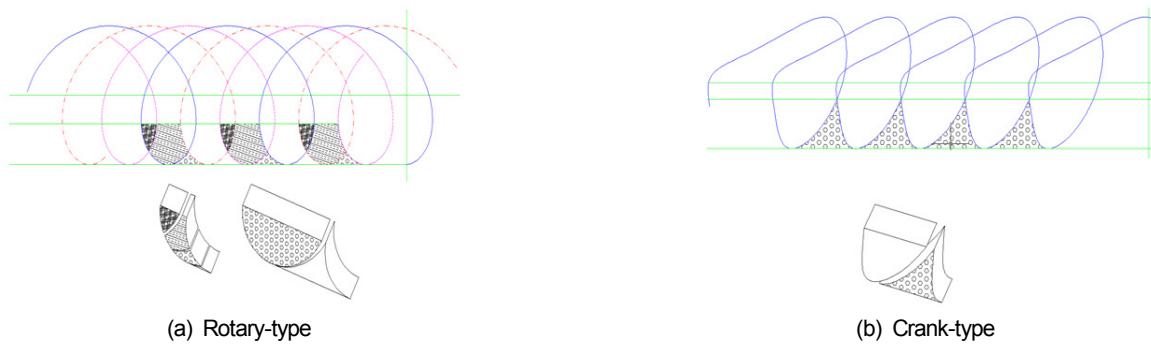


Figure 6. Shape of tilled soil slices.

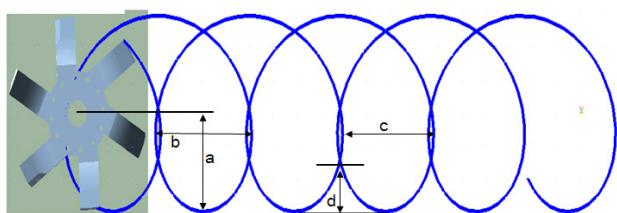


Figure 7. The variables for trace analysis of rotary-type rotavator.

Tillage characteristics analysis by tillage trace

Figure 7 and 8 show the variables for trace analysis of each rotavator. 'a' is the length from the center of rotor shaft (rotary type) or from the bottom of supporting frame (crank type) to the end of tillage blade, and it is related to rotavating depth. 'b' is the largest width in a trace. 'c' and 'd' are crossing width and crossing height between adjacent traces, respectively, and related to the soil pulverizing ratio.

The variables for trace analysis at each work condition

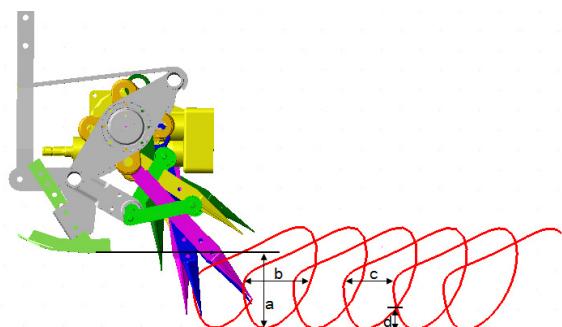


Figure 8. The variables for trace analysis of crank-type rotavator.

of both rotavators are listed in Table 5 and 6, and the corresponding graphs are shown in Figure 9 and 10. For each rotavator, 'b' increases and both of 'c' and 'd' decrease as PTO speed increases, which means the soil pulverizing ratio is larger at the faster PTO speed. In contrast, as actual working speed increases, 'b' decreases and 'c' and 'd' increase, which means the soil pulverizing ratio is smaller at the faster actual working speed. In addition, 'a' does not change in all the work conditions, which means that rotavating depth is maintained constant at the same

Table 5. Trace variables from motion analysis of rotary-type rotavator

Gear of PTO	Trace related variable	Gear of tractor								variation
		LL1 (0.86 km/h)	LL2 (1.08 km/h)	LL3 (1.46 km/h)	LL4 (1.92 km/h)	L1 (2.21 km/h)	L2 (2.78 km/h)	L3 (3.76 km/h)	L4 (4.94 km/h)	
1	a (mm)	294	294	294	294	294	294	294	294	constant
	b (mm)	545.4	534.9	516.9	494.8	481.6	451.9	411.5	357	decrease
	c (mm)	28.1	36.6	48.7	63.4	75.4	90.8	127.9	168.9	Increase
	d (mm)	0	0	0.5	3.4	6	9.7	12.7	17.3	Increase
2	a (mm)	294	294	294	294	294	294	294	294	constant
	b (mm)	555.3	548	534.8	520.3	510.7	492.8	459.6	417.6	decrease
	c (mm)	23.8	25.81	33.8	45.9	52.8	66.4	89.8	118.5	Increase
	d (mm)	0	0	0	1.2	3.4	7.8	9.5	12.7	Increase

Table 6. Trace variables from motion analysis of crank-type rotavator

Gear of PTO	Trace related variable	Gear of tractor								variation
		LL1 (0.86 km/h)	LL2 (1.08 km/h)	LL3 (1.46 km/h)	LL4 (1.92 km/h)	L1 (2.21 km/h)	L2 (2.78 km/h)	L3 (3.76 km/h)	L4 (4.94 km/h)	
1	a (mm)	314	314	314	314	314	314	314	314	constant
	b (mm)	259.9	247.6	232.6	207.1	193.1	165.7	118.4	60.6	decrease
	c (mm)	85.8	108	148.9	192.7	221.9	279.4	378.2	499.2	Increase
	d (mm)	19.98	30	57.8	123.7	N/A	N/A	N/A	N/A	Increase
2	a (mm)	314	314	314	314	314	314	314	314	constant
	b (mm)	267.3	259.9	247.9	231.6	221.8	202.6	169.5	129	decrease
	c (mm)	56.7	90.4	100	132.4	153.1	193.8	263.7	349.4	Increase
	d (mm)	6.6	13.1	27	46	66.3	125.6	N/A	N/A	Increase

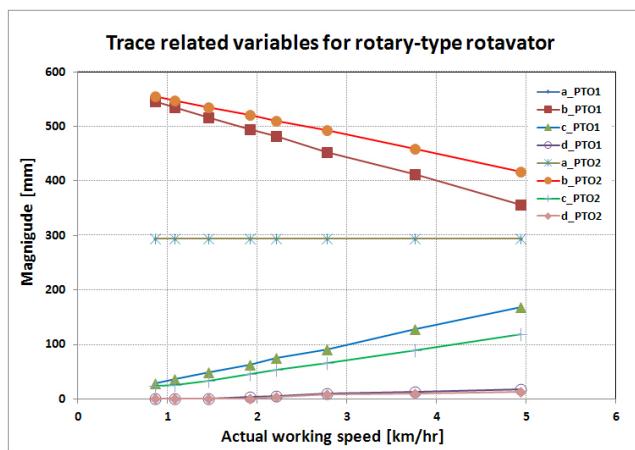


Figure 9. Trace variables from motion analysis of rotary-type rotavator.

type of rotavator regardless of operating conditions. These results, i.e. the soil pulverizing ratio increases at higher PTO speed and lower actual working speed, and rotavating depth is constant regardless of working conditions, are consistent with currently known trend (Celik and Altikat, 2008).

In a view point of rotavator type, rotary-type rotavator has deeper 'b' and smaller 'a', 'c' and 'd' than crank-type rotavator at the same work condition. This means that crank-type rotavator has lower pulverizing ratio and larger rotavating depth than rotary-type rotavator at the same work condition.

Regarding trace crossing between tillage blades, rotary-type rotavator showed crossing trace by 3 tillage blades at all work conditions. For crank-type rotavator, however, it did not show trace crossing and consequently cannot make 'd' at tractor gear higher than L1 for PTO gear of 1, and L3 for PTO gear of 2.

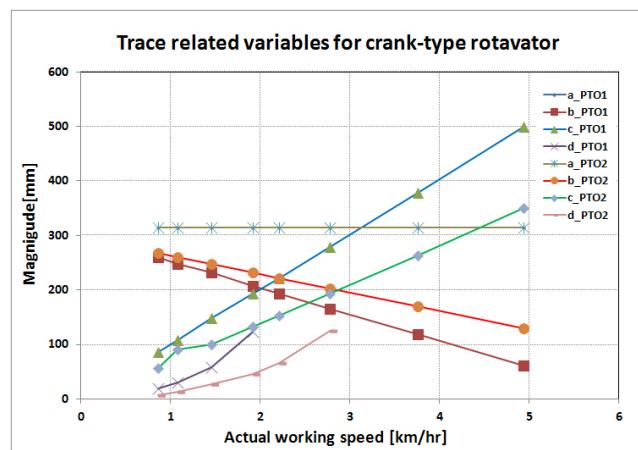


Figure 10. Trace variables from motion analysis of crank-type rotavator.

Comparison with field test results

Table 7 shows the field test results of the same test set up as that of motion analysis (Nam et al., 2012). The soil pulverizing ratio becomes smaller when actual working speed increases for both rotavators, which means that the soil pulverizing ratio according to actual working speed is consistent with the motion analysis result. Soil inversion ratio also shows the same trend with the motion analysis, that is lower soil inversion ratio at crank-type rotavator with gear of L1/1 at which 'd' is not derived. And finally, rotary-type rotavator has lower rotavating depth and higher soil pulverizing ratio than crank-type rotavator at the same work condition of gear of L1/1, which is also the same trend derived from motion analysis.

Conclusions

In this study, tillage characteristics from motion analysis

Table 7. Field test results of the same test set up as that of motion analysis

Rotavator type	Gear of Tractor/PTO	Actual working speed (km/h)	Rotavating depth (mm)	Pulverizing ratio (%)	Inversion ratio (%)
Rotary-type	L1/1	1.91	130	91.51	100
	L2/1	2.35	130	83.44	100
	LL1/2	0.98	250	76.44	100
	LL2/2	0.84	250	80.48	100
Crank-type	LL3/2	1.38	280	75.72	100
	LL4/2	1.69	280	64.09	100
	L1/2	1.92	280	57.58	100
	L1/1	2.30	280	62.17	80

of tillage blade for rotary-type and crank-type rotavators were investigated and verified by comparing it with actual field test results.

The main findings of this study are as follows:

- (1) Trace of blade edge was used to investigate the tillage characteristics from motion analysis.
- (2) Blade edge trace of stationary rotavator is circular shape for rotary-type rotavator, and ellipse-like shape for crank-type rotavator.
- (3) From the motion analysis results, the soil pulverizing ratio was larger as PTO speed increased and the actual working speed decreased. This is consistent with current known trend. Also, crank-type rotavator had larger rotavating depth and lower soil pulverizing ratio compared to rotary-type rotavator at the same work condition.
- (4) From the field test results using the same models of rotavator and tractor, both soil pulverizing ratio according to the actual working speed and work characteristics by rotavator type are consistent with the results of motion analysis.
- (5) It is able to use motion analysis to compare tillage characteristics between various rotavators simply and quickly. However, it needs more advanced study to achieve the accurate quantitative information of tillage characteristics such as rotavating depth, soil pulverizing ratio and inversion ratio from motion analysis.

Conflict of Interest

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

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