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# Water leakage control by using vibratory roller on a dry-seeded rice field in southwestern Japan

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A B S T R A C T

Dry-seeded rice cultivation is an effective low-cost cultivation method in Japan, but preventing water leakage from cultivated rice fields remains a challenge. Here we assessed the efficiency of using a vibratory roller in a dry-seeded rice field for preventing water leakage. The tests were conducted at two different soil-water contents (*WC*: 32 and 39%) before roller compaction. We measured the acceleration response of the vibrating roller by using a micro-electro mechanical system (MEMS) accelerometer, and we determined the volume of water leakage from the field by using a rapid leakage capacity tester. We analyzed the changes in the soil structure by using a micro-focused X-ray CT scanner. We analyzed all of the resulting data to identify any correlation. We observed that water leakage from the field was sufficiently prevented when prior to roller compaction, soil moisture content was 39%. The shape of the soil pores that could efficiently prevent water leakage was flatter than that of the inefficiently compacted soil. In addition, the total porosity decreased, but the small-sized pore fraction increased. The vibration acceleration of the roller significantly increased with the decrease in the volume of water leakage. Thus, in addition to assessing the efficiency of vibratory rollers in reducing water leakage, our data suggest that it is to some extent possible to estimate the water leakage prevention effect from the acceleration response of a vibrating roller.



## 1. Introduction

Rice (*Oryza sativa* L.) is the most important cultivated food crop in Japan, and it is thus of primary importance to ensure low rice production costs and labor-saving. Generally, expansion of the management scale leads to a reduction in production costs because the efficiency of the machinery used for the large-scale production increases. However, in the transplanting system that accounts for 90% of Japan's rice production, the raising of seedlings becomes a disincentive for scale expansion. In recent years the use of direct seeding systems in Japan has thus increased.

Direct seeding in Japan can be roughly classified as the direct seeding of rice on well-drained paddy fields (dry seeding) versus the direct seeding of rice on submerged soil (wet seeding) (Chosa et al., 2014). For example, a seed-shooting seeder of rice (Togashi et al., 2001a,b) combined with a tractor-mounted paddy harrow is widely used in submerged soil (Fig. 1, wet seeding). In western Japan, the requirements for the use of this method include the puddling of the field and seed coating by iron powder (Yamauchi, 2012) or calcium dioxide ($CaO_2$) before seeding, and controlling apple snails (Wada, 2004). In contrast, dry seeding (Fig. 1) is low-cost and enables the saving of labor compared to wet seeding, because dry seeding does not have the requirements mentioned above (Farooq et al., 2011; Tasaka et al., 2013). However, with the upcoming upland cropping systems in southwestern Japan, in which rice is rotated with wheat, soybean and barley within a two-year period, a plow pan rich in macropores has developed. Thus, the prevention of water leakage from the cultivated field is a principal challenge during dry-seeding cultivation.

Compaction by using a tractor-mounted roller is effective to prevent water leakage from a dry-seeded rice field (Kanmuri et al., 2012; Fukami et al., 2014). However, the upsizing of the roller and the tractor are required to obtain sufficient effects of the static compaction produced by the weight of the roller. The use of a

*Abbreviations:* MEMS, micro-electro mechanical system; CT, computed tomography; PTO, power take-off.

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**Fig. 1.** The method used for the direct seeding of rice.

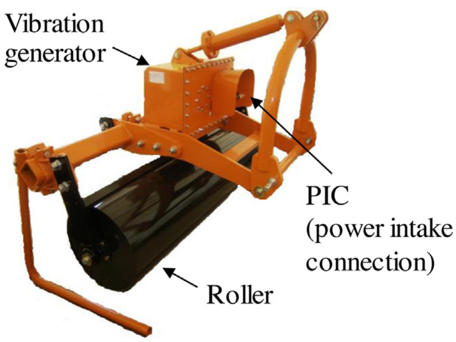


**Fig. 2.** Photograph of the vibratory roller.

vibratory roller as an alternative could be expected to have a higher compaction effect by dynamic compression even when the roller load is small. A cost reduction could also be expected due to the general-purpose use of the vibratory roller machine, because the work can be done by a general-sized tractor (power 14.7–29.4 kW, 20–40 PS). The acceleration response of a vibratory roller is also useful for the evaluation of the stiffness of compacted soil (Fujiyama and Tateyama, 2000; Fujiyama et al., 2002; Mooney and Rinehart, 2007).

The water permeability and water retention of a field depend on the soil's structure, and changes in soil structure have a close relation to the growth of crop roots. Thus, analyses of soil structure based on X-ray computed tomography (CT) images (Munkholm et al., 2003; Peth et al., 2010; Garbout et al., 2013; Ferro et al., 2014; Tracy et al., 2015) have increased in recent years. However, few studies have analyzed the structure of roller-compacted soil for the purpose of prevention of water leakage from a dry-seeded rice field.

To reduce water-supply rates to ~2 cm/day, it is desirable to compact the subsoil during tractor operations, preferably when water content is high. Studies by Kanmuri et al. (2012) have shown that, particularly medium to fine textured soils are most susceptible to compaction when wet.

In this study, we assessed how well a vibratory roller could prevent water leakage in a dry-seeded rice field. To assess the effect of antecedent water content, the tests were conducted at two different soil-water contents (*WC*: 32 and 39%). We measured the acceleration response of the vibrating roller by using a micro-electro mechanical system (MEMS) accelerometer, and we assessed the volume of water leakage from the field by using a rapid leakage capacity tester. We evaluated the changes in the soil structure by using a micro-focused X-ray CT scanner. We analyzed the resulting data to identify any correlation.

**Table 1**
Specifications of the vibratory roller.

| |
|---|
| Manufacturer: KAWABE Noken Sangyo Co., Ltd. |
| Model: SV3-T |
| Roller weight/width: 350 kg/150 cm |
| Compaction weight: 750–3125 kg (PTO:800–1100 rpm) |
| Appropriate power of tractor: 22–37 kw (30–50 PS) |

## 2. Materials and methods

### 2.1. The vibratory roller

Fig. 2 and Table 1 provide a photograph and the specifications of the vibratory roller (model SV3-T, Kawabe Noken Sangyo Co., Tokyo). This machine is mainly composed of a vibration generator and a roller part. The roller's total weight (without vibrating) is 350 kg, and the roller's width and diameter are 150 and 40 cm, respectively. The roller compaction weight (vibrating) is 750–3125 kg (power takeoff [PTO]: 800–1100 rpm). The appropriate power of the tractor is 22–37 kW (30–50 PS). This machine can also be used as a vibrating wide subsoiler by changing the roller part to the curved shank (Tanaka et al., 2000).

### 2.2. Test conditions

We conducted field experiments in 2013 at the Kyushu Okinawa Agricultural Research Center (KARC), Chikugo, Fukuoka, Japan (33°12′N, 130°30′ E, 10 m elevation). The basic soil characteristics of the 0–200 mm layer are given in Table 2. The soil texture was Light clay (classification: International system). The plastic and liquid limits were 38% and 56% (gravimetric water content), respectively. Before the roller compaction test, the experimental field was tilled to 13 cm deep using a rotary tiller. The conditions during the compaction test with the roller are given in Table 3. The test tractor power was 25 kW (34 PS). We set the rotational speed of the PTO at 1100 rpm, the operating speed of the roller at 1 and 2 km/h, and the pass number of the roller as two.

The test days were April 11 and 18, and there was rain (10 and 28 mm) on April 14 and 17 (Japan Meteorological Agency data), respectively. Thus, the moisture conditions varied according to the experiment day. We measured the soil gravimetric water content (% dry basis) by core sampling (core size: dia. 50 mm, height 51 mm; depth: 20–70, 70–120, and 120–170 mm). The water

**Table 2**
Soil characteristics of the test field.

| Soil texture | Light clay |
|---|---|
| Clay (<2 μm), % | 36.5 |
| Silt (2–20 μm), % | 37.8 |
| Fine sand (20–200 μm), % | 15.7 |
| Coarse sand (200–2000 μm), % | 9.9 |
| Plastic limit (% d. b.)[a] | 38 |
| Liquid limit (% d. b.)[a] | 56 |

[a] Gravimetric water content.