

Study of Coaxial Counter Rotating Rotary Tilling System at Front Rotary Type Compact Walking Tractor

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ABSTRACT

A computer simulation of tilling force has been conducted for a compact walking tractor equipped with rear driving wheels and a front rotary shaft to estimate the effect of tilling force on behavior and tilling depth for a down cut rotary and a coaxial counter rotating rotary. The tractor uses a down cut rotating tine that rotates in the same direction of the driving wheels, and a coaxial counter rotating tine that rotates on the same shaft simultaneously. Further, an actual machine test was conducted to examine the correlation between the simulation and test results. It was demonstrated that by using the coaxial counter rotating rotary, the effect not only stabilized the behavior of the tractor but also accomplished twice the tilling depth of a conventional down cut rotary.

1. Introduction

Compact walking tractors with rotary tilling systems comprised of tines that rotate about a rotary shaft to till the soil are configured with a rotary shaft in two different formats; with and without separate driving wheels.

Of those tractors configured with separate driving wheels, there are rear rotary types, which are configured with a rotary shaft behind the driving wheels as shown in Fig. 1, and front rotary types which are configured with a rotary shaft in front of the driving wheels as shown in Fig. 2.

In the rear rotary type, the direction of the tilling reaction passes close to the unit's center of gravity. Therefore, fluctuations in the tilling reaction do not cause unstable tractor behavior. For similar reasons, the rotary shaft is prevented from lifting up off the earth's surface due to the tilling reaction, which facilitates a more desirable level of deep tilling.

However, fitting the motor in a forward position that will help reduce the handle operating load as the rotary shaft is lifted from the soil's surface during turning makes the tractor

larger. Fitting it in a higher position that allows the rotary shaft to be lifted up as required, makes the center of gravity higher, which causes an unbalance. As a result, the usual positioning for the motor is low and in close proximity to the driving wheels and an iron balance weight is then needed to be attached to the forward underside of the tractor to adjust the center of gravity. The weight of a tractor increases by that of the balance weight (Fig. 3).

Additionally, because the wheels and motor are located in front of the rotary shaft and the handles are set behind the rotary shaft, it inevitably becomes difficult to perform tilling in narrow field areas surrounded by walled boundaries.

In front rotary type tractors, the rotary shaft is mounted on the front of the unit enabling tilling right up to the barrier edge. Moreover, the handles are located behind the driving wheels and the motor is mounted at the front, which provides an optimal center of gravity without having to add a balance weight. This reduces the overall weight of the tractor unit and contributes to its compact design since the motor is not mounted in an overhanging position.

Contrary to the rear rotary type tractors, the direction of

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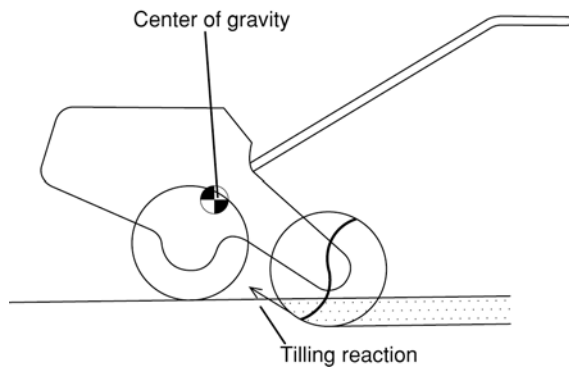


Fig. 1 Rear rotary walking tractor

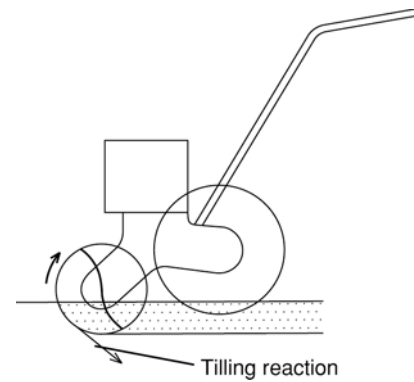


Fig. 4 Front rotary walking tractor with up cut tilling

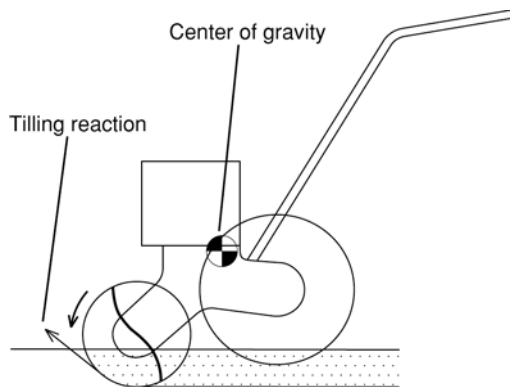


Fig. 2 Front rotary walking tractor

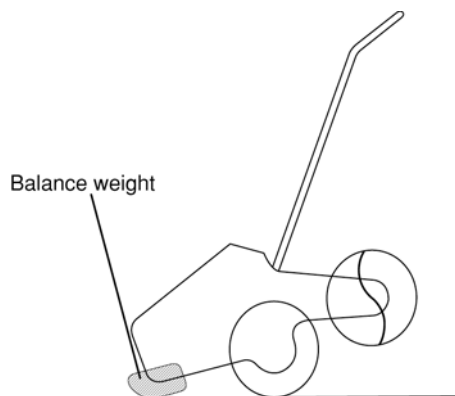


Fig. 3 Turning position of rear rotary walking tractor

the tilling reaction of the front rotary type is offset from the center of gravity. The resultant fluctuation in the tilling reaction causes imbalanced tractor behavior.

Also, in adopting a down cut rotary in which the driving wheel direction and the rotational direction of the rotary shaft are the same, the tilling reaction causes the rotary shaft to lift up, which does not promote tilling depth.

Whereas in adopting an up cut rotary configuration as shown in Fig. 4, in which the rotary shaft rotates in the opposite direction of the driving wheels, the tine bites the soil more forcefully and the tractor tends to lift upward in the back direction leading to what is commonly known as dashing. Regardless, neither of these configurations provide a satisfactory level of performance.

The coaxial counter rotating rotary, which is configured with a rear rotary, is highly praised for its stable deep tilling performance without giving rise to any dashing action. It offsets the reactive tilling force by tilling as the down cut tine and up cut tine rotate along a shared axis. As shown in Fig. 5, combining the coaxial counter rotating rotary with the front rotary configuration would diminish the fluctuating tilling reaction, stabilize tractor behavior, and also serve to suppress any dashing and lifting up of the rotary shaft. This gave impetus to the idea of creating a new tractor that would be lightweight and compact but capable of stable tilling, deep tilling, and tilling up to the barrier edge.

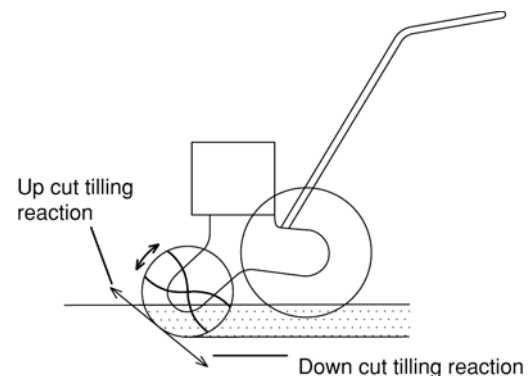


Fig. 5 Front rotary walking tractor with coaxial counter rotating tines

This report describes that the above stated effects were verified by estimating the tractor behavior from its simulated tilling reaction and then correlating the estimation with actual test results.

2. Estimating Tilling Performance

2.1. Calculating Tilling Reaction

A computer simulation⁽¹⁾ of the tilling force was conducted respectively for compact walking tractors with a down cut rotary and a coaxial counter rotating rotary. A newly designed tine for the FF300, Honda's front mount coaxial counter rotating rotary tractor, was used in the testing. The tine layout was designed to provide a constant tilling pitch to minimize the fluctuation in vertical tilling reaction movement. Furthermore, a right and left alternating tine configuration was employed to minimize fluctuation in

the yawing and rolling momentum. These settings provided a tilling width of 450 mm, a tine diameter of ϕ 280 mm, a tilling depth of 120 mm, a machine speed of 0.15 m/sec and a rotary speed of 130 rpm. The soil hardness was set to an approximate value of 20 with a Yamanaka soil hardness tester assuming typical untilled soil.

Figures 6 and 7 show the tine layout configuration and Figs. 8 and 9 show the simulated results of the two tilling reactions. Figure 10 shows the definitions of the six components of the tilling reaction.

2.2. Estimating Tractor Behavior

The six tilling reaction components shown in Fig. 10 were considered for the influences they exert on the tractor behavior during operation.

The yawing momentum, M_z , and the side force, F_x , cause yawing to the tractor and the deterioration of the tractor's straight line stability.

The longitudinal load, F_y , influences the tractor's propelling force causing the tires to slip which in turn causes the actual machine speed to fluctuate during tilling.

The vertical load, F_z , and the pitching momentum, M_x , act to cause the rotary shaft to lift up (+) or sink (-) at the ground contact tire center. If a momentum were exerted to

cause the rotary shaft to lift upward (+) and this momentum was greater than the momentum created by the weight of the tractor unit itself, the rotary shaft would tend to lift up off the ground surface and decrease the tilling depth.

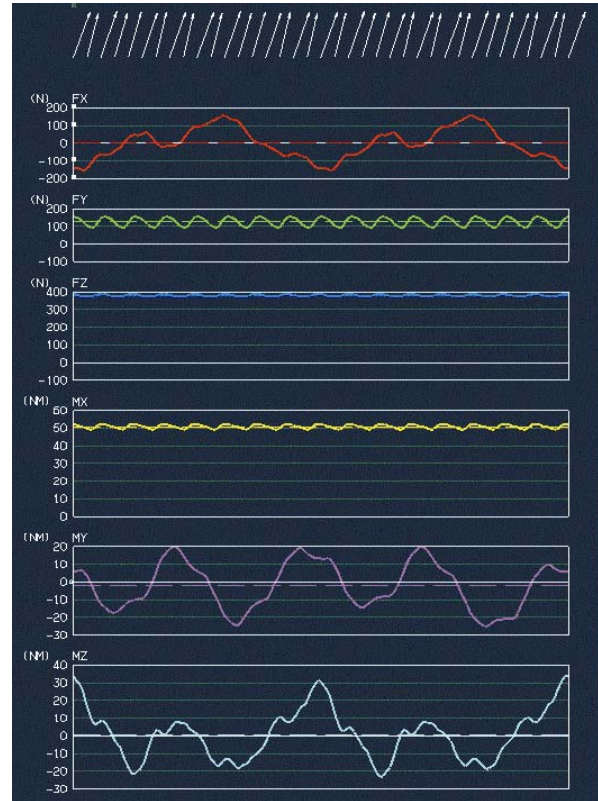


Fig. 8 Simulated result of down cut tilling reaction

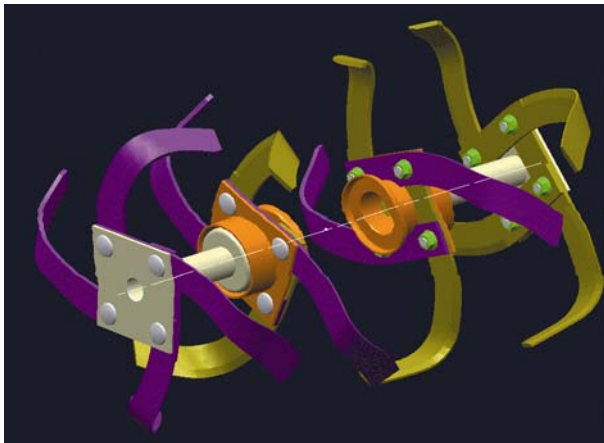


Fig. 6 Tine layout of down cut tines

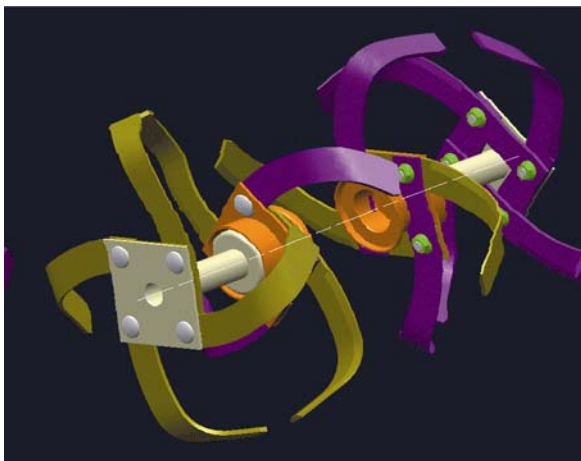


Fig. 7 Tine layout of coaxial counter rotating tines

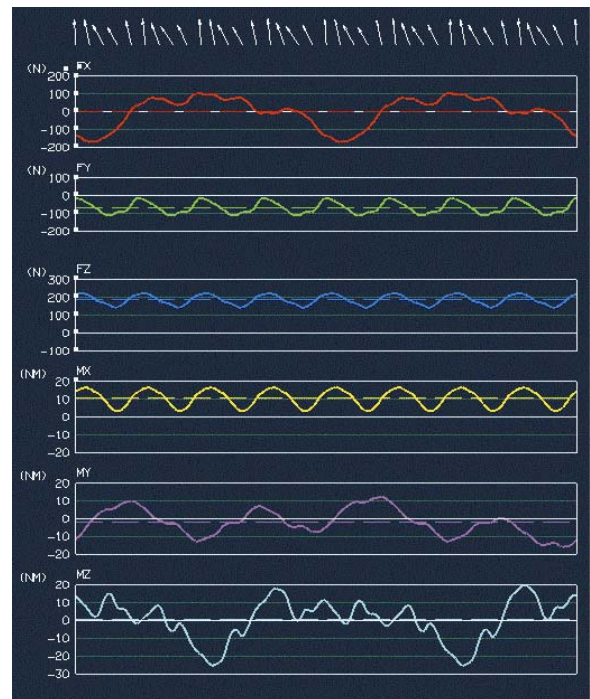


Fig. 9 Simulated result of coaxial counter rotate tilling reaction

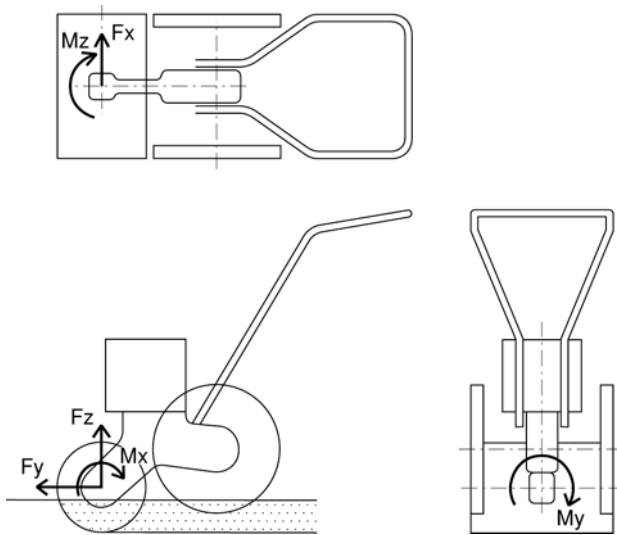


Fig. 10 Six components of tilling reaction

The sinking momentum has been addressed by attaching a tilling depth adjustment wheel in front of the rotary shaft to help prevent sinking. The rolling momentum, M_y , causes the tractor to roll, which prevents even tilling.

Based on actual machine specifications and the calculated results, an analysis was conducted into the performance differences between the down cut rotary (hereafter abbreviated to down cut) and the coaxial counter rotating rotary (hereafter abbreviated to counter rotating) to evaluate the lifting action of the rotary shaft and its effect on tilling depth.

Actual measured values on the FF300 were used to set the tire sinking depth to 20 mm from the soil's surface before tilling.

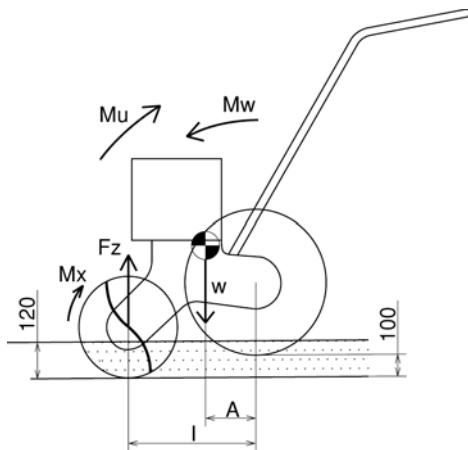


Fig. 11 Moment of tilling reaction and gravity moment on the ground contact center of tires

The average lift momentum value around the ground contact tire center is represented by $\overline{M_u}$ and expressed as follows:

$$\overline{M_u} = \overline{M_x} + l \cdot \overline{F_z} \quad (1)$$

The rotary shaft push momentum exerted by the tractor weight is represented by M_w and expressed as follows:

$$M_w = W \times A \quad (2)$$

Here, in order to help prevent the rotary shaft lift momentum caused by the tilling reaction, the following formula must be satisfied:

$$M_w > \overline{M_u} \quad (3)$$

The FF300 tractor specifications and the average values from the calculated results for F_z and M_x as shown in Fig. 8 and Fig. 9 were used to verify whether this relationship could be satisfied.

Table 1 Comparison of moment of tilling reaction and gravity moment

l(m)	A(m)	W	M _w (Nm)	Rotating direction	$\overline{M_x}$	$\overline{F_z}$	$\overline{M_u}$	Judgment
0.347	0.18	480N	86	Down cut	51	380	183	$M_w < \overline{M_u}$
				Coaxial counter rotating	11	180	73	$M_w > \overline{M_u}$

The calculated results showed $M_w < \overline{M_u}$ for the down cut for which the rotary shaft tended to lift up, and $M_w > \overline{M_u}$ for the counter rotating for which the rotary shaft did not lift up.

2.3. Estimating Tilling Depth

The point at which M_w and $\overline{M_u}$ balance each other out is considered to be an ideal tilling depth. If it is assumed that $\overline{M_u}$ is relative to tilling depth d , then the tilling depth d can be estimated from the ratio of M_w to $\overline{M_u}$, as shown in Table 1.

With M_u being the estimated value when the tilling depth is 120 mm, then the following formula can be used to calculate the value d .

$$d = 120\text{mm} \times \frac{M_w}{\overline{M_u}} \quad (4)$$

Table 2 shows the calculated results.

Table 2 Estimation of tilling depth

	M _w (Nm)	$\overline{M_u}$ (Nm)	d (mm)
Down cut	86.4	183	56.7
Coaxial counter rotating	86.4	73	142

The difference between the down cut and the counter rotating is 2.5 times.

3. Correlation with Actual Machine Test

The correlation between the above calculated results and the actual machine test result was examined. Table 3 shows the specifications of the test machine used.

3.1. Straight Line Stability

Straight line stability is thought to be influenced by the fluctuation in M_z and F_x . The fluctuation ranges M_z and F_x taken from Fig. 8 and Fig. 9 are listed in Table 4.

All the M_z and F_x values associated with the down cut are larger indicating that the straight line stability is less than that of the counter rotating.

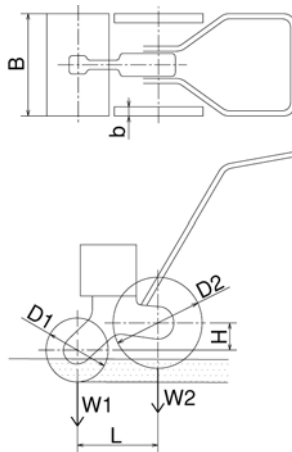


Fig. 12 Explanation of Table 3

Table 3 Specifications of test machine

W1	249N
W2	231N
D1	280mm
D2	400mm
L	0.347m
H	0.160m
b	40mm
B	450mm
Vehicle speed	0.15m/sec
Tine rotating speed	130rpm

Table 4 Fluctuate ranges of yawing moment and side force

		Max	Min	Fluctuate range
Mz	Down cut	35Nm	-24Nm	59Nm
	Coaxial counter rotating	20Nm	-25Nm	45Nm
Fx	Down cut	150N	-150N	300Nm
	Coaxial counter rotating	100N	-160N	260Nm

Table 5 shows the actual test machine results taken from soil hardness tests measured with a Yamanaka soil hardness tester.

As the soil became harder, the down cut configuration showed an irregularity in the forward movement component of the tilling reaction due to lateral differences in soil hardness. This resulted in a deterioration of the tractor's straight line stability. However, no particular differences were detected in the high frequency vibration inferred from the tilling reaction graph waves.

Table 5 Test result of yawing stability

Soil hardness	12	17	22
Down cut	○	△	×
Coaxial counter rotating	○	○	○

3.2. Actual Machine Speed

Fluctuation in the actual machine speed is thought to be influenced by $\bar{F}_y$. Table 6 shows the respective $\bar{F}_y$ values. From this, speed increases for the down cut and speed decreases for the counter rotating can be estimated.

Figure 13 shows the evaluation results of the actual testing machine.

Table 6 Forward element of tilling reaction (average)

	$\bar{F}_y$
Down cut	120N
Coaxial counter rotating	-65N

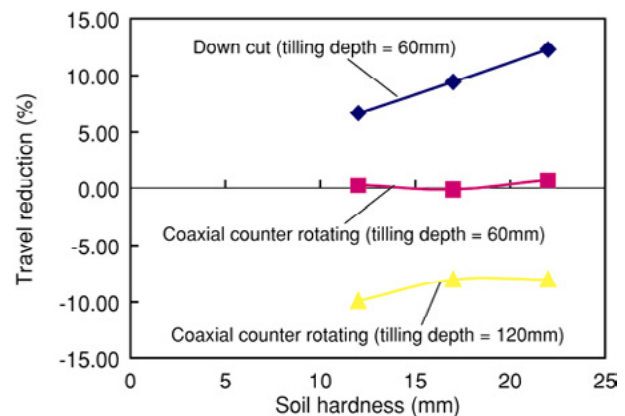


Fig. 13 Travel reduction versus Soil hardness

Test results indicated down cut speed increases and counter rotating decreases, which matches the calculated results. This was due to the tilling reaction directed in the backward direction on the up cut tine being greater than the forward directed tilling reaction on the down cut tine. Therefore, even if the down cut / up cut ratio is greater on the down cut rotary, the tilling reaction on the up cut rotary is superior in the longitudinal direction. Consequentially, since the tilling reaction increases as the soil becomes harder, fluctuation of machine speed also tends to increase.

3.3. Tilling Depth

Table 7 shows the estimated values for tilling depth for a soil hardness of 20.

Figure 14 shows a comparison of estimated values and the results of the actual testing machine.

The comparison was conducted on a soil hardness of 20 for which the counter rotating showed a tilling depth approximately twice that of the down cut. Also, this difference tends to increase as the soil becomes harder.

The counter rotating tilling depth closely approximated the estimated value; however, the down cut tilling depth was 1.5 times greater than the estimated value. This large discrepancy with the estimated value has been left as an issue that will need to be investigated in the future.

Table 7 Estimated tilling depth

	Tilling Depth
Down cut	56.7mm
Coaxial counter rotating	142mm

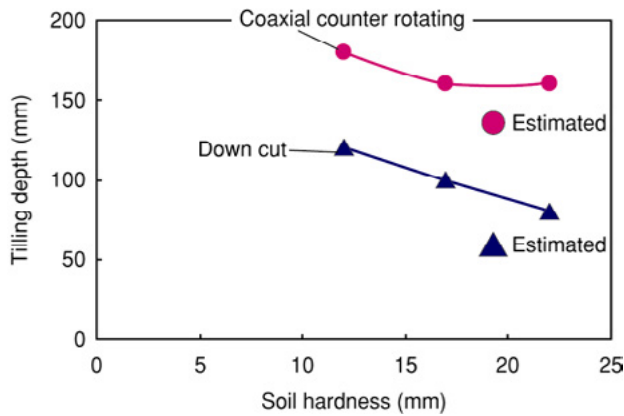


Fig. 14 Tilling depth versus Soil hardness

3.4. Rolling

Rolling is thought to be influenced by the fluctuation range of M_y . Table 8 shows the respective M_y fluctuation ranges.

Table 9 shows the results of the actual testing machine.

Almost no difference was detected between the down cut and counter rotating construction. Since the down cut tilling depth becomes shallower as the soil becomes harder, the absolute value for the tilling reaction decreases. This has led to the belief that because the rolling momentum fluctuation range also decreases, there is little difference between the two formats.

Table 8 Fluctuate ranges of rolling moment

	M_y		
	Max	Min	Fluctuate range
Down cut	20	-25	45
Coaxial counter rotating	12	-16	28

Table 9 Test result of rolling stability

Soil hardness	12	17	22
Down cut	○	△	△
Coaxial counter rotating	○	△	△

4. Conclusion

A comparison of the front rotary type walking tractors was conducted on a down cut rotary configuration and a coaxial counter rotating rotary configuration. The testing yielded the following results.

- (1) When tilling untilled soil with a hardness approximating 20, the coaxial counter rotating rotary showed significant performance improvement over the down cut rotary with respect to straight line stability. This is due to minimized variation in the forward movement component of the tilling reaction due to random variation in soil hardness engaged by the right and left tines.
- (2) The down cut rotary showed an increase in the actual machine speed caused by the tilling reaction. Conversely,

the coaxial counter rotating rotary showed a decrease in speed.

Furthermore, the fluctuation of machine speed tended to increase as the soil became harder.

- (3) In tilling soil with a hardness approximating 20, the coaxial counter rotating rotary achieved a tilling depth twice that of the down cut rotary. Also, the difference in tilling depth tended to increase as the soil became harder.
- (4) No particular difference was detected between the down cut rotary and the coaxial counter rotating rotary with respect to rolling.



Fig. 15 External view of FF300

Table 10 Major specifications of FF300

Items	Specifications
Engine model name	GXV57
Engine type	Air cooled 4-stroke OHV single cylinder
Engine displacement (cm ³)	57
Maximum power (kW)	1.8
Rated power (kW/rpm)	1.0/4 000
Maximum torque (Nm/rpm)	3.0/4 000
Compression ratio	8.0
Minimum specific fuel consumption (g/kWh)	354
Fuel tank capacity (cm ³)	1 100
Overall length (mm)	1 465
Overall width (mm)	465
Overall height (mm)	1 010
Dry weight (kg)	50
Tine speed (rpm)	131
Tilling width (mm)	450
Tine diameter (mm)	φ 280
Starting system	Recoil starter
Main clutch type	Shoe clutch
Transmission speeds	3Forward, 1Reverse

5. Afterword

This research has led to the development of the FF300, a front mounted coaxial counter rotating rotary walking tractor, released for sale in the Japan domestic market in March 2003. The unit is a lightweight, compact walking tractor that is easy to turn and provides increased tilling depth and straight line stability. The FF300 has received high praise and is popular among users.

Figure 15 shows an external view of the FF300 and Table 10 lists the unit's main specifications.

In carrying out this research, the authors would like to extend their deepest appreciation to the cooperating research team, and individuals, both internal and external, for their invaluable support.

Reference

(1) Kokuryo, T. et al.: Development of Coaxial Counter Rotating Rotary Tilling System, HONDA R&D Technical Review, Vol. 6, p. 110-118 (1994)

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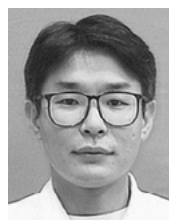
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