

Full Paper

Field evaluation of slot openers for minimum tillage (part 3) - Dried soil cover on the slot -

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Abstract: The direction and feature of slot opener can produce different amount of dried soil cover on the slot. Four different slot openers, namely of a bubble coulter, a V-shaped slot opener, a VR_A-slot opener and a VR_B-slot opener were tested in the rice field which was covered with chopped arable weed. The direction of these four slot openers was set following the direction of travel. Several field trials of all slot openers were carried out to validate their drill performance on sandy loam soil with four different levels of residual density (0, 2, 4, 6 t/ha) and three levels of soil moisture content (31.67, 46.34, 49.07 %). Significant interactions among the major factors were discussed for each slot opener. High amounts of dried soil cover on the slot were discerned in the case of a VR_A-slot opener, especially under lower levels of soil moisture content. Some amount of dried soil cover on the slots was observed for the VR_B-slot opener. Generally, dried soil cover on the slot tended to decrease with the increase of residual density after the operation of the bubble coulter and the V-shaped slot opener, due partly to hairpinned residue in their slots.

Keywords: rice, slot opener, residue handling, minimum tillage, crop residue, dried soil

Introduction

Minimum-tillage systems, with the purpose of retaining soil moisture content, reducing time requirement and saving fuel consumption, have recently been replacing traditional tillage practices. Furthermore, retaining crop residue on the field surface can provide a resource of plant nutrients, improve organic matter, increase soil moisture content and increase infiltration rate [1, 2]. A slot opener design should aim towards low soil disturbance to minimise loss of water from the slot during post-seeding in dry spell, as addressed by Janelle et al. [3]. Arable weeds are a problem in the rice field when using the minimum-tillage systems. For successful plantation of rice in the field, one should be concerned with how to manage arable weeds before seeding trial, especially before the rainy season or the first crop of planting period. Instructions of weed management procedure are very rare. The chopping or mowing action by machine equipment is one of the alternative ways for weed management. Previous crop residue is claimed to cause variation in seed placement indices such as depth [4-7].

Slot profile should be compact and clear-cut to enable the slot opener to more comfortably place the seed at the bottom of the slot [8]. The configuration of the slot opener and the direction of its revolution can produce different amounts of loose soil that covers the slot. A high amount of loose soil in the slot does not necessarily secure seed placement, seeding depth and planting process.

The objective of this research work is to comparatively study dried soil cover in each slot which may affect soil moisture content and residue density. The result from this research can identify the different performance of each slot opener, which can be adapted to field condition.

Materials and Methods

Field conditions

For chopped arable weed condition, the study was conducted at Saiki, Tsukuba city, Ibaraki Prefecture, Japan (latitude of 36°12'N, longitude of 140°05'E) from August to September 2005. In 2004, rice was not planted in the field, which was left open and covered with Japanese arable weeds. Before testing, the weeds in the rice field were cut using a mowing implement (Figure 1a.). Then chopped arable weeds were collected and removed from the field. A field test was done by dividing a specified field area into four plots and the chopped arable weeds were spread manually over the plots at the rates of 0, 2, 4, and 6 t/ha. The size of each subdivided plot was 20 m × 20 m. The average length of the chopped arable weeds was 11-12 cm. To confirm the density of the covered residue, a 1-m² steel rectangular plank was placed on each plot. Measurements were made in triplicate for each trial. Basic soil characteristics were represented by the soil moisture content and its composition determined from samples taken from a depth of 100 mm in each experimental field treatment. The properties of the soil, namely dry bulk density, moisture content (31-49%), particle size distribution, and penetration resistance were investigated. A certain amount of rainfall as well as a dry spell was needed in order to control the moisture content in the field so that soil hardness could be measured. It took roughly a one-month interval for each testing.

Soil penetration resistance was measured by a cone penetrometer (Daiki Rika Kogyo Co., Ltd, Japan, Model 5500) and found to be in the range of 1.37-1.42 MPa. The tested soil consisted of 77%

sand, 22% silt and 1.0% clay. Thus, this soil type was classified as sandy loam according to JIS A 1204 Standard. Table 1 summarises the tested properties of the soil.



(a)



(b)

Figure 1. Field preparation: (a) chopping arable weeds by using a mowing implement, (b) chopped arable weeds laid on the field

Table 1. Summarised items related to the measurements of soil

| Item | Value |
|---|----------------------|
| Sand : Silt : Clay (%) (Particle size distribution) | 77 : 22 : 1 |
| Residue type | Chopped arable weeds |
| Residue density (t/ha) | 0, 2, 4, 6 |
| Moisture content (%) | 30, 40, 50 |
| Dry bulk density (Mg/m^3) | 0.82-0.86 |
| Working depth of slot opener (mm) | 30-40 |
| Soil penetration resistance (MPa) | 1.37-1.42 |

Tested implements

Four different slot openers were evaluated on a drill performance test. Figure 2(a) shows the full view of a bubble coulter. This slot opener was a circular disc corrugated along the circumferential edge and made from high carbon steel, SK-5. The shape of the bubble coulter portion was expected to



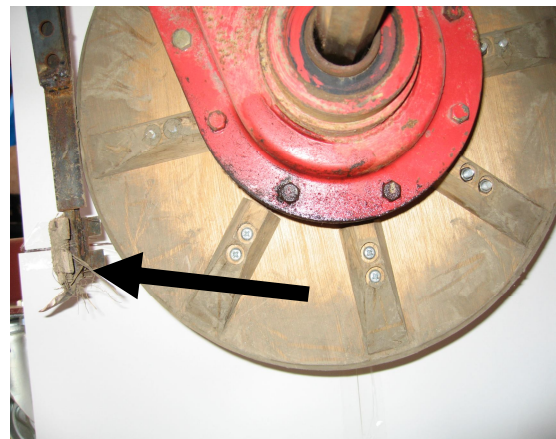
(a)



(b)



(c)



(d)

Figure 2. Four slot openers: (a) bubble coultter, (b) V-shaped slot opener, (c) VR_A-slot opener, (d) VR_B-slot opener (Arrow indicates residue handling device.)

accomplish soil loosening in the agitated zone area and required comparatively less force in penetrating into the soil during operation. Then the V-shaped slot profile could be generated after the operation of this machine.

Figure 2(b) presents a V-shaped slot opener that was made from hard wood. Eight equidistant inclined trapezoidal projecting portions were placed on both sides. This slot opener was designed to provide a smooth clear soil cutting and a compressed slot. The inclined trapezoidal projecting portions were capable of creating a V-shaped slot profile.

The entire body of a VR_A-slot opener is shown in Figure 2(c). This slot opener was composed of a V-shaped slot opener incorporated with a residue handling device made from two straight steel rods which were installed 225 mm apart in front of the V-shaped slot opener. The arrangement of the residue handling rods functioned to push the residue aside from the slot to secure a good seeding operation.

The the case of a VR_B-slot opener this is shown in Figure 2(d). This slot opener consisted of a V-shaped slot opener with a residue handling device mounted 225 mm apart in front of the main body.

This device was made from an equal-leg steel angle with a size of 50 (length) × 50 (width) × 4 (thickness) mm. The function of this residue handling device was to move the residue beside the slot to enable the seeds to be safely placed at the bottom of the slot after the slot making operation.

Experimental design

Weed problem is the bottleneck of the minimum-tillage system especially during the rainy season. Weeds compete with rice for nutrients, light, soil moisture, etc. While conventional method of weed control is inconvenient, alternative methods are hard to find. Residues left on the field surface possibly affect moisture content, hardness of strata, and soil macro-pores. In utilising residues to maintain desirable moisture content and to prevent erosion, a stable growing rate in the field is considered as a criterion to evaluate its effectiveness. In these trials of finding a preferable placement of the seeds, a working depth was set at 30- 40 mm and the travelling speed of the tractor was set at 2.5 m/s. A 3×4×4 factorial experiment in completely randomised design was adopted to evaluate the dried soil cover on the slot. A statistical analysis was performed using the SPSS software to prepare the required field area. Each treatment was performed in triplicate and the mean values of the treatments were analysed using Duncan's Multiple Range Test (DMRT) method. The results of these analyses on drill performance were expected to be used for assessing the slot making capability of the tested machines.

Methodology of the field measurement

Dried soil cover on the slot was the amount of loosening soil that was moved into the slot after being made by the slot opener. The amount of loosening soil in the slot was prone to hamper seeding depth mechanism, which would bring about poor germination. After the drill performance test, hairpinned residue in the slot was removed carefully. Then loosening soil on each slot was collected and put in an envelope. Loosening soil samples in the envelopes were dried at 110 °C for 24 hours in the oven and were then weighed. Loosening soil samples were collected in triplicate at 150 mm (length) from each slot immediately after seeding operation.

Hairpinned residue is defined as the amount of crop residue moved into the slot by the mechanical action of the slot opener, as presented in Figure 3. As for residue density, it is defined as the amount of crop residue covered in a specified field area, as shown in Figure 4.

Results and Discussion

Dried soil cover on the slot

Four different types of slot openers were comparatively studied in relation to the dried soil cover on the slot in the four subdivided plots. Loosening soil in the slot was mainly used to confirm its contribution towards the improvement of the per cent germination of rice, which can be reduced by a high amount of loosening soil in the slot because the rice seeds cannot be placed at the bottom of the slot. Figure 5 shows similar trend of the dried soil cover on the slot among the three tests with different



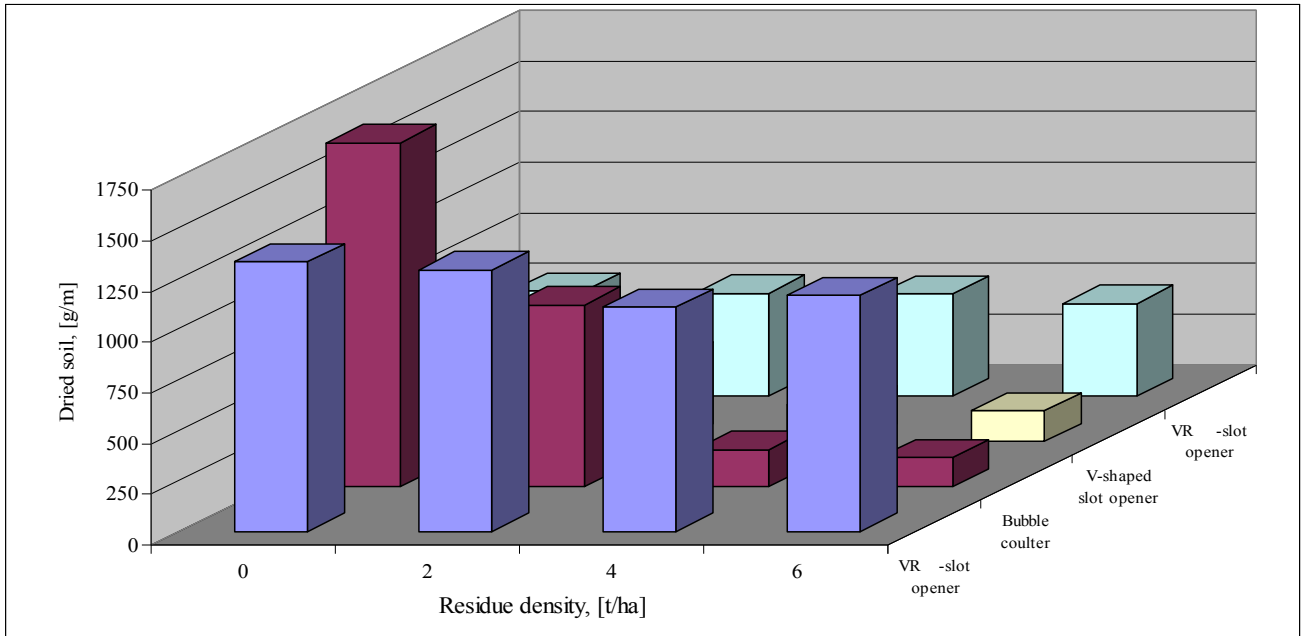
Figure 3. Hairpinned residue (indicated by arrow) **Figure 4.** Residue density (in the rectangle)

moisture content values (31.67, 40.34, and 49.07 %). In general, with an increase of residue density, it could be found that the dried soil cover on the slot decreased steadily. However, the decreasing rate of dried soil cover on the slot fluctuated irregularly due to the effect of the field surface condition and the residue density in particular. In the case of bare soil or lower level of residue density, both the bubble coulter and the VR_A -slot opener generated high amount of dried soil cover on the slot. With an absence of residue handling devices, both the bubble coulter and the V-shaped slot opener tended to press a high amount of residue into the slot and bring the minimum loosening soil in the slot under higher levels of residue density. In the case of the VR_B -slot opener, some amount of dried soil cover on the slot was obviously observed under the entire combination.

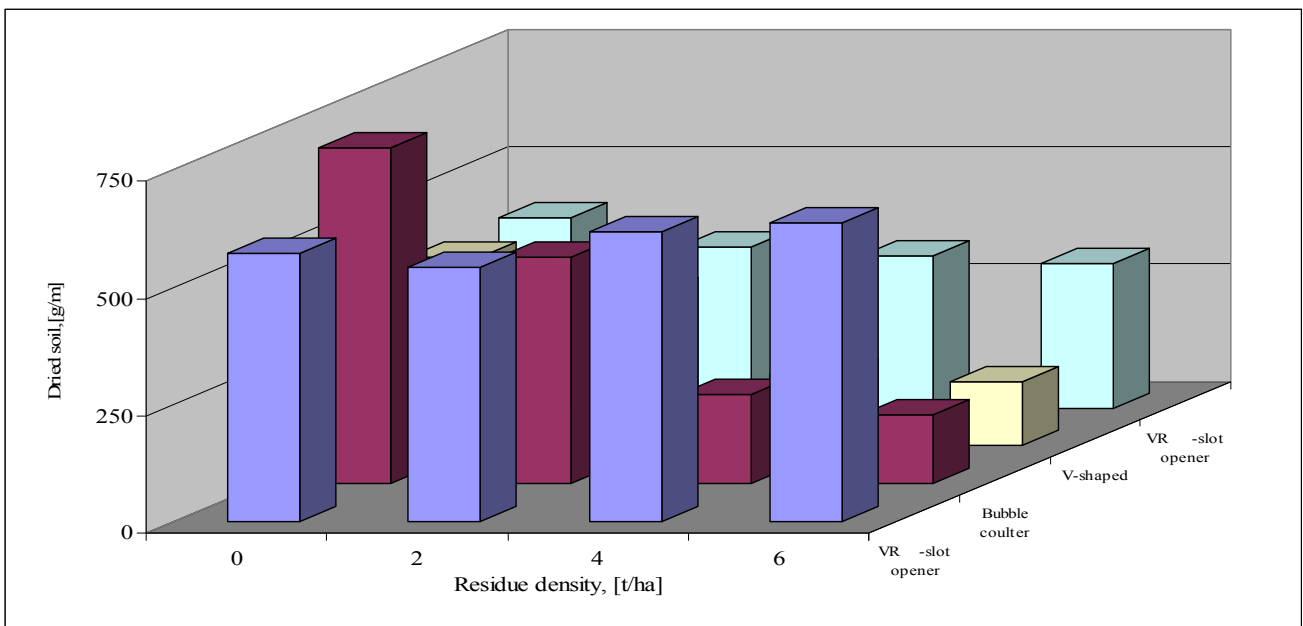
The VR_B -slot opener induced some amount of dried soil to cover on the slot when compared to other slot openers. This result can be used to confirm that the configuration of a V-shaped slot opener and its rotation tend to produce some amount of loosening soil in the slot.

Furthermore, variation analysis was used to verify the practical effectiveness, as shown in Table 2. The results from ANOVA indicated that all major factors and their interactions were found to be significantly different at $P=0.05$. The statistical analysis showed significance difference in all parameters, thus implying an engineering significance for improving the major design parameters. In fact, the modification of a prototype slot opener had been proposed as an ideal model for slot making. But the design of the slot opener needs some adjustment of the opener for the success of the seeding mechanism.

A comparison based on mean values using DMRT method was represented in Table 3. Through the analysis of this experiment, it could be emphasized that an unclear cut of the slot profile due to high amount of loosening soil cover on the slot had been observed after the operation of the VR_A -slot opener under the entire combination. This result came from the fact that the residue handling device disturbed the aggregate seeding zone before the seeding operation. High amounts of soil particles were falling into the slot so that soil moisture loss, soil covering, and seeding depth could not be controlled after the slot making operation of this machine.

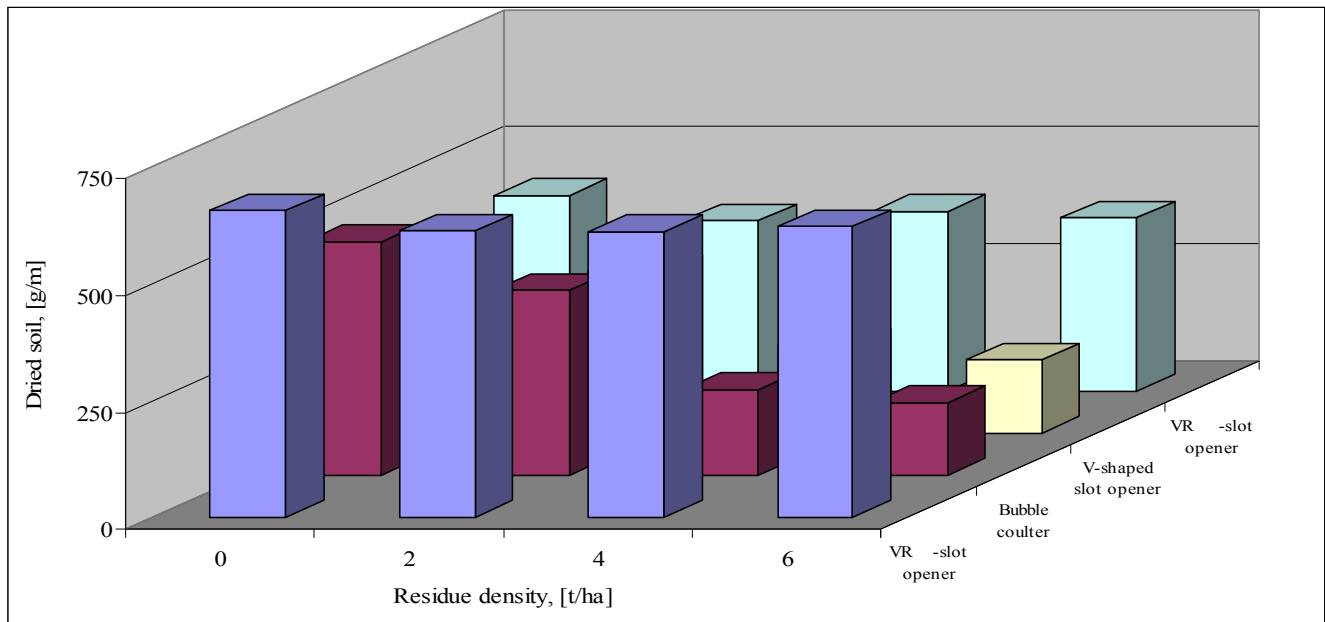


(a) 31.67 % moisture content



(b) 40.34 % moisture content

Figure 5. Results of dried soil tested



(c) 49.07 % moisture content

Figure 5 (continued). Results of dried soil tested**Table 2.** ANOVA results related to dried soil cover on the slot

| | Degree-of-Freedom | Sum of Squares | Mean Square | F |
|----------------------|-------------------|----------------|--------------|--------|
| Treatment | 47 | 16,424,437 | 349,456.1 | |
| A (Residue density) | 3 | 2,247,597.5 | 749,199.17 | 74.82* |
| B (Slot opener) | 3 | 5,607,983.94 | 1,869,327.98 | 186.7* |
| C (Moisture content) | 2 | 2,757,409.04 | 1,378,704.52 | 137.7* |
| A×B | 9 | 2,371,849.12 | 263,538.79 | 26.3* |
| A×C | 6 | 630,380.3 | 105,063.38 | 10.49* |
| B×C | 6 | 1,668,293.35 | 278,048.89 | 27.77* |
| A×B×C | 18 | 1,140,023.85 | 63,384.65 | 6.33* |
| Error | 96 | 961,212 | 10,012.62 | |
| Total | 143 | 17,385,649 | 121,577.96 | |

* significant at P=0.05

Table 3. Comparison between mean values of dried soil covered on the slot

| Residue density (t/ha) | Moisture content (%d.b.) | Mean value (g) | | | |
|------------------------|--------------------------|----------------|----------|------------------------------|------------------------------|
| | | Bubble coulter | V-shaped | VR _A -slot opener | VR _B -slot opener |
| 0 | 31.67 | 1696.7a | 483.3b | 1330.0a | 520.0b |
| 2 | | 896.7b | 400.0c | 1290.0a | 510.0c |
| 4 | | 183.3c | 183.3c | 1106.7a | 508.3b |
| 6 | | 143.3c | 150.0c | 1166.7a | 460.0b |
| 0 | 40.34 | 717.3a | 402.7b | 571.3ab | 405.7b |
| 2 | | 482.0a | 325.7b | 541.7a | 342.3b |
| 4 | | 189.3c | 154.0c | 618.0a | 325.0b |
| 6 | | 148.0c | 136.3c | 638.3a | 307.3b |
| 0 | 49.07 | 496.7b | 422.3b | 653.7a | 417.0b |
| 2 | | 393.3b | 344.0b | 610.0a | 362.0b |
| 4 | | 182.7c | 186.0c | 609.3a | 382.7b |
| 6 | | 155.0c | 155.0c | 620.0a | 369.0b |

Note : Different superscripts in the row indicate significant differences between the mean values at P=0.05.

In the case of the bubble coulter, a high amount of dried soil cover on the slot had been observed with bare soil and a lower level of residue density. However, the amount of dried soil cover on the slot decreased with an increase of soil moisture content. This was due to the pertinent physical variables of the soil and the irregular field test of each of the four subdivided plots. However, under higher levels of residue density, minimum amount of dried soil cover on the slot had been observed, which was due partly to some amount of hairpinned residue in the slot. This result could be used to conclude that the configuration of the bubble coulter representation was unsatisfactory for a slot making operation under the entire combination.

Under bare soil and lower levels of residue density, the amount of dried soil cover on the slot tended to be stable in the case of the VR_B-slot opener. Some amount of loosening soil covered on the slot after the slot making action had been observed. These results came from the fact that its configuration and rotation produced some amount of dried soil cover on the slot.

In the case of the V-shaped slot opener, some amount of dried soil on the slot was discerned under the conditions of bare soil and lower levels of residue density, while minimum amount of dried

soil was observed at higher levels of residue density, being partly due to hairpinned residue in the slot. Under this particular experiment, it could be confirmed that the set rotation of all slot openers had produced some amount of residue and fine loosening soil falling into the slot after the slot making operation. This behaviour would tend to hamper depth seeding mechanism, thus causing poor germination percentage. Thus, for a successful operation, there should be a modification of the rotor blade of the reversible V-shaped slot opener to allow a theoretical study of the experiment concerning slot configuration, hairpinned residue and dried soil cover on the slot for the succeeding seeding operation.

Conclusions and Recommendations

This research was conducted to clarify the relationship between the residue density, the soil moisture content and four different types of slot openers by taking into account the dried soil cover on the slot and the residue handling in conjunction with the drill performance, as had been discussed extensively based on the field test. Selected findings can be drawn as follows.

- (1) A bubble coulter showed unfavourable results in terms of dried soil cover on the slot under bare soil condition or that of even lower level of residue density. As a result, moisture conservation was obviously managed to keep it at the target value under the set condition of the implement.
- (2) A bubble coulter and a V-shaped slot opener showed positive performance regarding the dried soil cover on the slot at higher level of residue density. However, the residue fallen into the slot then hampered desirable seed-soil contact.
- (3) A VR_B-slot opener exhibited some amount of dried soil cover on the slot. This slot opener demonstrated practically significant and recommendable performance of the slot making in which desirable seedbed condition could be created to meet the requirement of stable plant growth. However, some theoretical experiments are still needed including comparative studies regarding minimum dried soil cover on the slot.
- (4) The residue handling device using a VR_A-slot opener generated soil-residue mixture which brought about a high amount of dried soil cover on the slot, thus hampering depth control mechanism.
- (5) A theoretical study of the experiment on minimum dried soil cover on the slot and hairpinned residue should be comparatively performed for the VR_B-slot opener and the rotor blade of the reversible V-shaped slot opener.

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