Performance of a New Up-Cut Rotary Tiller with Rake-Type Filtering Screen

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Many studies on the rotary tiller with a rotating direction reverse to that of the usual rotary tiller have been carried out over the past years.[1,5] The former is usually called "up-cut rotary tiller" and the latter "down-cut rotary tiller" in Japan,[2,5] hereafter abbreviated "U.C.R. tiller" and "D.C.R. tiller" respectively. As compared with the D.C.R. tiller, the U.C.R. tiller has a tendency to pulverize and turn over soils better, but its tilling capacity is lower and the range of eligible soil conditions is narrower. Because the above merits are not sufficient enough to offset the demerits, the U.C.R. tiller has received little attention directed to practical application so far. In 1966, a special U.C.R. tiller, which has a filtering screen near the rear of rotor for the purpose of enhancing the above merits, was developed in Europe.[4] The filtering screen was made in the shape of a curved rake. When soil clods flow along the movement of up-cut rotating blades, and hit the filtering screen, large clods which cannot pass through the screen fall down first and then small clods which passed through the screen fall down to cover those large clods. This special performance of the U.C.R. tiller with a rake-type filtering screen had also been overlooked for long.

Recently, the use of paddy fields for growing upland crops by converting paddy fields to dry field condition has strongly been pursued with a purpose of adjusting demand-supply balance of rice since 1978 in Japan. The total area of converted fields is more than 600,000 ha at present. Importance of getting good pulverization of soil on the converted fields ranks second to that of drainage works. Accordingly, the authors examined tilling and harrowing methods by the use of U.C.R. tiller with a filtering screen, and studied adaptability and effectiveness of this type of tiller by designing a series of prototypes from 1978. Based on the result of this study, many domestic manufacturers began to produce U.C.R. tillers with a rake-type filtering screen on the commercial basis. Recently, tillers of this type are gradually spreading as a suitable machine for preparing seeding or transplanting beds for upland crops and vegetables on clayey soils which are difficult to pulverize.

Construction of U.C.R. tiller with rake-type filtering screen

The main specifications of the authors' prototypes are shown in Table 1. Fig. 1 schematically gives the working principle of the final, improved prototype. Plate 1 shows the rear and inside view of the prototype.

The structure of filtering screen has a marked influence on all phases of tiller operation, from the power requirement through to the final soil condition. Therefore, the opening[a] of the rake-type screen was investigated at the first stage of the study. The results obtained are shown in Fig. 2, in which the pulverizing performance is evaluated in terms of clod size distribution in the tilled surface

a) : Space between arms of the rake-like screen.

Table 1. Main specifications of experimental up-cut rotary tillers with rake-type filtering screen

Type		A	B	C
Tilling width (mm)		1800	1600	1200
Kind of blade		Curved blade		
Number of blades		52	32	24
Average tilling width per single blade (mm)		35	50	100
Attaching method of blades		Holder type		Flang type
Diameter of rotor (mm)		520	510	490
Screen	Diameter of rake arms (mm)	12	12	10
	Opening (mm)	28	28	25
Rubber sheet cover		Without	With	
Year of manufacture		1978	1980	1981

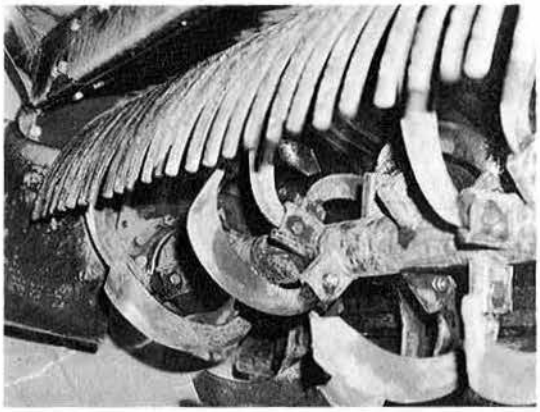
Plate 1. Arrangement of the rake-type filtering screen and curved blades

layer (from the soil surface to the depth of ca. 5 cm), because the better pulverization in this layer directly results in the higher accuracy of seeding or transplanting. This result was obtained in the Attached Farm of the Institute of Agricultural Machinery. Most of the experiments shown below were conducted in the same farm, unless otherwise indicated by notes of tables and figs.

Fig. 2 shows that nearly satisfactory performance can be obtained with the opening slightly narrower than 3 cm, and that such a good soil-pulverization is mainly given by the filtering screen. In Fig. 3, soil pulverization ratio is shown. This word signifies percentage of soil fraction composed of soil clods less than 2 cm in size to the total amount of all clods produced by tilling, as usually called in Japan. It is observed from Figs. 2 and 3 that there was only a little disturbance in the flow of tilled soils when the screen had the opening mentioned above.

On the other hand, the size of arms of the rake is also one of the important problems. At the early stage of this study, emphasis was laid on the strength so that the diameter of arms was 12 mm, as shown in Table 1. However, the tests conducted on the field of clayey soil with relatively high water contents showed that the screen was sometimes clogged. Therefore, the diameter of arms was thinned to 10 mm. In this connection, an experiment was done to know the relationship between clogging and arm sizes. A rake-type screen composed of three parts, side by side, having different diameters of arms, i.e., 10(L), 8(M) and 6 mm(S), was prepared, and attached to the prototype C (in Table 1). The distance between arms was 35 mm (center to center) in each part. The tilling test was done in a loamy field with relatively high water content after the rain, that is to say, in such a field condition as the soil stuck easily on the arms of rake. As the result, the S part was not clogged at all and the M part was a little clogged at the time when the L part was wholly clogged. It was also observed that clogging was caused at first by soil sticking on the arms and then it developed by further sticking of soil, straws, weeds, etc. Thus, it became evident that the surface area of arms is an extremely important factor for clogging. On the other hand, the steel arms (S45C) of 6 mm in diameter were deformed after the tilling work in the field of clayey soil, whereas the arms of 8 mm were kept without deformation. Diameter of 6 mm can be used only for the filtering screen specially designed for loamy soils.

The another problem of this machine is soil

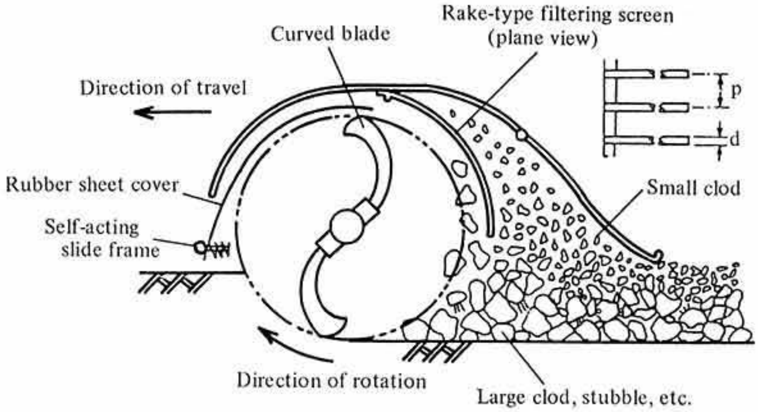

Fig. 1. Structure and working principle of the up-cut rotary tiller with a rake-type filtering screen
Notes: p = 35~38 mm, d = 8~10 mm

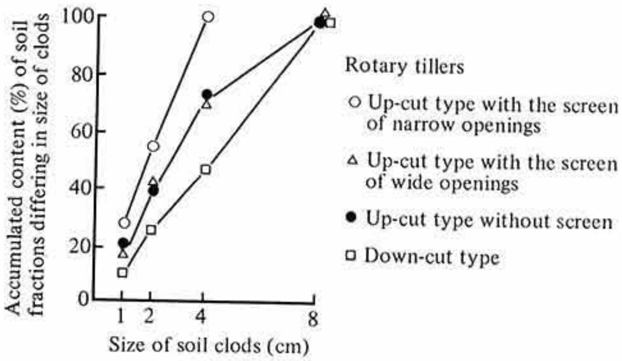

Fig. 2. Effect of up-cut tilling and opening of screen on clod size distribution in the surface layer of tilled soil

Notes 1) Up-cut rotary tiller: A-type with the screen having the opening of 28 mm (narrow type) or 68 mm (wide type). Tractors: 69 PS

2) Soil texture: SiC. Water content: 44.8% (d.b.). Field condition: Rice stubbles remain on field, chopped straws scattered. Tilling pitch: 8 cm

3) Surface layer: From the soil surface to the depth of ca. 5 cm

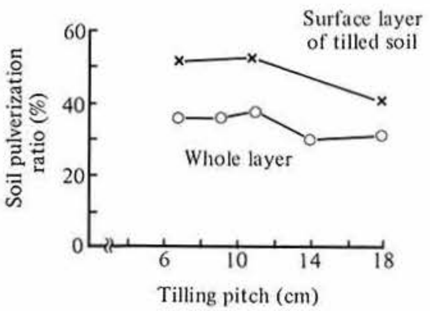

Fig. 3. Effect of rake-type filtering screen on soil pulverization ratio

Notes 1) Soil pulverization ratio: Percentage of soil fraction composed of soil clods less than 2 cm in size to the total amount of all clods produced by tilling

2) Up-cut rotary tiller: B-type Tractor: 69 PS. Rotating speed of rotor: 209–218 rpm. Tilling depth: ca. 13 cm

3) Soil texture: SiC Water content: 50.3% (d.b.) Field condition: Rice stubbles remain, straws removed.

sticking to the inside of top covers. In order to solve this problem, a cover made of a rubber sheet, which was fixed to the frame at the lower end and kept free at the upper end, as shown in Fig. 1, was introduced. Its performance and durability were good enough for practical use. In addition, preventing the scattering of clods to forward of the rotary tiller and securing the inflow of clods to the rotor were mostly attained simultaneously by constructing a self-acting slide frame on the lower end of the rubber sheet cover. (See Fig. 1).

Performance in pulverizing soils and burying stubbles and weeds under the ground

Table 2 shows the performance of this machine in preparing seedbeds of soybeans under the condition of the soil which was more or less easily pulverized because one year had passed since the field was converted from the paddy field to the dry field. As compared with the D.C.R. tiller, this machine showed about 16% higher soil pulverization ratio in the surface layer, in spite of the double tilling pitch. As a result, percentage of soybean stands and final yield were increased by about 12% and by about 50 kg/10 a, respectively.

Table 2. Effectiveness of the up-cut rotary tiller with filtering screen used for preparing a seedbed of soybean

Item		Test plot	
		DN	UP
Rotating speed of rotor	(rpm)	411	194
Forward speed	(m/s)	0.30	0.28
Tilling pitch	(cm)	4.4	8.7
Tilling depth	(cm)	7.7	11.0
Soil pulverization ratio (%)	in surface layer	69.5	85.7
	in whole layer	69.2	71.2
Percent soybean stands		80.9	92.4
Yield (winnowed soybean grains, kg/10a)		316.5	365.7

Notes 1) DN: Down-cut rotary tiller (1.46 m) and 25 PS tractor
UP: B-type (See Table 1) and 35 PS tractor
Seeding: Unit-type seeder.

2) Soil texture: LiC–SiC. Water content: 40.7% (d.b.)

3) Field condition: After harvest of soybean cultivated after rice.

4) By the Saga Pref. Agr. Exp. Sta.

In another test, this machine was used for preparing a bed for transplanting onion nurselings, which requires fine pulverization of soil. The test was conducted in the field just after the harvest of rice, and hence soil pulverization was not easy there. As shown in Table 3, the soil pulverization ratio of the surface layer was only about 50% even after the double runs of the D.C.R. tiller, and the ratio of nurselings transplanted with poor poses was about 7%. On the other hand, the soil pulverization ratio of the surface layer was about 80–90% even after a single run of the U.C.R. tiller with a filtering screen operated at about the same forward speed and

Table 3. Effectiveness of the up-cut rotary tiller with filtering screen used for preparing a bed for transplanting onion nurselings

Item		Test plot				
		DN		UP		
Rotating speed of rotor	(rpm)	343	346	275	268	185
Forward speed	(m/s)	0.14	0.14	0.13	0.13	0.28
Tilling pitch	(cm)	2.4	2.4	2.8	2.9	9.2
Tilling depth	(cm)	11.1	11.1	11.5	11.5	11.0
Number of tilling times		2	1	1	1	1
Soil pulverization ratio (%)	in surface layer	49.2	42.8	92.0	81.5	56.3
	in whole layer	60.0	48.3	84.8	77.1	49.5
Quantity of rice straws (kg/10a)		960	1080	0	1120	1180
Ratio of buried straws (%)		94	91	—	91	89
Ratio of buried rice stubbles (%)		77	91	—	99	99
Ratio of nurselings transplanted in poor poses (%)		7.3	8.9	2.5	3.3	7.3

Notes 1) DN: Down-cut rotary tiller (1.70 b). UP: B-type (See Table 1). Other machines used: 35 PS tractor and transplanter
2) Soil texture: LiC–SiC. Water content: 40.1% (d.b.)
3) Field condition: Rice stubbles left on field, chopped straws scattered.
4) By the Saga Pref. Agr. Exp. Sta.

tilling pitch as the D.C.R. tiller. Consequently, the ratio of nurselings transplanted with poor poses decreased to around 3%. Besides, it was often recognized with D.C.R. tillers that the soil pulverization ratio of the surface layer had a tendency to be less than that of the whole layer, that is to say, small clods tend to sink to the lower layer.

Table 3 also shows that the U.C.R. tiller with a filtering screen was extremely effective in burying rice stubbles under the ground. However, the performance of burying straws under the ground did not differ between the two rotary tillers, because the straws had been chopped into pieces of about 5 cm long on average. But it was confirmed by other field tests that this machine can bury almost all corn straws chopped by a flail mower and weeds under the ground. The buried materials, however, are mostly sandwiched in the nearly middle layer. And also, as the tilled layer is considerably spongy after burying stubbles, straws, etc. under the surface layer, a press roller has to be attached to the U.C.R. tiller with a filtering screen, especially for the work of upland fields.

Although the machine can give such a high degree of surface layer pulverization as mentioned above, the pulverization degree varys mainly with soil textures, water contents and tilling pitches. Fig. 4 shows the characteristics of pulverization of surface layer in a paddy field of light clay soil, which is considerably difficult to pulverize. The less the tilling pitch or the water content, the higher the soil pulverization ratio. The filtering screen is often clogged under the condition that clods stick together to form so-called "dumplings" due to high water contents. However, this should be regarded as a case beyond the adaptability of the machine.

Characteristics of power requirement

The results of field tests to compare the

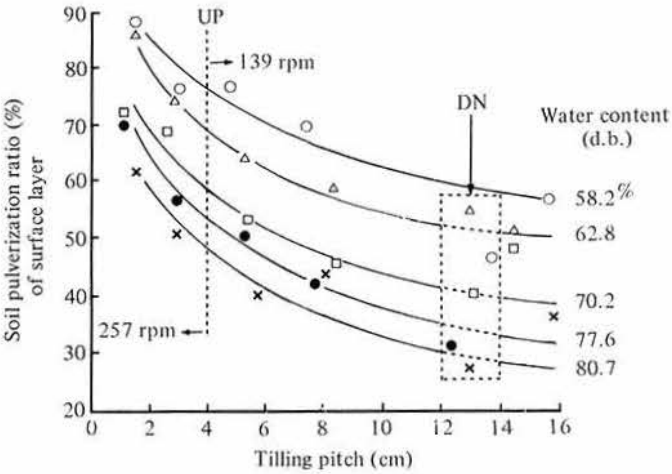

Fig. 4. Relationship among soil pulverization ratio of surface layer, tilling pitch and water content of soil

Notes 1) UP: Rotating speed of rotor of the up-cut rotary tiller with a rake-type filtering screen. DN: The inside of dotted lines shows data after tilling three times with a down-cut rotary tiller (1.80 m, 190 rpm).

2) Up-cut rotary tiller: B-type. Tractor: 43~45 PS. Tilling depth: 13~15 cm. Soil texture: LiC. Field condition: Rice stubbles remain, straws removed.

3) By the Niigata Pref. Agr. Exp. Sta.

working characteristics of the U.C.R. tiller with a filtering screen and the D.C.R. tiller are shown in Fig. 5. The power requirement of PTO-shaft was higher in the former, and the difference of power requirements increased with increasing forward speeds. Besides, the slip ratio of the tractor was plus values in the latter, whereas minus values in the former, and the absolute values of the both slip ratios increased with increasing forward speeds. The force acting to the tractor, when estimated by the result of studies on D.C.R. tillers,[3] is the driving force of around 350 kgf at the forward speed of 0.55 m/s with the D.C.R. tiller working by the width of 1.37 m, whereas the draught force of around 350 kgf at the forward speed of 0.35 m/s with the U.C.R. tiller working by the width of 1.20 m. Therefore, when a tractor of a given power is used, the U.C.R. tiller with a filtering screen must run with lower forward speeds in comparison with the D.C.R. tiller.

However, the former can produce considerably better soil-pulverization necessary for sowing seeds and for transplanting nurselings than the latter.

After all, the result of studies for five years has proved the followings; judging from the relationship between the power requirement and the soil pulverization ratio of the surface layer, the work of the U.C.R. tillers with a filtering screen at low forward speed is more efficient than that of D.C.R. tillers, when the fine pulverization of the surface soil layer necessary for sowing seeds and for transplanting nurselings is required with soils difficult to pulverize.

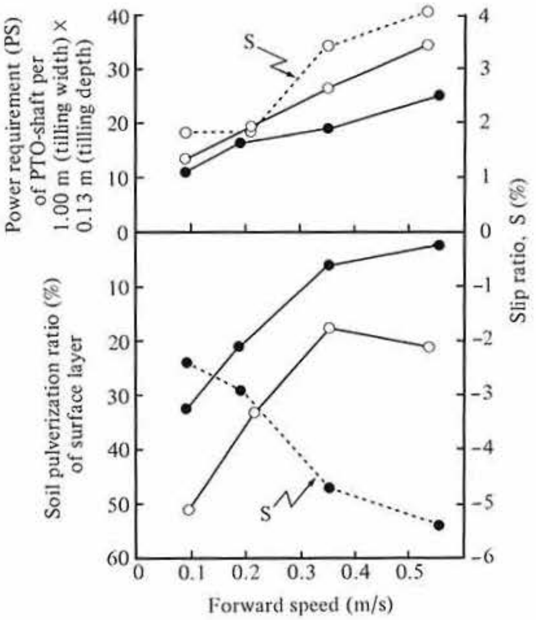

Fig. 5. Comparison of characteristics of tilling work between the up-cut rotary tiller with a filtering screen and a down-cut rotary tiller

Notes 1) Tractor: 69 PS. Rotating speed of PTO-shaft and rotor: ca. 740 rpm and 222 rpm, respectively

2) Soil texture: LiC. Field condition: Rice stubbles remain, straws removed. Water content: 45.7% (d.b.)

Studies to be done in future

As great power to throw up soil clods is required for manifesting the full potential of the U.C.R. tiller with a filtering screen, the rotating speed of at least 200 rpm was estimated necessary by using the U.C. rotors to which curved blades originally designed for D.C.R. tillers were attached. On the other hand, it is shown experimentally and theoretically that smaller diameters and lower rotating speeds of rotors are favorable for the power requirement of PTO-shaft. Therefore, it is urgently needed to develop designing criteria for rotors which secure the effective handling of clods with reduced rotating diameters and speeds.

References

1) Hendrick, J. G. & Gill, W. R.: Rotary-tiller design parameters. Part I–III, *Transactions of the ASAE*, 14 (4), 669–683 (1971).
2) Kawamura, N. & Shibusawa, S.: Studies of deeper rotary tillage. I. *J. Soc. Agr. Mach.*, 42 (2), 211–219 (1980) [In Japanese with English summary].
3) Kisu, M. et al.: Studies on trafficability, tractive and rotary tilling performance of tractor. Tech. Rep., Inst. Agr. Mach. (1966) [In Japanese with English summary].
4) "Lely-Buryvator" Rotary Cultivator, *Farm Implement and Machinery Review*, 92 (1099), 1266 (1966).
5) Matsuo, M.: Studies on the up-cut method of rotary cultivation (I), *J. Soc. Agr. Mach.*, 24 (3), 129–133 (1962) [In Japanese with English summary].

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