



Transplanting system beneficial for small-scale rice farmers

Rakoto Malala Andoniaina

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Doctoral dissertation

**Transplanting system
beneficial for small-scale rice farmers**

(小規模稲作農家に資する移植システムに関する研究)

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Graduate School of Agricultural Science
Kobe University

RAKOTO MALALA ANDONIAINA

ABSTRACT

The objective of this research is to develop a transplanting system beneficial to small-scale rice farmers. In general, this research combines two correlated techniques that are rice transplanting machine and rice mat seedlings. A simple mechanism termed free-pivoting suspension is developed and used as a simplification of the structure of a one-wheel two-row rice transplanter. Additionally, mat seedlings named arrayed mat seedlings are conceived with an intension of reducing the number of seeds used per nursery tray while covering the same area of planting as broadcast seedlings so that seeds can be saved and seedlings plant last longer. In the end, the arrayed mat seedlings are tried on the free-pivoting suspension rice transplanter as a combination of the two techniques.

In CHAPTER 1, the background of this study is described and the advantages of a simplified structure on a rice transplanter and of saving seeds on rice seedlings are raised up as the main purposes of this study. Mechanization of the operation of transplanting which represents 25% of the total labor requirement in rice farming is generally used to face the unbalanced demand and supply in rice. Mechanical transplanting saves labor while improving the quantity and quality of rice production; it combines both machine and seedlings. First, a walk-behind rice transplanter was developed with a simplified suspension mechanism that eliminates the use of a hydraulic cylinder while maintaining enough control of the position of the wheel relative to the body of the machine during transplanting. With the simplified mechanism, the structure of the transplanter would become simple and easy to fabricate in addition to the weight and the cost that would be reduced. Second, a new arrangement of seedlings was developed to reduce the quantity of seeds required per nursery tray for the same area of planting. With this method, seeds

can be saved and, subsequently, the low density would allow more nutrients, light and aeration to the plants to live longer.

In CHAPTER 2, a mechanism termed free-pivoting suspension is developed as a simplification of the suspension mechanism of a walk-behind rice transplanter. The free-pivoting suspension of the wheel was mounted on a modified rice transplanter with a clamping device installed for switching between the free-pivoting and the fixed suspensions. The fixed suspension was first tested in various settings of the depth of the wheel and the hardpan in order to elucidate the necessity of adjusting the depth of the wheel over that of the hardpan. As an improvement, the free-pivoting suspension was compared with the fixed suspension. Thereafter, ameliorations were made on the weight distribution of the rice transplanter to further improve its mobility performance before finally testing it in transplanting seedlings on a varying soil pan of field. With the fixed suspension, it was found that adjusting the wheel to the same depth as the hardpan is necessary for maintaining a horizontal position of the body while generating low and stable slippage at the wheel. With the free-pivoting suspension, in the field of varying soil pan, the pitch angle of the transplanter was maintained stably at an average of 1.8° on the soil surface, compared to 4.7° that tended to change with the sinkage of the wheel with the fixed suspension. With the free-pivoting suspension, an addition of 98 N of weight on the wheel reduced the slippage by half on uniform surfaces of the soil pan. The prototype of rice transplanter achieved an average slippage of 10.3% and a lodging angle of the planted seedlings of 17° when planting seedlings in the field of varying soil pan.

In CHAPTER 3, a seedling arrangement in array was developed to reduce the amount of seed per nursery tray, and so, to extend the lifespan of the seedling plants. The arrayed seedlings were made by sowing 82 g of germinated seeds in a 30-row arrayed of furrow

scratched on a coco-peat mat with a grinder. They were grown with broadcast seedlings (138 g of germinated seeds) used as the control. The 30-row arrayed and the control seedlings were transplanted with a 30-lateral feed rice transplanter set at 7 mm vertical feed and a 26-lateral feed transplanter set at 13 mm vertical feed, respectively. The 30-row arrayed seedlings allowed a 40% saving of seeds over the control and the remaining seedlings survived until headings. The combination of the 7 mm vertical feed and the 30 lateral feeds setting of the transplanter reduced the number of trays per unit of area to 46%. However, the percentage of hill mortality investigated upon harvest in the arrayed seedlings was significantly high (19%), which was partly attributed to the narrow and sharp tines of the planting mechanism for high-density seedlings that damaged the grown-up singular plants of the seedlings although they were spared at transplanting.

In CHAPTER 4, based on the result from the 30-row arrayed seedlings (CHAPTER 3), another experiment was carried out as a follow-up. The objective was to save seeds while covering the same area of planting as that of broadcast seedlings by focussing on settings to reduce hill mortality. The arrayed mat seedlings were prepared by sowing seeds in 26-furrow arrays on coco-peat mats made with a plastic mold. They were transplanted with the use of a conventional 8-row transplanter, set at 26 lateral feeds and three vertical feeds (7, 10, and 13 mm), and grown along with the broadcast (control) seedlings. The arrayed seedlings were prepared with 40% fewer seeds than were the control and their foliar ages were 3 to 4 on the day of transplanting. Neither of the seedlings were suitable for the 7 mm vertical feed in terms of missing hills at transplanting. The arrayed seedlings at transplanting missed 11.3% and 6.3% of hills in the 10 and 13 mm-vertical feed, respectively, but they were still larger than those in the control (9.0% and 3.3%). With the arrayed seedlings, the hill mortality during the growth period was

low ($< 5\%$) and the grain yield was 500 g/m^2 , which were not different from the control.

In CHAPTER 5, the 26-row arrayed seedlings were tested on the prototype of the free-pivoting suspension rice transplanter with an objective of combining the two techniques (i.e. the seedlings and the transplanter) so that they would simultaneously profit small-scale farmers. The test was carried out in a varying soil pan of the field. The rice transplanter was loaded with 98 N weight as was suggested in CHAPTER 2 and set at 16 mm- vertical feed. Three types of seedlings were prepared: 26-row arrayed seedlings on a scratched and a pressed coco-peat mat (sown at 90 g of germinated seeds per tray) and broadcast seedlings on soil only (sown at 150 g of germinated seeds per tray) as the control. The mobility performance of the rice transplanter, such as forward speed and slippage, were measured and hills investigation including measurements of plant depth and lodging angle were carried out right after the transplanting operation whereas hill mortality was investigated 12 days later. During the experiment, the forward speed of the rice transplanter was between 0.5 m/s and 0.6 m/s with a slippage average of 10.7% which tended to increase with the depth of the hardpan. The plant numbers per hill were one to three with a missing hill of 8.9% on the average, which was not significantly different among the seedling types. At 12 days after transplanting, the hill mortality was low $< 2\%$ and not different among types of seedlings. They tended to decrease with an increase in the number of the singular plants per hill. The depth of planting was between 2 and 4 cm whereas the lodging angle was slightly large (31°) but was recovered 12 days after transplanting.

In CHAPTER 6, the general conclusion of each section of this study is elaborated and the prospect of the study is described. On one hand, the prototype of rice transplanter indirectly preserves small rice fields from abandoning and helps traditional farmers to

easily adopt mechanical transplanting. However, the performance of the rice transplanter can further be improved by changing the weight distribution on the machine without compromising the engine power and by using a wider size of the wheel lugs. On the other hand, the use of the coco-peat mat in the arrayed seedlings helps to preserve the environment as it alleviates soil displacement from mountains to the paddy field. Nonetheless, the arrayed seedlings should be improved by adjusting the orientations of the seeds in the mat in the same direction, by adding guides near the position the tines pick up seedlings, and by designing tines with a similar width as the pitch of the arrays to minimize the percentage of the missing hill at transplanting and the hill mortality.

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LIST OF SYMBOLS

D	Average distance of the ultrasonic sensors relative to the water surface
d	Water depth
DAS	Days after sowing
DAT	Days after transplanting
d_m	Measured intra-row distance of planted seedlings
d_t	Theoretical intra-row distance of planted seedlings
f	Sinkage of the skis of the rice transplanter
H	Vertical distance of the ultrasonic sensors from the ski
n_h	Number of missing hills upon harvest
n_p	Number of missing hills at transplanting
n_t	Total number of the investigated hills
r_d	Hill mortality
S	Slippage of the wheel of the rice transplanter
v_f	Forward speed of the rice transplanter
v_t	Peripheral speed of the wheel of the rice transplanter

CHAPTER 1. INTRODUCTION

1.1. Background

1.1.1. Overview of rice farming mechanization

Rice (*Oryza Sativa* L.) is the staple food of many countries in the world. Demand for rice is increasing with the growth of the global population. The world consumption of rice reached 518 Mt (milled bases) in 2016 and is expected to rise around 1.1% per year toward 2025 (Grain central, 2018). By contrast, land and water resources for rice crop are shrinking and the growth rate of the yield production is declining (FAO, 2019). To face the unbalanced demand and supply in rice, effort in improving rice production and in reducing waste and losses has been established as parts of the strategies for the United Nations to reach the sustainable development goals for food security and sustainable agriculture by 2030.

Mechanization plays an important role in agriculture. Apart from saving labor, it reduces the time spent in farm work and increases productivity as well as work quality. In rice cultivation, different types and sizes of machines are available on the market, which covers different types and stages of operation from soil preparation to post-harvest and for small to large scale farmers. Those technologies are fruits of many years of research and have nowadays incredible results and evolutions.

In rice farming, transplanting is the most demanding and laborious operation among others, which represents about 25% of the total labor requirements, i.e. equivalent to 250-350 man-hour/ha (Singh et al., 1983). Initially, rice seedlings were transplanted randomly by hand in rice fields but this practice was gradually abandoned mostly in developed countries but also in some developing countries. The cause of this shift is generally the difficulty of farm management during peak period due to shortage of labor, the

nonuniformity of operations (i.e. planting depth, planting density, distances between plants, etc.) that causes difficulty or impossibility of intercultural operations (i.e. weed control, water management, etc.) and instable growth of the plants, etc. Moreover, the benefits that mechanical transplanting provides, such as reducing labor requirement, providing uniform operation that improves quantity and quality of grain yield, rapidly convinced farmers to switch from manual to mechanical operation.

Mechanical transplanting is a well-known technique that provides high efficiency in rice planting operations. It reduces labor and provides uniform operation, resulting in improved grain yield. Mechanical transplanting that started in the 1960s is practiced in nearly 100% of the rice fields in Japan (Sasaki, 2004) and has gradually spread across the world. It involves both machine and seedlings and requires special preparation to achieve smooth and precise transplanting operations. Agronomical parameters such as physical properties of the plant (foliar age, sizes, etc.) and adequate conditions for the seedlings to grow (depth, spacing, etc.) have to be considered for designing an appropriate machine. Subsequently, seedling plants should be arranged in such a way that the machine can easily plant them without complexity.

1.1.2. Rice transplanter

Rice transplanters have been invented in Japan in the 1960s and were developed to assist farmers in planting rice seedlings speedily and with less manpower. Starting from manually-driven to power-driven and from walking-type to riding-type, the field capacity of rice transplanters has been improved dramatically (NARO, 2019). Riding-type transplanters are equipped with four wheels and have 4 to 8 transplanting rows. They are appropriate for large size rice fields and require enough transportation facilities to allow their displacement to the rice field.

Walk-behind rice transplanters are favored by farmers owning small or fragmented rice fields where large-scale machines cannot be operated. Besides being less costly, they are more adaptable to fields with poor transportation facilities (i.e. narrow and/or hilly terrain) because of their small size, light weight, and one or two closely-spaced wheels.

One of the devices commonly used on walk-behind rice transplanters is the suspension mechanism which connects the main body to the wheel(s). Known as a “height control mechanism” (Mori, 1975), it adjusts the wheel depth to the various depths of the hardpan (Kanai, 1980). Walk-behind rice transplanters are equipped with the wheel(s) and the floats to travel on rice fields. The floats carry a larger weight of the machine than do the wheel(s).

At their initial stage of development, the float and the wheel(s) were fixed to the main body without any adjustment mechanism. On irregular surfaces of the hardpan in the field, controlling the machine was difficult because of the various consistencies of the soil and the depth of the hardpan, both of which cause uneven weight distribution on the wheel(s) and the floats. An adjustment mechanism was later incorporated with the use of springs that adjust, to some extent, the position of the floats relative to the wheel(s); thereafter, the springs were replaced by a hydraulic cylinder for an automatic adjustment (Hoshino, 1974).

The purpose of such adjustment was to maintain the floats on the surface of the soil and to have the wheels encounter the hardpan and generate traction. This minimizes the pitch angle of the planting mechanism, thus ensuring the precision of planting. Figure 1.1 shows one-wheel two-row walk-behind rice transplanters with (a) manual and (b) automatic suspension adjustment mechanisms.

Study has not been found within the authors' recognition specifically on the suspension

mechanism of walk-behind rice transplanters neither within nor outside Japan. This is maybe because of the satisfactory performance of the hydraulic cylinder that was adopted before 1974 as reported by Hoshino (1974). The use of spring in the suspension seems to have been abandoned because of its property that could not be at the same time soft enough to absorb shocks from the wheel to maintain a horizontal pitch angle of the body and strong enough to push the wheel against the soil pan to obtain traction, and its limited stroke and tension that confined the swinging motion of the wheel.

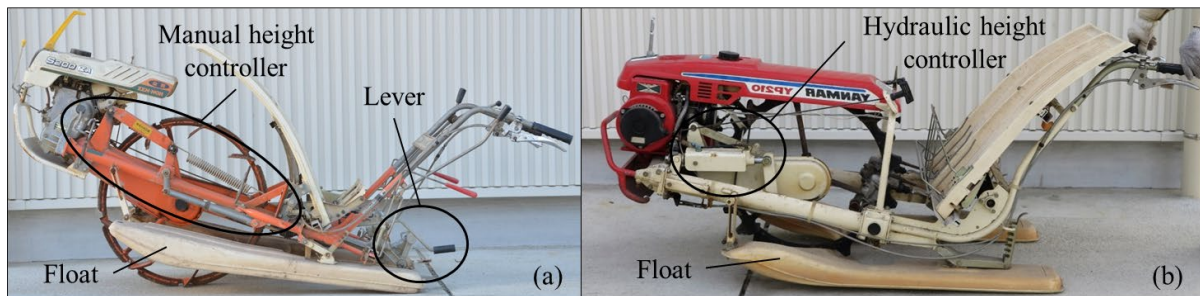


Figure 1.1 Height control mechanisms on one-wheel two-row walk-behind rice transplanters, (a) manual height controller (S200ZA, Kubota, Japan), (b) hydraulic height controller (YP210, Yanmar, Japan).

1.1.3. Rice seedlings

Seedlings require special preparation to allow them be used on a rice transplanter. Seedlings have to be arranged in such a way that there are always seedlings ready to be picked up by the tines of the transplanter in order to avoid null-picking and thus avoiding also missing hills to occur in the field. Among several types of seedlings for mechanical transplanting such as band, pot, and mat, mat seedlings, the most preferred nowadays, are prepared basically by sowing seeds in fine soil in rectangular boxes (58 cm × 28 cm × 3 cm) and transplanted at their 2 to 4 foliar age (Kanai, 1980). This type of seedling requires about 150 g germinated seeds per nursery tray.

In Japan, a new technique of growing seedlings has been recently developed (Yanmar, 2018). It aims to reduce nursery trays, material cost, space, and labor by sowing seeds at a high seeding rate (312 to 375 g of germinated seed) and by using a precise planting mechanism with a narrow tines (10 mm-wide) which increases the number of pick-up of seedlings per nursery tray. In spite of such advantages, the fact that a large population of plants are growing together in the tray with the same size as that of conventional mat (generally sown at 150 g/tray) limits the life span of the seedlings as their growth stops or declines 20 days after sowing. Therefore, the seedlings should be planted withing a limited period of time which would result in a less flexible farm management to farmers.

1.2. Objectives

The main objective of this study is to develop a transplanting system that would be profitable for small-scale farmers. It combines a simplified suspension mechanism of a one-wheel walk-behind rice transplanter and a seed saving rice mat seedlings. A walk-behind rice transplanter is developed with a simplified suspension mechanism that eliminates the use of the hydraulic cylinder while having enough control over the position of the wheel and the body of the machine. With such a simple mechanism, the structure of the machine would be simple and thus the fabrication becomes easy, also the weight and the cost of fabrication would be reduced. Besides, a rice mat seedling with an arrangement that reduces the quantity of seeds required per nursery tray is developed by sowing seeds in lines with the same number as the lateral feed of the transplanter in such a way that seedlings grow only on locations where tines of the planting mechanism of transplanter pick up plants of the seedlings on the mat. This would reduce the amount of seeds required per mat and would provide a better agronomic environment such as nutrients, light, and aeration to the plants so that they would live longer.

CHAPTER 2. FREE-PIVOTING SUSPENSION ON ONE-WHEEL TWO-ROW WALK-BEHIND RICE TRANSPLANTER

2.1. Introduction

The present study describes a mechanism, termed “free-pivoting suspension”, developed to potentially be used as a height control mechanism for a one-wheel rice transplanter. On the whole, this study targets a simplification of the suspension mechanism of a one-wheel two-row rice transplanter by improving its adaptability to various field conditions without the use of hydraulic components. By excluding the hydraulic circuits, the weight of the machine is reduced and its fabrication is simplified. A prototype of such a simplified structure would benefit small-scale farmers owning fluctuating soil pan of rice field.

2.1.1. The free-pivoting suspension

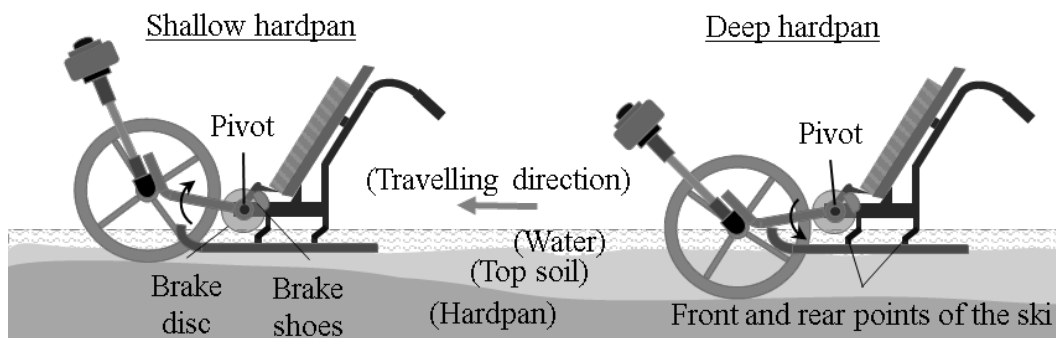


Figure 2.1 Behavior of the transplanter with the free-pivoting suspension on varying depth of the hardpan; the wheel moves down in deep hardpan and moves up in shallow hardpan following the soil profile while the body stays on the surface of the soil.

The free-pivoting suspension is a mechanism intended to have the wheel of a one-

wheel rice transplanter swing freely about the pivot by gravitational forces on the wheel, and to keep the body of the rice transplanter stable on the surface of the field, letting the wheel move independently in the quasi-vertical direction (Figure 2.1). With such a height control mechanism, the range of the swinging angle of the wheel is unconfined, and the body of the transplanter, on which the planting mechanisms are installed, is maintained stably on the surface of the field, thus enhancing planting accuracy. Also, the sinkage of the wheel into the soil would depend mostly on its own weight and on the bearing capacity of the soil; therefore, the soil-wheel interactions improve by modulating the weight of the wheel, thereby improving its mobility.

2.2. Materials and methods

2.2.1. The rice transplanter

The rice transplanter (Figure 2.2) has two main sections: the wheel (front section) and the body (rear section). The front section comprises a rigid rubber wheel, a two-stroke gasoline engine, and a gearbox from a commercially available ditch maker (NT-3, Otake, Japan). The engine is mounted on the wheel through the gearbox as one whole unit, and a counterweight is added to the lateral side of the engine for balancing. The rear section incorporates a two-row four-link (hereinafter crank) planting mechanism accommodating seedling trays and their sliding mechanism taken from a walk-behind transplanter (YP210, Yanmar, Osaka, Japan), a pair of skis corresponding to conventional “floats” made of 5 mm-thick polyvinyl chloride plates in place of the floats and a handle made of steel pipe.

The front and the rear sections are connected through a swing-arm fixed at one end to the wheel and pivoted at the other end to the body. A lift arm and a brake arrangement (Figure 2.2) installed near the pivot for switching the body between “free-pivoting suspension” (free-linkage) and “fixed suspension” (desired position) of the wheel allows

the operator to lift the machine from behind when transporting it. The power from the wheel shaft is transmitted to the body through chains and sprockets.

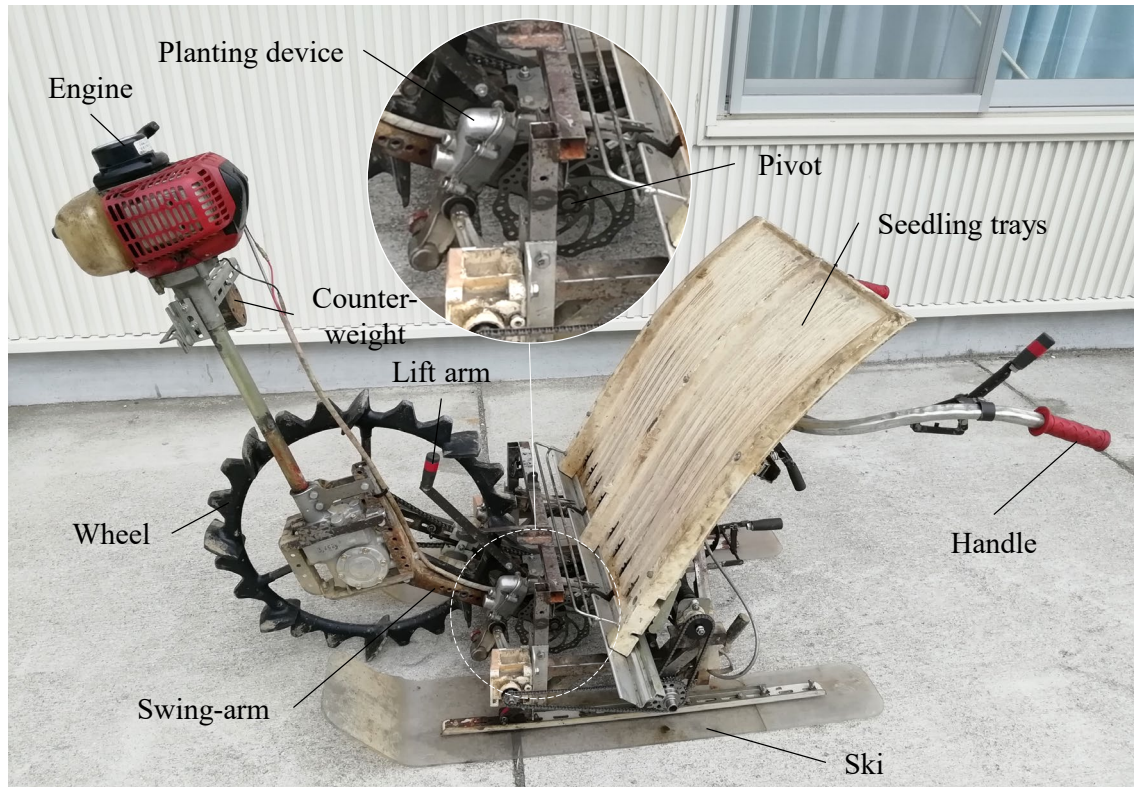


Figure 2.2 The prototype of the rice transplanter.

The skis are connected to the main frame at the front and rear points (Figure 2.1). With the fixed suspension, the front points have a 2 cm vertical free-play while the rear ones are hinged, around which the wheel is allowed to partly swing, mirroring the conventional settings of the basic transplanter. Thus, the wheel can move 9 cm downward without pushing down on the skis that continue level on the surface of the field. With the free-pivoting suspension, since the body of the machine is supported by the skis only, the front and rear points of the skis are fixed in place to prevent the body from leaning forward.

The prototype of this rice transplanter is 1.66 m long, 0.86 m wide, and 1.00 m high with front and rear sections weighing 290 N and 240 N with the free-pivoting suspension

and 320 N and 210 N with the fixed suspension on a flat plane without the seedlings. This difference in weight distribution is due to the suspension setting: with the fixed suspension the weight of the rear section is partly distributed to the wheel, whereas with the free-pivoting suspension the rear section is entirely supported by the skis.

2.2.2. Experiments

The experiments were carried out in a field of loamy sand in the research plots of the Graduate School of Agricultural Science, Kobe University, Kobe, Japan. During the whole experiments, the forward speeds of the rice transplanter were manually adjusted as stable as possible at 0.5 m/s to 0.6 m/s.

2.2.2.1. Identification of the behavior of the fixed suspension on a changing hardpan depth over the wheel depth.

To clarify the behavior of a suspension without adjustment mechanism on a changing depth of the soil pan, the fixed suspension of the transplanter was tested by setting the depth of the wheel (defined as the relative position of the lowest edge of the wheel to the skis) either greater or less than the depth of the hardpan. The rice transplanter was loaded with 160 N weight as a substitute for two mats of seedlings during the experiment. Two 1.2 m x 5 m areas of the field with uniform hardpans, one shallow (ca. 11.0 cm), and one deep (16.0 cm) were prepared. Four depths of the wheel were set for each field: one close or equal to the average depth of the hardpan and the other three at >11.0 cm in the shallow area and <16.0 cm in the deep area so as to represent improper settings of the depth of the wheel. The field was tilled and leveled in dry condition with a rotary tiller (RS1303, Yanmar, Japan) manually guided by a laser beam (Emitter on the ground: NL-600, Nikon-Trimble Co., Japan; Receiver attached onto the implement: LR30, Nikon-Trimble Co., Japan) to acquire uniform hardpans. The field was paddled twice with a mini-tiller (FF300,

HONDA, Japan), leveled manually, left one day without water for a quick settlement, and flooded with 3 cm of water a few minutes before the test (Figure 2.3) (Experiment 1).



Figure 2.3 The testing field with uniform soil pan: in the left, hardpan 11 cm filled with water and in the right, hardpan 16 cm before flooding.

2.2.2.2. Performance of the free pivoting suspension in comparison with the fixed suspension.

As a solution for the drawbacks of the fixed suspension, the free-pivoting suspension was compared to the fixed one on rough surfaces of the soil pan. The 160 N weight was maintained on the trays to imitate two mats of seedlings. With each of the suspensions, the transplanter was run 10 m three times in randomized order. With the fixed suspension, the wheel depth was set equal to the average depth of the hardpan that was measured in advance, and the runs were conducted in a 13 m × 5 m field (Figure 2.4) that was first tilled with the rotary tiller to create a rough surface by randomly lifting the hitch, followed

by similar paddling and water management as in Experiment 1 (Experiment 2).



Figure 2.4 The experimental field with varying hardpan depth.

2.2.2.3. Improvement of the mobility performance of the free-pivoting suspension.

To further test the mobility performance of the transplanter with the free-pivoting suspension, an additional experiment was carried out with the free-pivoting suspension to evaluate the effect of different weight distributions on slippage and to improve the mobility of the machine. Three different weights were loaded on the wheel (0 N, 29 N equal to the difference in the static weight of the wheel between the free-pivoting and the fixed suspensions, and 98 N), and two different weights were loaded on the seedling trays (120 N the total weight of the on-board measuring instruments, and 160 N equivalent to two mats of rice seedlings). The machine was tested in the shallow and deep hardpans used in Experiment 1 under the same field preparations. Each combination of weight in the front, weight in the back, and the depth of the hardpan was tested in one run of 5 m.

Analysis of variance was then carried out (Experiment 3).

2.2.2.4. Planting test on a varying hardpan of rice field with the free-pivoting suspension.

The rice transplanter with the free-pivoting suspension was tested to plant seedlings in a varying soil pan of the field. Based on the experiment 3, the rice transplanter was loaded with the appropriate weight on the wheel (98 N) and with two mats of seedlings on the trays. The rice transplanter had a 30 cm row distance and was set to pick up plants of seedlings at a vertical feed of 13 mm and a lateral feed of 26 times. The seedlings used on the experiment were prepared by uniformly sowing 240 g of germinated seeds per tray, which was chosen to compensate for the low germination rate of the seeds (55%) measured on the day of sowing. They were transplanted at their 37 DAS (about 3.5 foliar age). The experiment was carried out in the same field with the same preparation as in Experiment 2. The transplanting operation was done on three runs (i.e. 6 planting rows) of 9 m each (Experiment 4).

2.2.3. Measurement of parameters

The soil profile, the slippage of the wheel, the sinkage and the pitch angle of the skis, the pitch angle of the body and the sinkage of the wheel were measured and analyzed. The output from all the sensors was recorded in an on-board data logger (DR-C1MK2, TEAC, Japan) at a 10 Hz sampling rate. The raw data were averaged every 0.5 m so as to be in line with the soil profile measurement that was done every 0.5 m.

The soil profile was measured every 0.5 m along the designated path of the transplanter, where the depth of the hardpan was defined as the thickness of the paddled soil. The depth of the water was measured manually as the distance between the surface of the water and a 20 cm x 50 cm plastic plate gently placed on the surface of the soil. The surface of the

hardpan was similarly sensed with a rod (17 mm in diameter) through a hole in the center of the plate.

The slippage was measured with magnetic proximity (E2E-X5ME2, Omron Co., Japan) and ultrasonic (E4PA-LS50-M1, Omron Co., Germany) sensors attached on the wheel arm and on the right side of the body of the rice transplanter, respectively. The former detected the rotational speed of the wheel through sprocket, with which the peripheral speed of the wheel was calculated, and the latter measured its distance from the water surface where markers made of polystyrene were placed every 0.5 m along the path of the machine (Figure 2.5). The forward speed was then calculated from the recorded time on the data logger for each distance, and the slippage was calculated as follows:

$$S = \left(1 - \frac{V_f}{V_t}\right) \times 100 \quad (2.1)$$

where S is the slippage (%), V_f the forward speed (m/s), and V_t the peripheral speed of the wheel (m/s) of the rice transplanter.

The sinkage of the skis from the surface of the soil was also determined from the ultrasonic sensor attached on the right side with another ultrasonic sensor (UD-320, Keyence, Japan) installed on the left side of the body of the transplanter (Figure 2.5). The average distance of the two ultrasonic sensors relative to the water was used for determining the sinkage of the skis as follows:

$$f = H - (D + d) \quad (2.2)$$

where f is the sinkage of the skis (cm), H the vertical distance of the sensors from the ski (cm), D the average distance of the sensors relative to the water surface (cm), and d the

water depth (cm).

The pitch angles of the body and of the skis were measured with inclinometers (D5R-L02-60, Omron Co., Japan) placed on the main frame and the right side ski (Figure 2.5).

The sinkage of the wheel from the surface of the soil was sensed through an independent ski made of polyvinyl plate hinged on a bar attached to the wheel center through parallel linkages (Figure 2.5). The output from a rotational potentiometer (J50S, Copal, Japan) linked to the ski was calibrated to the sinkage of the wheel, and the pitch angle of the body was taken into account to correct the output.

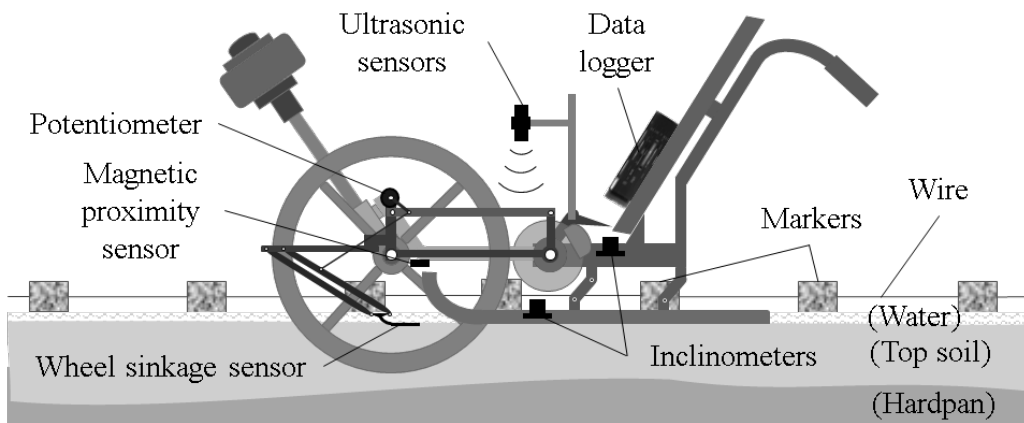


Figure 2.5 Measurement of sinkage of the wheel, pitch angle of the body and the skis, sinkage of the skis and slippage of the wheel.

In the Experiment 4, all the instruments of measurement were removed off the rice transplanter to provide a place for the seedling mats, and the parameters below were measured manually. The time made by the transplanter for 9 m run was measured for every run and the forward speed was calculated. The slippage of the wheel was measured from the theoretical and the measured planting distances (i.e. distance within a row) of the plants. After transplanting, the number of plant per hill were counted for 90

observations and the percentage of the missing hills was determined. Simultaneously, the depth and the lodging angle of the plants were measured.

2.3. Results and discussion

2.3.1. Fixed suspension set under various depths of the wheel

The experiment with the fixed suspension to identify the effect of various differences between the set depth of the wheel and the depth of the hardpan showed that the pitch angle of the body was affected directly by the wheel depth setting; the deeper the set depth of the wheel, the greater the pitch angle of the body, and vice versa (Figure 2.6).

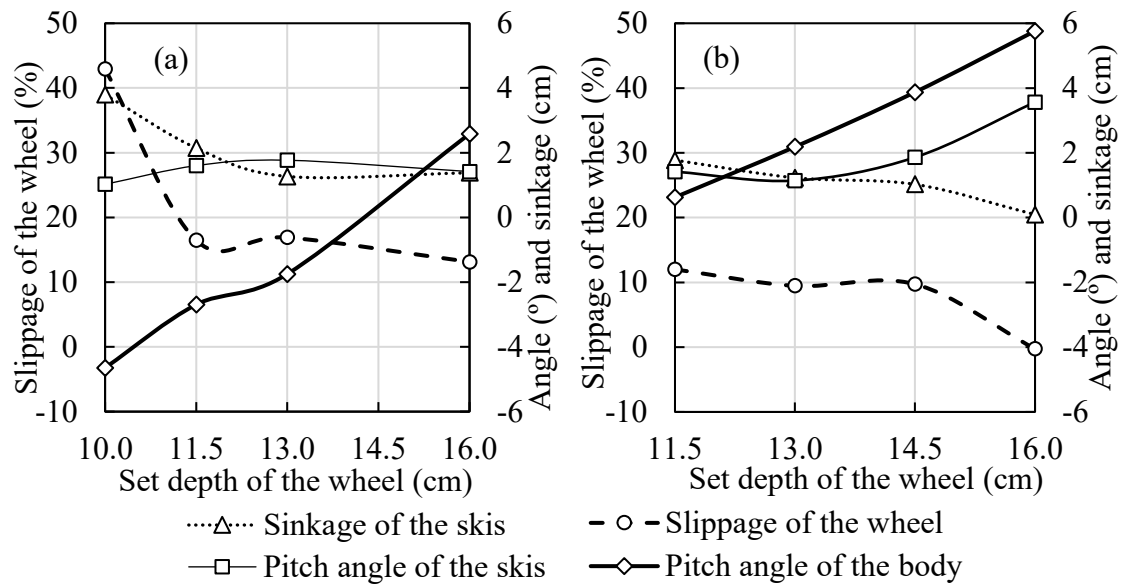


Figure 2.6 Effect of the difference between wheel depth setting and depth of the hardpan on pitch angles, slippage and ski sinkage with the fixed suspension, (a) hardpan depth 16 cm with decreasing wheel depth, (b) hardpan depth 11 cm with increasing wheel depth.

The largest slippage was observed when the wheel was set at its shallowest on the deep hardpan (Figure 2.6 (a)), which is partly attributed to the considerable sinkage of the skis (3.8 cm) and to the wheel that probably sunk due to the 2 cm free play at the front

point of the skis and induced a large rolling resistance on the wheel. Meanwhile, the lowest slippage occurred when the wheel was set at its deepest on the shallow hardpan (Figure 2.6 (b)), which is partly ascribed to the skis that barely sank with a large pitch angle and to the small rolling resistance on the wheel in shallow hardpan. The slippage of the wheel and the sinkage of the skis remained almost at the same level when the wheel depth was set within ± 3 cm of the depth of the hardpan. This may be due to the 2 cm free play at the front point of the skis that allow the wheel to move without pushing the skis. Despite such flexibility, adjusting the wheel to the same depth as the depth of the hardpan was thus necessary to maintain the horizontality of the body of the transplanter, at low and stable slippage.

2.3.2. Free-pivoting and fixed suspensions on uneven surfaces of the soil pan

Experimental data on comparing the free-pivoting suspension with the fixed suspension on uneven surfaces of the soil pan are shown in Table 2.1.

Table 2.1 Comparison of slippage of the wheel, pitch angle of the body and of the skis, and sinkage of the skis with the free-pivoting and the fixed suspension.

Suspension	Slippage of the wheel (%)	Pitch angle of the body (°)	Pitch angle of the ski (°)	Sinkage of the ski (cm)	Sinkage of the wheel (cm)	Depth of the water (cm)	Depth of the hardpan (cm)
Free- pivoting	24.6 (6.3)	1.8 (0.4)	1.8 (0.4)	2.5 (0.8)	14.1 (1.8)	3.6 (0.6)	17.5 (2.2)
Fixed	16.4 (7.1)	4.7 (1.1)	3.0 (0.8)	3.7 (0.6)	15.4 (2.2)	3.4 (0.4)	18.2 (1.7)

*Numbers in brackets are standard deviations.

The pitch angle of the body with the free-pivoting suspension was significantly small as compared with that of the fixed suspension (Table 2.1, 3rd column), and the small standard deviation (0.4) demonstrated that the free-pivoting suspension enhanced the stability of the machine under various depths of the soil pan. Figure 2.7 accordingly shows that the pitch angle with the free-pivoting suspension did not correlate with the wheel sinkage; with the fixed suspension, on the other hand, the pitch angle tended to decrease with the increase in wheel sinkage. This improved pitch angle was attributed to the independent pivoting of the wheel from the body with the free-pivoting suspension, i.e. the skis of the machine.

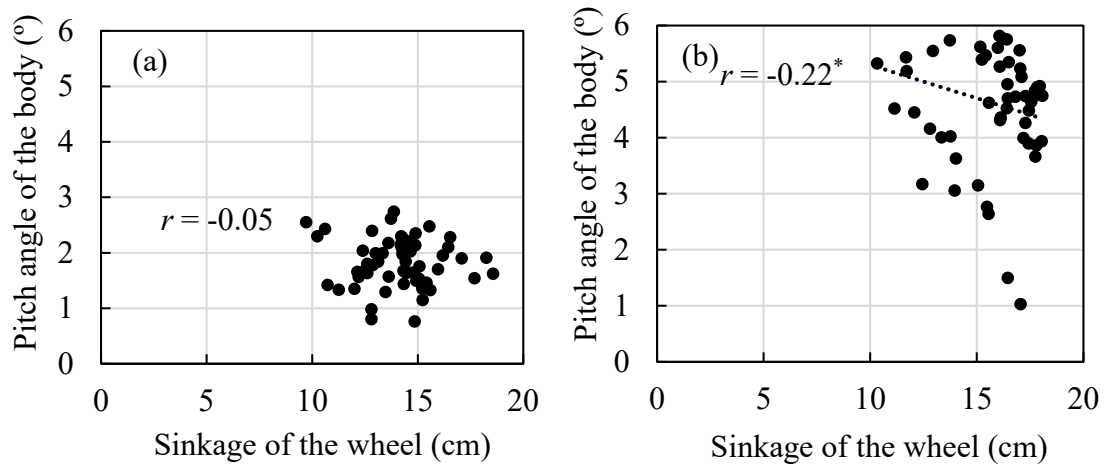


Figure 2.7 Effect of wheel sinkage on pitch angle of the body, (a) with free-pivoting suspension, and (b) with fixed suspension.

The slippage with the free-pivoting suspension was larger than with the fixed suspension (Table 2.1, 2nd column). This might be attributed to the difference in the distribution of the weight of the rear and the front sections with respect to the setting of the suspension. With the free-pivoting suspension, the wheel swung freely about the pivot and supported only the front section of the machine (290 N, compared to 320 N for fixed

suspension) while the skis supported the entire rear section (240 N, compared to 210 N for fixed suspension). The reduced the traction of the wheel and the increased the friction (i.e. draft force) on the skis, and so, generated a larger slippage. By contrast, with the fixed suspension, the front and rear sections were fixed as one unit, and the skis supported the body only through the rear points. Thus, the weight of the rear section was redistributed to the wheel, which increased the traction of the wheel and decreased the friction on the skis resulting in lower slippage.

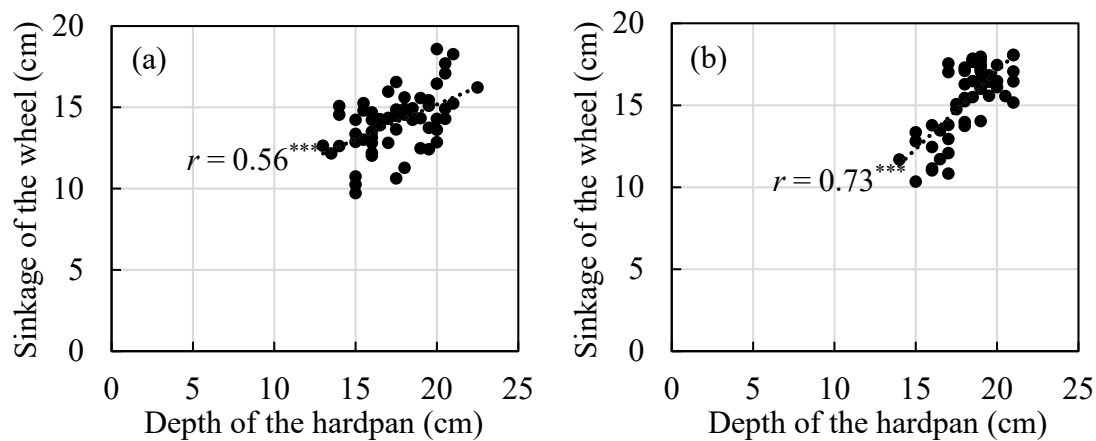


Figure 2.8 Effect of depth of the hardpan on sinkage of the wheel, (a) with free-pivoting suspension, and (b) with fixed suspension.

With the free-pivoting suspension, the wheel sinkage was slightly smaller with less fluctuation (Table 2.1, 6th column), probably due to the insufficient weight and the absence of downward pressure on the wheel, since the entire rear section was independently supported by the skis. A significant correlation of the sinkage of the wheel with the depth of the hardpan, even with the free-pivoting suspension (Figure 2.8), emphasized that the wheel did not always reach the hardpan and that the slippage occurred more frequently than with the fixed suspension.

The sinkage of the skis was less with the free-pivoting suspension than with the fixed

suspension (Table 2.1, 5th column) despite the greater load assumed to be on them. This shallow sinkage might be due to the near-horizontal angle of the skis with the free-pivoting suspension, leading to wider surface contact between skis and soil, and an evenly distributed weight over the entire surface of the ski.

2.3.3. Free-pivoting suspension under different weight distribution and depth of hardpan

The wheel load had a significant ($p < 0.01$) effect on slippage (Table 2.2). By Tukey's multiple comparison, the mean indicated that the reduction in slippage was insignificant when the wheel load changed from 0 N to 29 N, but became significant ($p < 0.05$) when the load changed from 29 N to 98 N. Increases of 69 N and 98 N in the wheel load reduced wheel slippage by 7.7 and 8.8 percentage points, respectively (Table 2.2). These results demonstrate that the heavier the wheel, the lesser the slippage. This could be ascribed to improved traction of the wheel by virtue of the increase in the contact between the wheel and the hardpan with an increase in wheel load although rolling resistance also increased. An increase in the axle load of the driving wheel of a tractor increases the net traction on paddy fields (Gholkar et al., 2009), implying that an insufficient wheel load requires more slippage to generate the same amount of traction. Similarly, the significant increase of the wheel sinkage with an increase in wheel load from 0 N to 98 N and 29 N to 98 N in the present study emphasizes that the interaction between the wheel and the hardpan has improved with an increase in wheel load.

The slippage seems to have decreased with the decrease in the tray weight (Table 2.2), yet the effect was not significant possibly due to its limited range between 160 N and 120 N. It is plausible that the slippage would gradually decrease with the reduction in the weight of the seedlings in practical transplanting operations.

Table 2.2 Effect of wheel load, tray load, and depth of hardpan on pitch angle, slippage, and sinkage of the wheel on the free-pivoting suspension, as expressed by the means.

Source of variation	Pitch angle of the body (°)	Slippage of the wheel (%)	Sinkage of the wheel (cm)
Wheel load			
0 N	1.5	18.1a	12.7a
29 N	1.4	17.0a	13.0a
98 N	1.3	9.4b	13.8b
Tray load			
120 N	1.4	14.4	13.3
160 N	1.4	15.3	13.0
Hardpan depth			
11 cm	1.3	11.9a	10.7a
16 cm	1.5	17.8b	15.7b

Different letters indicate significant differences by Tukey's test at $p < 0.05$ level.

The hardpan affected the slippage significantly ($p < 0.05$) (Table 2.2). At a depth of 11 cm of the hardpan, slippage was the least (11.9%); it increased by 5.9 percentage point at a depth of 16 cm of the hardpan. This is attributed to the effect of bulldozing a larger volume of soil as wheel sinkage increased in the deep soil pan, and to the large vertical component of the reaction to the wheel in the shallow pan. The vertical and horizontal component of the reaction force to the wheel are theoretically changing according to the angle of the pulling force: the more the pulling force is pointing upward the more the vertical component increase and the horizontal component decrease, and vice versa . Less force is required from a tall person in pulling a manual rice transplanter than from a short person because of the upward force by the former that reduces drag on the runners (i.e. skis) (Yadav et al., 2007).

The pitch angle of the body of the transplanter was maintained as low as $<1.51^\circ$ under all the treatments, which is attributed to the independence of the wheel swing from the body of the transplanter.

Wheel sinkage was nearly the same as the depth of the hardpan, demonstrating that the wheel followed the soil pan in a field up to 16 cm deep.

2.3.4. Planting test on a varying hardpan of rice field with the free-pivoting suspension.

The rice transplanter was loaded with the 98 N of weight on its wheel as was suggested (Section 2.3.3) and with the seedlings on its trays (Figure 2.9). The experimental field had an average hardpan depth of 15.9 cm (± 2.1 cm) and water depth of 2.1 cm (± 0.3 cm). The forward speed of the rice transplanter during the test was measured to be 0.5 m/s (± 0.1 m/s). The slippage of the rice transplanter during the planting operation was 10.3% ($\pm 1.8\%$) which is not different from the slippage of the rice transplanter loaded with the same weight on the wheel in an even hardpan (Section 2.3.3). This shows that the free-pivoting suspension worked satisfactorily also in a varying soil pan of the field with a low slippage by adding 98 N of weight on its wheel.

The hills investigation presented an average of 3.4 (± 1.7), 3.1 cm (± 0.5 cm), and 15.4 cm (± 0.3 cm) of number of plant per hill, depth of planting, and distance between plants, respectively. The missing hills were 8% which is slightly larger than the 5% Japanese standard allowance in rice transplanter test (Kanai, 1980) and is partly attributed to the distribution of the seeds that might have been uneven in some areas of the mat due to the manual sowing operation on the mat. The lodging angle of the plants was 17.0° ($\pm 15.0^\circ$) from the vertical, which was due to the wide hole left by the tines after the insertion of the seedling plants in the soil. Figure 2.10 shows the planted seedlings in the experimental

field.



Figure 2.9 The rice transplanting with the seedlings mat on its trays.



Figure 2.10 The seedlings planted in the experimental field.

2.4. Conclusions

- 1) The free-pivoting suspension mechanism was developed and tested on a one-wheel rice transplanter as a potential simplification of the height control mechanism. The mass of the rice transplanter was only 54 kg.

- 2) With the fixed suspension, adjusting the depth of the wheel to the depth of the hardpan of the field was a prerequisite for a more horizontal and stable pitch angle and less slippage.
- 3) The free-pivoting suspension maintained the pitch angle of the body of the transplanter stably at near the horizontal on the surface of the field, allowing the wheel to follow the hardpan down to a certain depth.
- 4) With the free-pivoting suspension, increasing the wheel load by 98 N reduced slippage significantly by up to 52%.
- 5) The walk-behind rice transplanter achieved a slippage of 10.3% and a lodging angle of plants of 17.0° during the transplanting seedlings on a varying hardpan depth of field.

CHAPTER 3. THIRTY-ROW ARRAYED RICE MAT SEEDLINGS FOR SAVING SEEDS

3.1. Introduction

Cost reduction and high productivity are among the essential targets for researchers and engineers to meet the increasing worldwide demand for rice. Recently, a new system of growing seedlings comprises dense sowing of seeds (312 to 375 g of germinated seed) and a precise planting mechanism that increases the number of seedlings picked up per nursery tray, have been developed for reducing nursery trays, material cost, space and labor (Yanmar, 2018). Despite these advantages, sowing seeds at a high density limits the life span of the seedlings as their growth stops or starts declining 20 days after sowing (DAS); therefore, seedlings need to be transplanted within a short period of time, which results in less flexible farm management.

To solve the above issue, reducing the amount of seed is an obvious choice to alleviate competitions, and consequently to allow plants to last longer. The reduction, however, with the conventional method (hereinafter broadcasting) of sowing leaves unevenness in distances among the seeds on the tray and increases occurrences of picking null plant. Therefore, a reduced amount of seeds should be accompanied by a precise sowing method.

Arrayed seedlings (sowing the seeds in lines) are one of the solutions; they have been adopted in part, although not thoroughly studied, on a commercial basis for over 40 years. According to Ogawa et al. (1977), arrayed seedlings require 25 % fewer seeds than broadcast seedlings to achieve missing hill rate of less than 10%, accelerate heading for two days and increase the grain yield by 9%. Similarly, Nakahashi et al. (1974) have reported that the quality of seedlings is better with less seeding rate and with arrayed seedlings. In an investigation on arrayed or paper pot seedlings, Tamura and Yamazaki

(1976) have reported that the heading dates and grain yields are not generally affected by the foliar age of the seedlings, indicating that late transplanting can be easily scheduled with sparsely sown seedlings at a high foliar age.

The objective of this study is to save seeds by reducing seeds quantity sown per tray by arranging them in lines equal to the lateral feed number of the transplanter so that the mat covers the same area as that of a conventional broadcast mat. Of particular note is that, apart from saving seeds, the reduced density of seeds contributes to providing more nutrients, light, and aeration to each plant, thus the seedlings would continue growing and last longer, allowing a longer period of transplanting for farmers.

3.2. Materials and Methods

Two types of mat seedlings were prepared, arrayed i.e. the experiment and broadcast i.e. the control. Mature rice seeds (cultivar: Hinohikari) were selected in the solution of salt (specific gravity: 1.13) and soaked in pure water at about 22 °C until they bore 1.5 mm sprouts (ca. 5 days). First, 6 mm wide and 7 mm deep V-shape furrows were with a grinder made on a 13 mm thick coco-peat mat (Hakobe no ie, 2018). The grinder that comprised of 30 discs, equal to the lateral feed number of the transplanter, were mounted on a shaft driven by a 0.75 kW-electric motor (Figure 3.1). The mat was then manually slid along guides onto the grinder table to furrow it (Figure 3.2). The coco-peat mat was placed in a tray filled with 15 mm-deep soil, 82 g of germinated seeds per tray were manually sown into the furrows (Figure 3.3), and the mat was covered with a thin layer of soil before being watered. Broadcast mat seedlings sown with a seeding machine (THK-2009B, Suzutec Co., Ltd, Utsunomiya) were prepared by conventional methods (138 g of germinated seeds per tray) and used as the control.

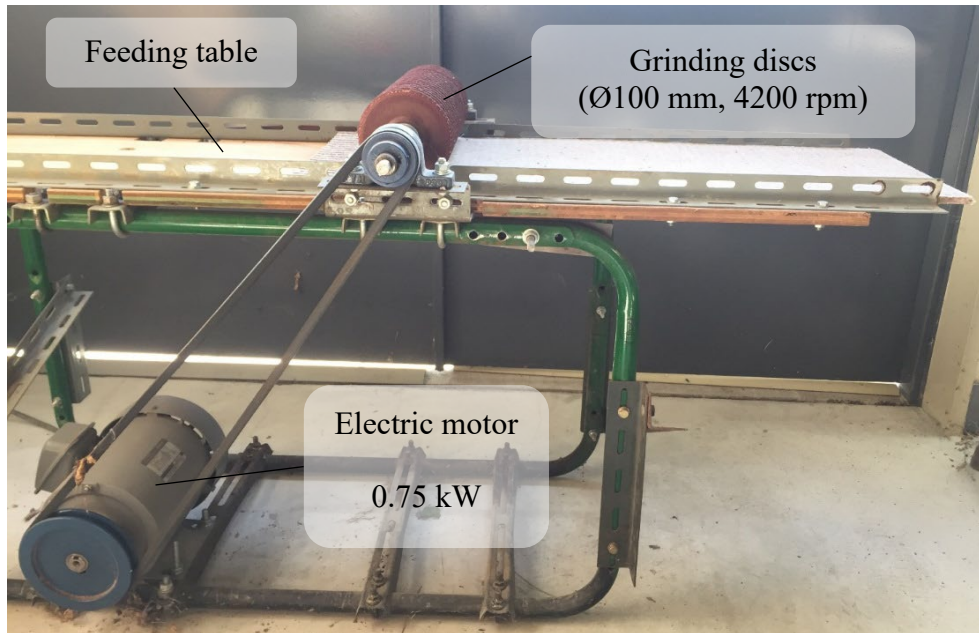


Figure 3.1 The grinding machine used for furrowing the coco-peat mat.

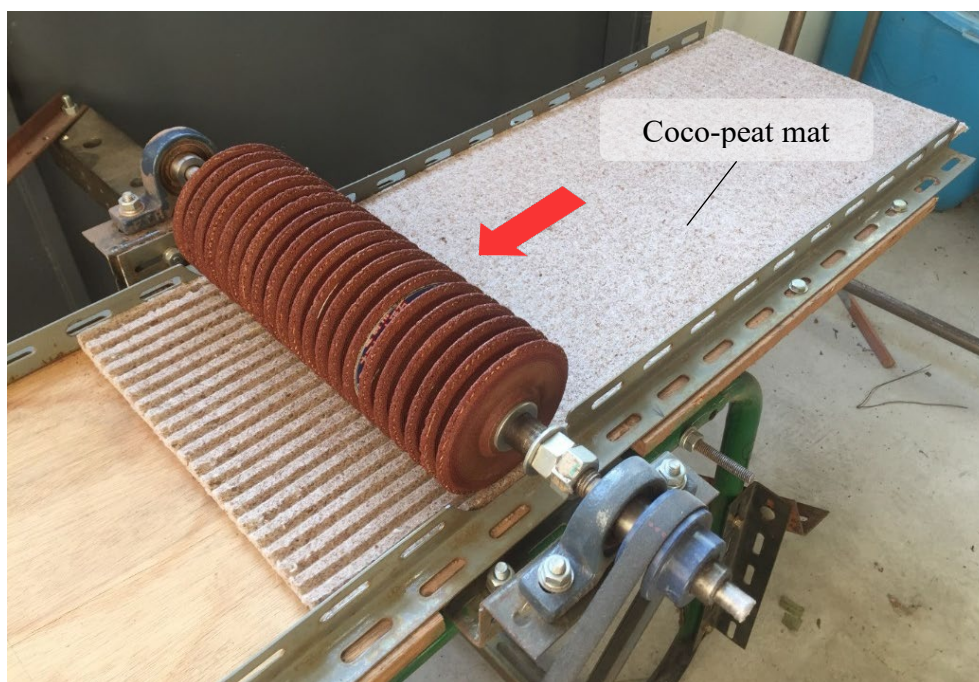


Figure 3.2 Furrowing the coco-peat mat.



Figure 3.3 The seeds sown in the furrows of the coco-peat mat

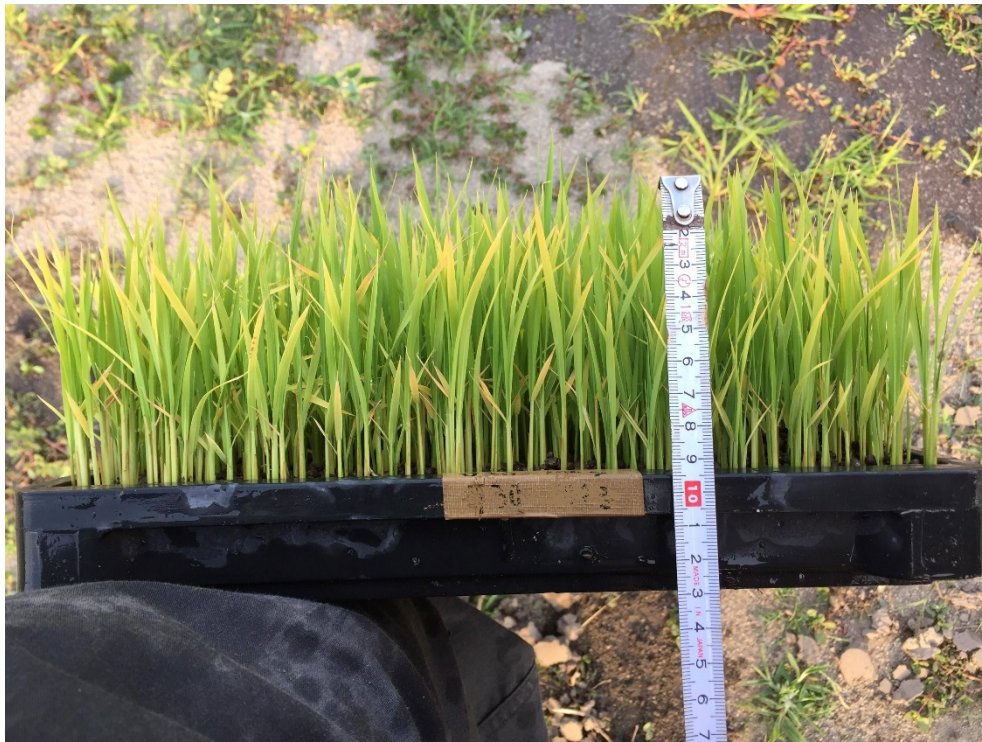


Figure 3.4 The arrayed seedlings on the day of transplanting.

The experiments were carried out in 2017. The arrayed and the broadcast seedlings were 2.5 to 3.5 and 4.0 to 4.5 foliar age (hereinafter of true leaves), respectively, on the day of transplanting. They were transplanted on June 26th (31 and 33 DAS, respectively) in sections of a 900 m² paddy field located in Chikuzen-cho, Fukuoka, Japan, where the control seedlings were planted in eight rows along the border of the field with 15.7 mats

per 1000 m² and the experiment seedlings (Figure 3.4) were planted in the remaining area in the center with 7.3 mats per 1000 m². An eight-row rice transplanter for high-density seedlings (YR8D, Yanmar Co., Ltd., Osaka) was used set at 30 lateral feeds with 7 mm vertical feeds for the arrayed seedlings, and 26 lateral feeds with 13 mm vertical feeds for the broadcast seedlings (the farmer's default setting). The planting pitch and depth were set to 17.3 cm and 2 to 3 cm, respectively, for both seedling types. The number of plants per hill of the arrayed seedlings was counted two days after transplanting (DAT) for a total of 160 observations.

On October 16th (112 DAT), 20 hill-plants were randomly sampled in each section, and yield components were measured. On the following day, an area 1.5 m wide and 15 m long plot was harvested in each section with a five-row combine harvester (AR585, Kubota Co., Ltd., Osaka) and the missing hills were investigated.

3.3. Results and Discussion

Of the arrayed seedlings, the set density of seeds has allowed 40% of saving per seedling tray from that of the control. The rate of missing hills at transplanting was a low 4.4%, nearly the same as the standard allowance (5%) of the transplanter test code in Japan (Mori, 1975). The combination of the shorter vertical feed and the 30 lateral feeds setting of the machine reduced the number of mats used per unit of area to 46% of that with the control. The reduced quantity of seeds per tray resulted in 66.7% single and 25.8% double plants per hill, whereas the triple and quadruple plants demonstrated only 2.5 % and 0.6%, respectively. Besides, the remaining seedlings have survived until their heading in their tray.

Table 3.1 shows the data collected upon harvesting. The yield of brown rice of the arrayed-mat seedlings was 11% lower than that of the control due to the large number of

missing hills (23.4%) at harvest. This was partially compensated, however, by the 11% higher grain weight per hill than that of the control. The high percentage of missing hills of the arrayed mat seedlings resulted presumably from the planting mechanism of the 30-feed rice transplanter, the narrow and sharp tines of which damaged the single seedlings although they were spared as shown by the analysis of the plant number per hill at transplanting. Therefore, a regular 26-feed transplanter is suggested for use in a further investigation as it has wider and less sharp tines, although one more mat per 1000 m² may be needed therewith.

Table 3.1 Harvest details

Criteria		In-line	Control
Missing hills* (%)		23.4	4.1
Thickness of brown rice ** (mm)		1.99	2.01
Yield components from the samples	Panicles per hill	20.3	18.8
	Grain per panicle	94.3	86.9
	Maturity (%)	86.9	86.7
	1000-grain weight of brown rice *** (g)	20.9	22.1
	Brown rice yield (g/m ²)	489.9	553.1
Combine-harvested brown rice yield ³ (g/m ²)		454.6	516.2

* Missing hills upon harvesting

** Weighted average after 0.1 mm-interval sieve analysis

*** Weight adjusted to 15% moisture content

3.4. Conclusions

- 1) The set density of seeds allowed 40% of saving as compared to the control
- 2) The missing hills at transplanting of the arrayed seedlings were a low 4.4%.
- 3) The combination of the short vertical feed (7 mm) and the 30 lateral feed reduced the number of mats per area to 46 % of the control.

- 4) The grain yield of the arrayed seedlings was lower than that of the control due to the large number of missing hills at transplanting which was partly attributed to the narrow and sharp tines of the 30-feed rice transplanter.

CHAPTER 4. ARRAYED RICE MAT SEEDLINGS FOR SAVING SEEDS

– FOCUSING ON MISSING HILLS AND HILL MORTALITY –

4.1. Introduction

Experiments with arrayed seedlings have been conducted to reduce the quantity of seeds sown per tray for prolonging their lifespan while covering the same planting area as that of broadcast seedlings (CHAPTER 3). In that study, seeds were sown in 30 rows corresponding to the 30 lateral feed number of the transplanter for high-density seedlings, so that the mat covered the same area of planting as that of a broadcast mat but with a smaller number of seeds. The arrayed mat seedlings with 40% fewer seeds than the broadcast seedlings showed a low percentage (4.4%) of missing hills at transplanting at 31 DAS, but 19% of the transplanted hills did not survive until harvest. This was attributed to the precise planting mechanism for the high-density seedlings (Yanmar, 2018) with narrow and sharp tines that possibly damaged the singular plants dispatched from the mat, although they appeared to have been successfully transplanted.

The current study, therefore, follows CHAPTER 3 by focussing on settings to reduce hill mortality. It is hypothesized that the use of conventional 13 mm-wide tines (not those for high-density seedlings, 10 mm-wide) of the transplanter of 26 lateral feed numbers would avoid the damage to seedlings, thus improving the survival rate of the seedlings transplanted from the arrayed mat.

4.2. Materials and methods

The experiment was carried out in a farmer's rice field located in Chikuzen-cho, Fukuoka, Japan, in the 2018 planting season. Of a 1052 m² rice field, 324 m² around the center was allocated for the experiment; the remaining area was planted by the owner with the same variety of rice. An eight-row rice transplanter [YR8D (XU-Z), Yanmar Co.,

Osaka] with a 30 cm-row spacing was used to transplant seedlings at about 17 cm- intra-row spacing and at a depth of 2 to 3 cm.

4.2.1. Experimental design

The experiment was laid out in a split-plot design comprising portions of the mat as main plots, vertical feed as the sub-plot, and the type of seedling as the sub-sub-plot. The field was divided into south, middle and north where transplanting was carried out from south to north, such that each plot corresponded to a portion of the mat: "First 1/3", "Middle 1/3", and "Last 1/3", respectively. Each plot was divided into three randomly chosen parts for vertical feeds (7 mm, 10 mm, and 13 mm) of the seedlings in one path of about 15 m, with each type of seedling (arrayed and broadcast) transplanted in four consecutive rows (Figure 4.1). The vertical feed at 7 mm is unusual for a conventional transplanter not for high-density seedlings, but this trial was to seek future possibilities for reducing necessary seedling tray per area, so as a case with the high-density seedlings (Sawamoto et al., 2019).

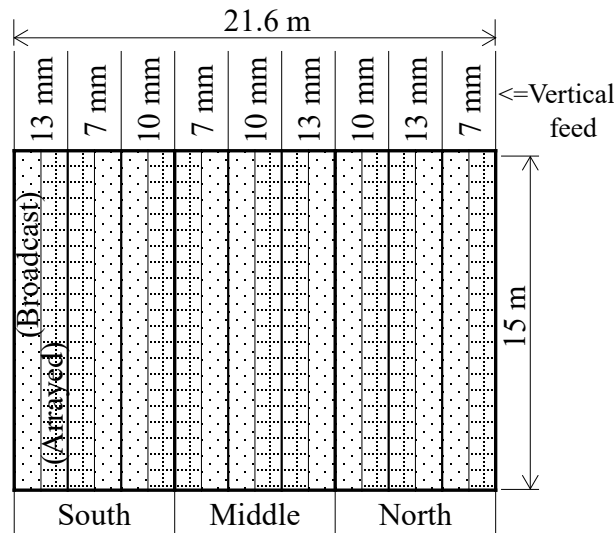


Figure 4.1 The experimental field arrangement.

4.2.2. Preparing seedlings

Seeds (cultivar, Hinohikari) were disinfected in 60 °C hot water for 10 minutes and left to germinate in a conditioner “sprouting machine” (YS-500L, Tiger Kawashima Co. Ltd., Japan) until they bore 1.5 mm sprouts. Two types of seedlings were prepared: arrayed (experiment) and broadcast (control) seedlings. Four seedling mats of each type were transplanted 30 days after sowing, at 3 to 4 foliar age (Figure 4.2), and managed under conventional farming practices until harvest.



Figure 4.2 Seedlings on transplanting day, 30 DAS: (a), 26-row arrayed seedlings and (b), broadcast seedlings.

For the arrayed seedlings, commercial coco-peat mats as described (Andoniaina et al., 2018), were crushed in water, and the mixture was poured into a plastic mold of 26 triangular furrows (10.8 mm in width and 7 mm in depth). The mixture was covered with a perforated plastic plate and clamped down to drain the water. The resulting furrowed mold was maintained under the sun for about two days to dry and harden (Figure 4.3), then placed in a tray filled with 10 mm-thick soil, and the 92 g of germinated seeds (34.5 g of 1000 grain weight) per tray were sown with a sowing machine (THK-2009B, Suzutec Co., Ltd, Utsunomiya) set at its minimum sowing capacity. Some misaligned seeds were

relocated manually into the furrows (17 grains/ 10 cm) before being covered over with a thin layer of soil (Figure 4.4 (a)).

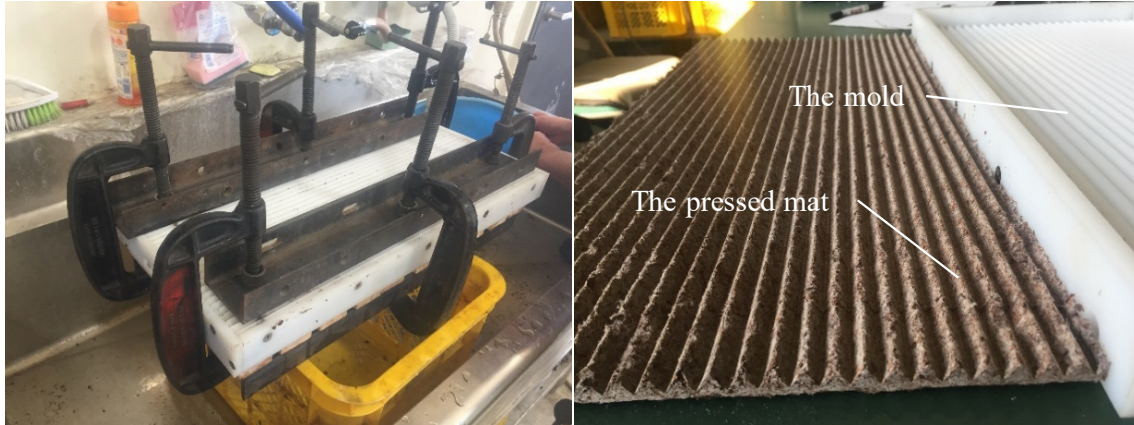


Figure 4.3 Molding the coco-peat mat by pressing.

The broadcast seedlings were prepared by conventional methods with soil only. Germinated seeds (150 g per tray; the farmer's default setting) were sown with the same sowing machine as above (Figure 4.4 (b)).

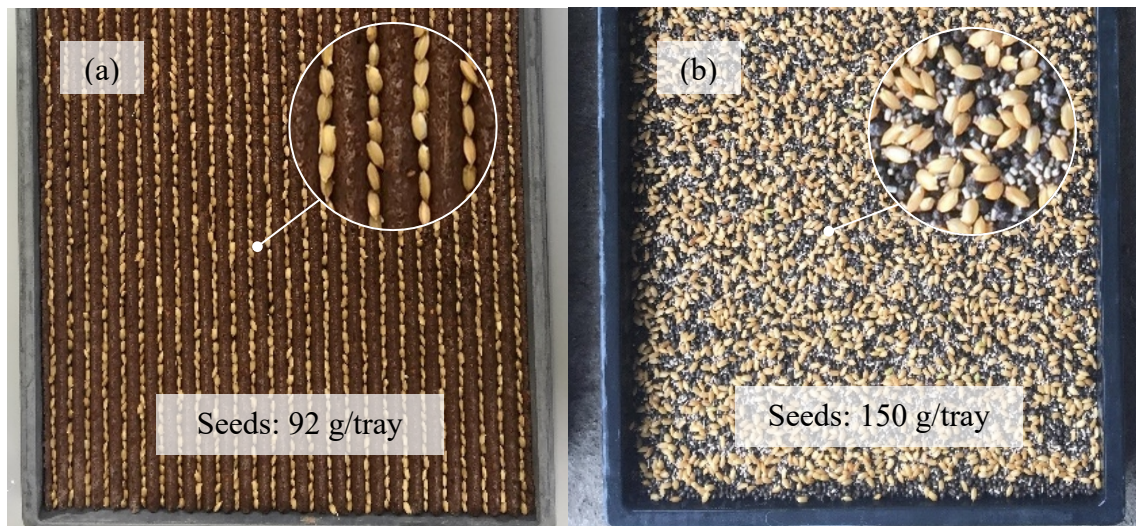


Figure 4.4 Seeds in trays: (a), arrayed seedlings and (b), broadcast seedlings.

4.2.3. Measurement

The hills devoid of any seedlings at transplanting were defined as missing hills. Two

days after transplanting (DAT), the number of plants per hill was counted for 100 hills (25 consecutive hills per 4 rows) in each portion of the field and the percentage of missing hills was calculated.

The percentage of hills that were successfully transplanted but disappeared before harvest were defined as hill mortality. At harvest, the number of missing hills n_h was counted at the same location as the missing hills at transplanting n_p . The hill mortality r_d was then calculated as a ratio of the total number of hills investigated in each portion of the field n_t as follows:

$$r_d = \frac{n_h - n_p}{n_t - n_p} \times 100 \quad (4.1)$$

On 112 DAT, samples of hill plants were harvested with a combine harvester (AR585, Kubota Co., Ltd., Osaka) from a 12 m² area for each portion of the field and the yield of brown rice was calculated.

4.2.4. Deformation experiment of the mat seedlings

An indoor experiment was carried out to compare the deformation in the arrayed seedlings (on pressed coco-peat mats and soil) and broadcast seedlings (on soil only) (Section 4.2.2) at pick-up time to investigate the following factors: (1) the presence or absence of the vertical feeder underneath the mat that moves the mat down on the trays and (2) location of the pick-up by the tines (start, middle, and end of every lateral motion of the trays). The experiment was done with a six-row rice transplanter (RR600, Yanmar Co., Osaka), equipped with a transplanting mechanism (rotary type) similar to the one used in the main experiment of the current chapter, set at a vertical feed of 10 mm. The shrinkage of the mat displayed by the lateral clearances between the mat and the tray

walls (Figure 4.7) was measured at 10 mm from the bottom of the mat (the height at which the tines pick up the seedlings).

4.3. Results and discussion

4.3.1. Plant number per hill at transplanting

At transplanting (30 DAS), the arrayed seedlings were about 14 cm tall and were 4 cm shorter than the control, which is partly attributed to the lack of fertilizer containing the mat itself compare to that of the control as the coco-peat mat contained no fertilizer. Their foliar age (3 to 4), however, was not different from that of the broadcast seedlings. (Figure 4.4)

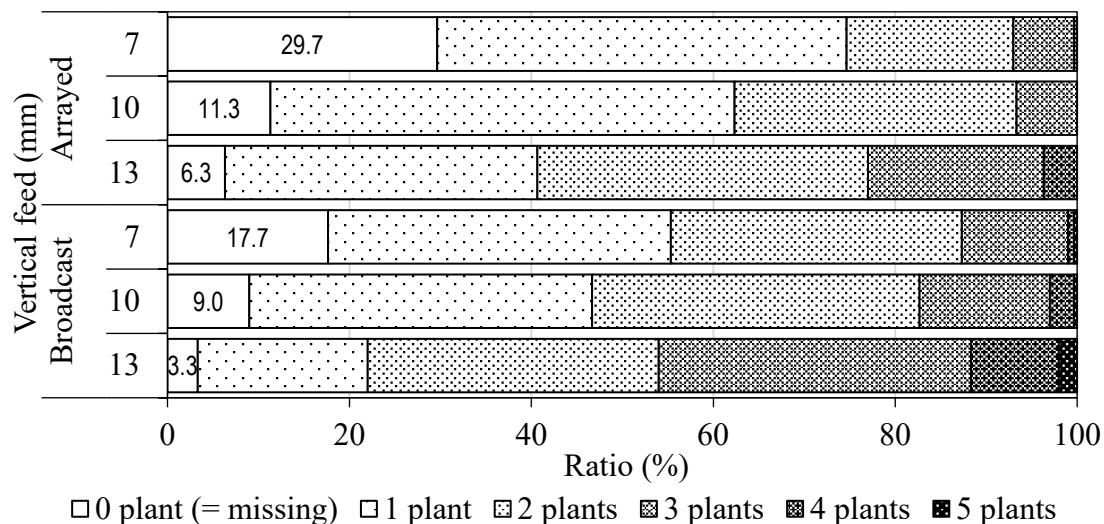


Figure 4.5 Plant number per hill at transplanting (numerals on the hollow label indicate % of missing hills).

The number of plants per hill was mostly one or two and tended to vary according to the type of seedling and the vertical feed setting of the rice transplanter (Figure 4.5). As the missing hills decreased, the number of plants per hill tended to increase when the vertical feed was increased from 7 mm to 10 mm and 10 mm to 13 mm. The percentage

of the number of plants (one or two) per hill did not significantly change, however, except at a vertical feed of 7 mm for the arrayed seedlings and 13 mm for the control, with the former showing between zero and one, and the latter between two and three plants per hill. This is obvious because, theoretically, the seeding rate of 17 grain along 10 cm of the furrow allows of picking up 1.2, 1.7 and 2.2 plants on the average in the settings of 7, 10, and 13 mm vertical feed, respectively. The vertical feed of 13 mm was most favorable in both types of the seedlings because the number of missing hills was the lowest at 6.3% for the arrayed seedlings *vs.* the 5% standard allowance for the transplanter test code in Japan (Mori, 1975) and 3.3% for the control (Figure 4.5).

4.3.2. Observation on the 7 mm-vertical feed

The largest percentage of missing hills at transplanting was observed at the lowest vertical feed (7 mm), at an average of 29.7% for the arrayed seedlings and 17.7% for the control (Figure 4.5). In the arrayed seedlings, the large percentage of missing hills was attributed partly to the lower density of seeds and to the uneven distance between seedlings along the array (Figure 4.6 (b)) due to the orientation of the seeds at sowing.

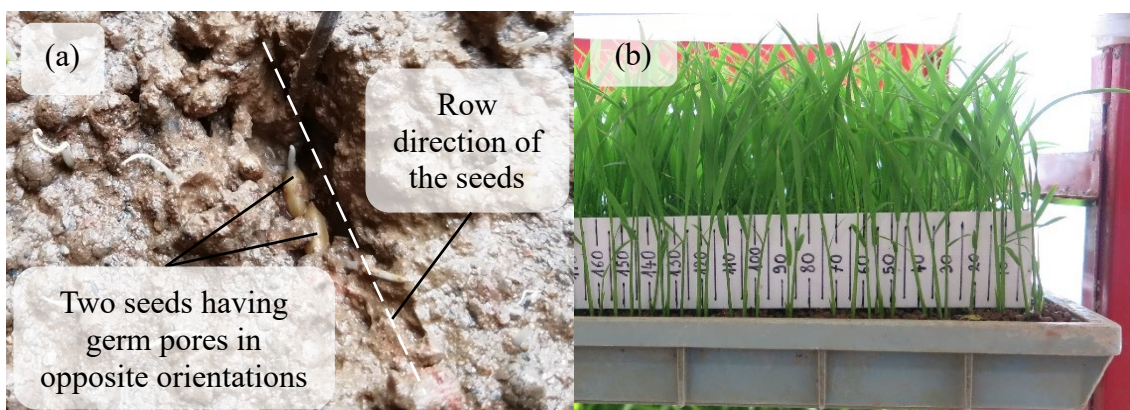


Figure 4.6 Arrayed seedlings: (a) seeds in opposite orientation in the furrow of the mat, (b) lateral view of a 26-row arrayed seedlings in a tray.

Although seeds were one by one carefully aligned in the furrows of the mat with neither space nor overlap between them (Figure 4.4 (a)), the location of their germ pores was not controlled (Figure 4.6 (a)). If two germ pores are facing together, two plants are likely to be trapped by the tines to be scratched at once, potentially leading to zero plant at the next pick-up along the same array. Yet, some ambiguity such as the root-induced excessive scratching may also have existed withing the array or across the arrays. There are technical options to make up for such uneven plant distances. Yamada et al., (2005) have achieved arranging the germ pore of large elliptical seeds to the same direction with an accuracy of about 95% at 5000 seeds per hour using image processing. More primitively, the seeding rate can be simply increased to the extent not affecting the plant lifespan, such as a similar amount with the control (up to 150 g).

A sharp increase in the percentage of missing hills of the arrayed seedlings at transplanting was observed in portions of the mat, reaching over 40% in the “Last 1/3” portion (Figure 4.8 (a)), whereas the control showed a nearly constant and lower percentage of missing hills. The constancy regardless of the portion of the mat reflects the randomness of the sowing, whereas the low percentage of missing hills is associated with the increased density of broadcast seeds that reduced the distances among the seeds (Figure 4.4). This implies that, with the arrayed seedlings, the lateral alignment of the arrays with the tines became gradually mismatched toward the last portion of the mat, resulting in increased frequency of tines moving down into the soil without seedlings. The tines 2 mm wider than the spacing of the arrays (i.e. 13 mm vs 10.8 mm) have possibly allowed of picking up two arrays at once, leading to missing hills at the next time or later. In contrast, this was possibly a reason for the low percentage of missing hills (4.4%) in our first trial (Andoniaina et al., 2018), where tines of the transplanter for high-

density seedlings had almost the same width (10 mm) as the spacing of the arrays (9.3 mm) of the 30-row arrayed seedlings, being less likely to pick up the adjacent array at the same time. Accordingly, the fact that 7% of hill had more than three plants (Figure 4.5, arrayed seedlings at 7 mm vertical feed) is attributable to the combination of this wider tines and the orientation of the germ pore facing together as already discussed.

The misalignment of the seedlings was attributed to external forces inducing deformation of the mat. At transplanting, the lower edge of the seedling mat near the tines was subjected to friction from the angle plate supporting the weight of the seedlings and to the reciprocating motion of the mat trays in lateral directions. The result of the deformation experiment (Table 4.1) demonstrated that, although the mat of the arrayed seedlings was not different from that of the control, its lateral clearance (Figure 4.7) was over 6 mm between the middle and the end of the motion of the trays.

The deformation in the mats of both types of seedlings was significantly affected by the vertical feeder of the rice transplanter ($p<0.05$) (Table 4.1). The function of the vertical feeder is to feed seedlings after every pass of the trays and to hold them in place at pick-up by the tines so that the vertical feed of the mat remains constant. When the length of the mat became shorter than the height of the lower edge of the vertical feeder, the lateral clearance between the mat and the wall of the trays increased. Also, when the mat was not on the vertical feeder, the seedlings on the tray rotated slightly toward where seedlings that had already been picked up (Figure 4.7). Therefore, in the field experiment, the lateral misalignment of the seedlings to the tines is assumed to have widened toward the last 1/3 portion of the mat, resulting in a higher percentage of missing hills.

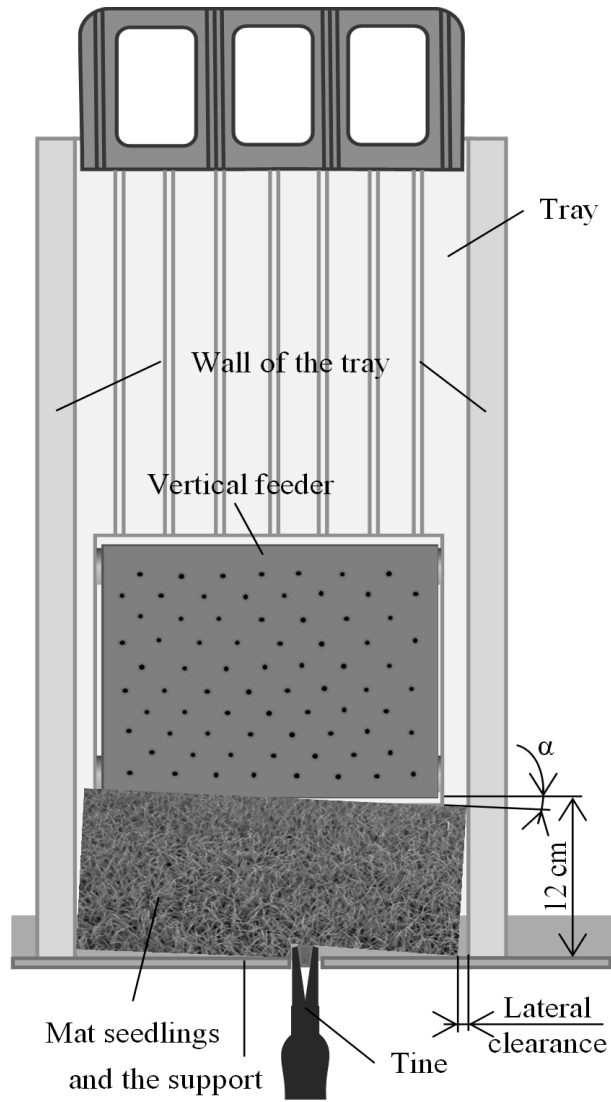


Figure 4.7 Illustration of the mat seedlings in a tray (moving to the right) slightly rotated at an angle α toward the side where seedlings have been already picked up.

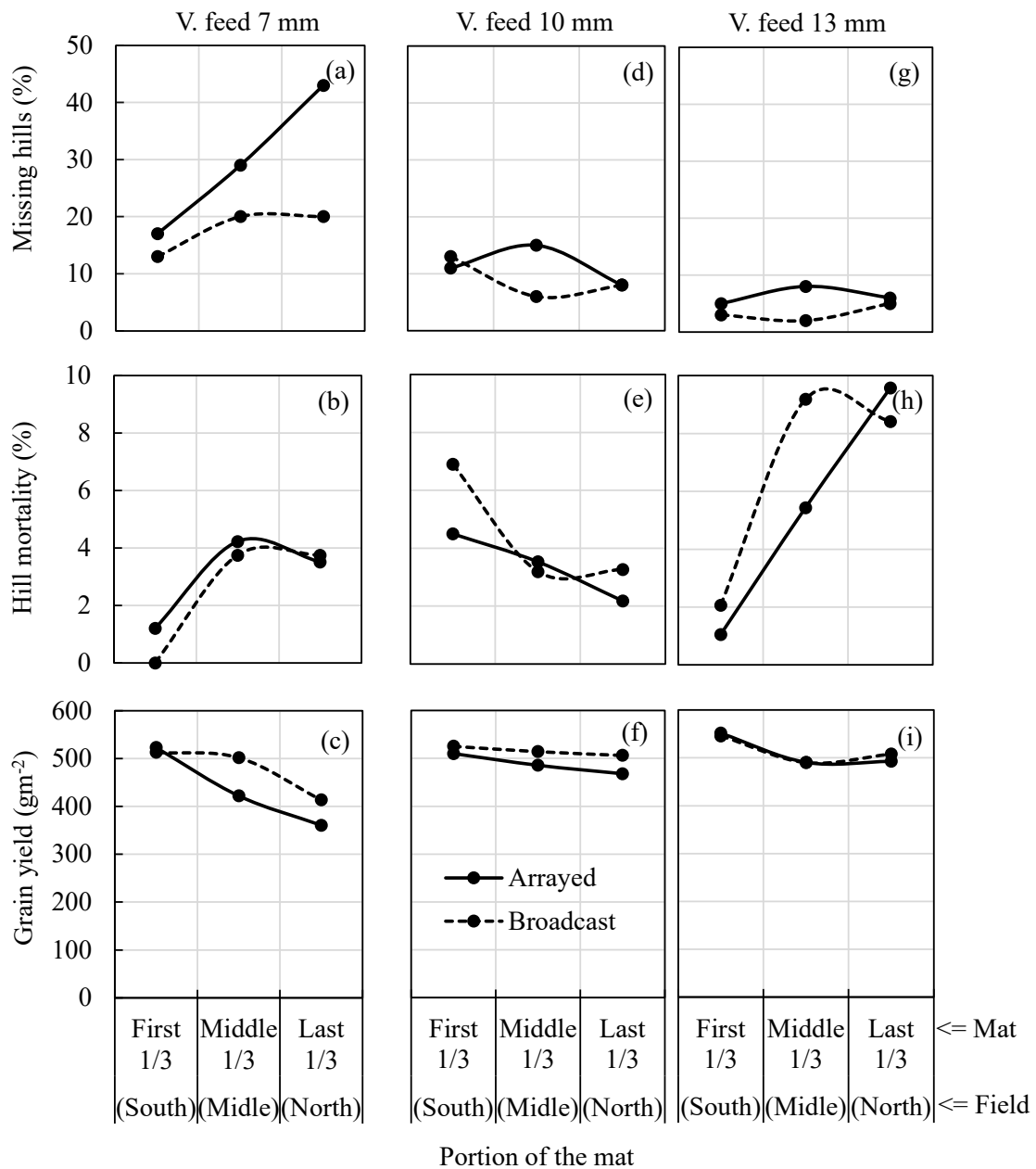


Figure 4.8 Effect of the portion of the mat on: missing hills at transplanting, hill mortality and grain yield of brown rice in vertical feed settings of 7, 10 and 13 mm.

Table 4.1 Deformation of the mat (lateral clearance) from an indoor experiment, as indicated by averages for three-way ANOVA with factors and the corresponding treatments listed in the table (see Figure 4.7 for definition of the terms).

Factor and treatment (source of variation)	Lateral clearance (mm)
Seedling mat	
Pressed coco-peat + soil (arrayed seedlings)	6.4
Soil only (broadcast seedlings)	6.1
Vertical feeder	
With ¹⁾	5.6a
Without ²⁾	6.9b
Pick-up locations in lateral directions	
Beginning	4.7a
Middle	7.5b
End	6.5c

Different letters indicate significant differences by Tukey's multiple comparison test at $p < 0.05$ level.

¹⁾ Length of seedling mat > 12 cm.

²⁾ Length of seedling mat < 12 cm.

4.3.3. Missing hills and grain yield at 10 mm and 13 mm vertical feeds

As shown in section 4.3.2, the vertical feed of 7 mm was not suitable for either type of seedling. For a rational comparison between both types of seedlings, vertical feeds of 10 mm and 13 mm are discussed here. A Three-way analysis of variance (ANOVA) was carried out on types of the mat seedlings (arrayed and broadcast), vertical feeds (10 mm and 13 mm) and portions of the mat (first 1/3, middle 1/3 and last 1/3) as the factors affecting the missing hills at transplanting and the grain yield (Table 4.2).

The number of missing hills at transplanting the arrayed seedlings was slightly higher

than that of transplanting the control (Table 4.2, 2nd column), but not significantly different. They were affected by the vertical feed but not by the portion of the mat, and decreased by half through simply increasing the vertical feed from 10 mm to 13 mm; apparently more plants were picked up at the greater vertical feed by bypassing missing hills. The increased vertical feed allows to reach another plant along the array, even if one plant is missing due to the excessive scratching as already discussed, thereby reducing the risk of picking zero plant. This is probably one of the reasons of the constant tendencies of the missing hills in 10- and 13-mm vertical feeds regardless of the portion of the mat.

Table 4.2 Effect of type of seedlings, size of the vertical feed and portions of the mat on missing hills, hill mortality, and grain yield.

Source of variation	Missing hills (%)		Hill mortality (%)	Brown rice yield* (g/m ²)
	at transplanting	at harvest		
Mat seedlings				
Arrayed	8.8	12.8	4.4	500
Broadcast	6.2	11.3	5.5	515
Vertical feed				
10 mm	10.2b	13.7	3.9	501
13 mm	4.8a	10.5	6.0	513
Portions of the mat				
First 1/3	8.0	11.3	3.6	533a
Middle 1/3	7.8	12.8	5.3	495b
Last 1/3	6.8	12.3	5.9	494b

Different letters indicate significant differences by Tukey's test at $p < 0.05$ level.

* Weight adjusted to 15% moisture content.

The grain yield was not significantly different between the two types of seedlings,

although that of the arrayed seedlings appeared to be smaller (Table 4.2, 5th column). The grain yield was not affected by the vertical feed; however, it was significantly high in the first 1/3 portion of the mat, then dropped in the middle and the last 1/3 portions of the mat. Possibly, lower hill mortality in the first 1/3 portion of the mat (Table 4.2) contributed, partly, to this higher grain yield.

4.3.4. The hill mortality not associated with mechanical damage at the tines

The hill mortality (Figure 4.8 (b), (e), (h)) is mostly lower than the one reported with the arrayed seedlings for a 30-lateral feed transplanter (Andoniaina et al., 2018), yet it is difficult to find tendencies associated with the treatments of the experimental factors. Generally speaking, however, the hill mortalities for arrayed and broadcast seedlings (solid and broken lines) seem to fluctuate in parallel. Their coefficient of correlation is as high as 0.84 ($p < 0.01$, one-sided test)

As the arrayed and the broadcast seedlings were planted side by side at each treatment (Figure 4.1), a paired t-test was performed on the hill mortalities for both types of seedlings. As expected, the null hypothesis was accepted on the paired differences ($p = 0.31$, two-sided test), i.e. there is no significant difference between these mortalities. Considering the fact that they widely fluctuate between 0 % and 10 %, it is plausible that the fluctuations were originated from environmental conditions such as micro-elevation of the field or softness of the soil, not from routine damages such as the ones occurring at the tines. Apparently, the wide tines for the 26-lateral feed transplanter did not explicitly damage the seedlings associated with the arrayed configuration of each plant.

4.4. Conclusions

- 1) The hill mortality in the 26-row arrayed seedlings transplanted with the 26 lateral

feed conventional rice transplanter was lower than 5% on the average. Potential damage at the tines is assumed to be low.

- 2) The arrayed seedlings required 40% less seeds than that of the broadcast seedlings but they covered the same area of planting with no difference in grain yield.
- 3) The number of plants per hill of the arrayed seedlings was mostly one or two and tended to increase with the vertical feed of the rice transplanter.
- 4) The vertical feed of 7 mm was not suitable for either type of seedling, especially for the arrayed seedlings where the missing hills at transplanting exceeded 40% in the last 1/3 portion of the mat. In addition to the lower density of the seeds, this high percentage of missing hills was attributed to the varying distances between the plants along the array and to the lateral deformation of the mat itself. The deformation is assumed to have interacted with the tines wider than the spacing of the arrays to cause such a high percentage of missing hills.
- 5) The arrayed seedlings were not different from the control in terms of missing hills, hill mortality, and grain yield under the vertical feed of 10 and 13 mm, with 13 mm being the most favorable and the 10 mm being an acceptable setting for both types, in terms of fewer missing hills at transplanting.

CHAPTER 5. THE ARRAYED SEEDLINGS ON THE FREE-PIVOTING SUSPENSION OF RICE TRANSPLANTER

5.1. Introduction

Simplification and cost reduction are among the objectives of researchers and manufacturers. In mechanical engineering, a simple structure generates numerous advantages such as reducing workload and time of fabrication, avoiding the use of complex parts, tools, and machines, which results in a reduced cost of production.

The free-pivoting suspension has been developed and installed on a walk-behind rice transplanter with the target of simplifying the suspension mechanism of the machine. This mechanism excluded the use of a hydraulic suspension while having the same functionality and result as the conventional rice transplanter that uses a hydraulic suspension mechanism as described in CHAPTER 2 (Andoniaina et al, 2020a). The results show that the exclusion of the hydraulic components reduced partly the weight of the machine to 54 kg and the machine achieved to maintain the pitch angle of the planting mechanism stably as required while having a low slippage percentage when the weight distribution was improved.

Besides, the arrayed mat seedlings were developed in order to reduce the amount of seeds used per tray for prolonging the plants lifespan. CHAPTER 3 (Andoniaina et al., 2018) and CHAPTER 4 (Andoniaina et al., 2020b) show that the arrayed seedlings require 40% less seeds than the broadcast seedlings, and they generate low hill mortality in the 26-rows transplanted with a conventional 26 feeds transplanter than in the 30-rows transplanted with the precise rice transplanter for high-density seedlings.

In this chapter, given that the free-pivoting suspension of rice transplanter has a different type of planting mechanism which is crank type whereas the arrayed seedlings

were tested with a rotary type planting mechanism, the arrayed seedlings were tested on the free-pivoting suspension rice transplanter with a target of combining both systems (rice transplanter and seedlings) so that they can be a package that farmers can benefit at once. The difference between the two planting mechanisms is that the crank type is less stable in terms of weight balance due to its structure with only one tine in each planting row whereas the rotary type has two tines arranged in opposite position in each planting row. However, the crank type planting mechanism is more suitable for small size transplanter because of its light weight and low cost.

5.2. Materials and methods

The experiment was carried out in the experimental field of the Graduate School of Agricultural Science, Kobe University, Japan. The field was tilled twice with a rotary tiller (RS1303, Yanmar, Japan) and left two days for the soil to settle before the experiment.

The rice transplanter with the free-pivoting suspension (Figure 2.2) was set with the optimum weight distribution based on the improvement experiment described in CHAPTER 2. Therefore, the wheel was loaded with 98 N of weight whereas the trays were loaded with the experimental mats of seedlings. On the other hand, the arrayed seedlings experiment (CHAPTER 4) shows that a minimum missing hill was obtained in the largest vertical feed setting. In the current experiment, the rice transplanter was set at 16 mm vertical feed to compensate for the low germination rate of the seeds noticed on the seedlings on the day of transplanting.

Three types of mat seedlings were prepared for the experiment: arrayed seedlings on a scratched coco-peat mat with soil, arrayed seedlings on a pressed coco-peat mat with soil and broadcast seedlings on a soil mat only. For the arrayed seedlings, the scratched

and pressed coco-peat mats were made with a grinder and a plastic mold as described in CHAPTER 3 (Andoniaina et al., 2018) and CHAPTER 4 (Andoniaina et al., 2020b), respectively, with the same number of furrows (26 furrows) as the number of lateral feed setting (26 feed) of the transplanter. The coco-peat mats were placed in the trays filled with 10 mm soil and 92 g of germinated seeds were sown manually in the furrows and a thin layer of soil was added to cover the seeds. The broadcast seedlings were prepared with a conventional method of preparation of seedlings with 150 g of germinated seeds sown manually by broadcasting (Figure 5.1).

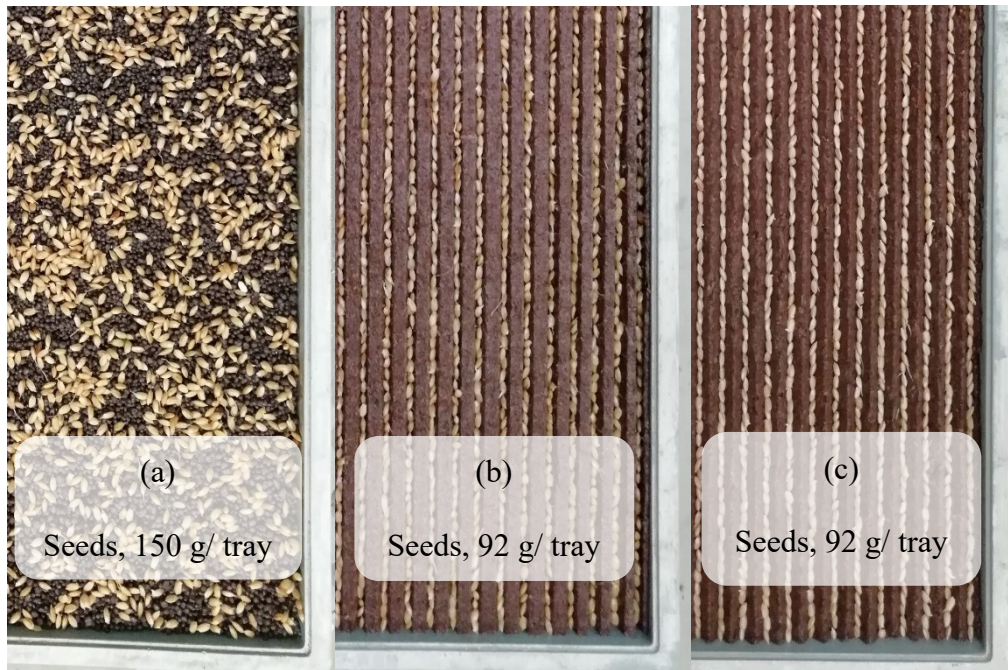


Figure 5.1 The three types of seedlings before the addition of the final covers of soil: (a) broadcast seeds on the conventional soil-only mat, (b) arrayed seeds on the coco-peat-mat with scratched furrows, (c) arrayed seeds on the pressed coco-peat mat with furrows.

The transplanting test was carried out in three runs (i.e. six rows of planting) where each run measured 18 m- long. The arrayed seedlings on a scratched coco-peat mat with

soil and the arrayed seedlings on a pressed coco-peat mat with soil were transplanted in the first (1st and 2nd) and the last two rows (5th and 6th) of the field in a randomized order; whereas broadcast seedlings were planted in the middle two rows (3rd and 4th row) as the control (Figure 5.2).

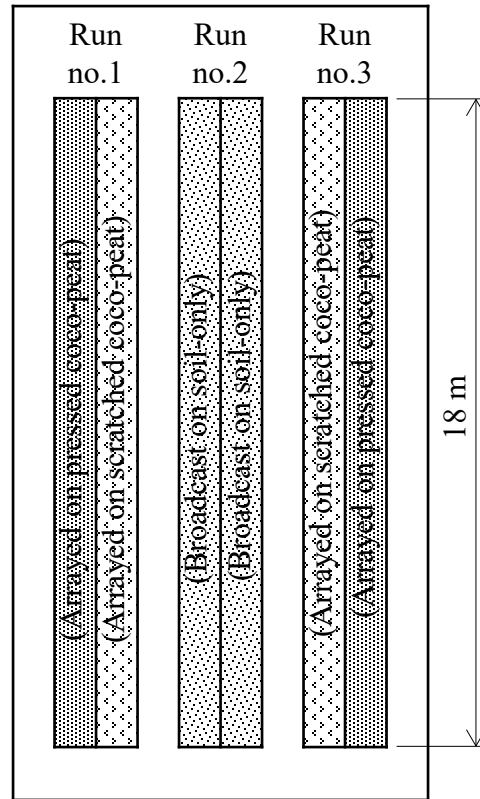


Figure 5.2 The experimental field setup.

The soil profile such as depth of the hardpan and of the water was measured manually for four points in each run a few minutes before the planting test. The time the rice transplanter made for running 9 m distance around the middle of each run was measured and the forward speed of the machine was calculated. The slippage S of the wheel was determined from the theoretical d_t and the measured d_m intra-row distances of the planted seedlings obtained from the average distance of 10 consecutive hills, as in Equation (5.1).

$$S = \left(1 - \frac{d_m}{d_t}\right) \times 100 \quad (5.1)$$

After transplanting, the number of plants per hill was counted for 97 hills for each seedlings type and the missing hills at transplanting were calculated. Similarly, the depth of planting and the plants lodging angle were measured for 20 hills in each type of the seedlings. At 12 DAT, the missing hill at the same place of the investigation of the plant number per hill at transplanting was counted and the hill mortality, defined as the number of hill that was successfully planted but disappeared, was calculated as a ratio of the total investigated hills as in Equation (4.1).

5.3. Results and discussion

5.3.1. The performance of the rice transplanter

The hardpan depth was slightly different among the three locations (i.e. runs) of the experimental field (Table 5.1). The shallowest was in the first run whereas the deepest was in the third run. There was slight variation within each run in the field. The water depth was 2.7 cm on average.

The forward speed of the rice transplanter was between 0.5 and 0.6 m/s, and the effective field capacity was 9 to 10 a/h, which are similar to what Mori (1975) found when testing a two-row rice transplanter. The average of the (wheel) slippage was 10.7% as calculated from Table 5.1. The slippage tended to increase slightly with the increase of the depth of the hardpan. The lowest slippage was found to be in the first run where the hardpan was the shallowest, whereas the largest slippage was in the third run where the hardpan was the deepest. This slippage average is similar to the result found with the same rice transplanter loaded with the same weight as in the current experiment (i.e. 98 N) on the wheel but with even hardpan depths. The variation of the slippage is also in line

with the previous experiment which shows a significant increase in slippage when the hardpan depth increases from 11 cm to 16 cm (Andoniaina et al., 2020a).

Table 5.1 Performance of the rice transplanter and soil profile

	1st run	2nd run	3rd run
Forward speed (m/s)	0.6	0.5	0.5
Theoretical field capacity (a/h)	13.0	10.8	10.8
Effective field capacity (a/h)*	10.4	8.7	8.7
Slippage (%)	9.0 (0.19)	10.2 (2.12)	12.8 (1.12)
Hardpan depth (cm)	13.9 (1.03)	14.8 (1.19)	16.6 (0.95)
Water depth (cm)	2.3 (0.79)	3.4 (0.48)	2.5 (0.91)

*Calculated based on turning, supplying seedlings, and adjusting time according to Kanai (1980). Numbers in brackets are standard deviations.

5.3.2. Hill investigation

The plant number per hill ranged mostly between one to three plants with a maximum number of 7, 6 and 5 plants for the broadcast, the arrayed on a scratched coco-peat and the arrayed on a pressed coco-peat mat seedlings, respectively (Figure 5.3). These numbers are larger than that of the previous experiment (CHAPTER 4) and were less than 8% of the total hills number, which was probably due to the wider vertical feed setting of 16 mm in the current experiment.

The percentages of the missing hill were 8.9% on the average as calculated from Figure 5.3, which is larger than the 4.4% in the 30-row arrayed seedlings (Andoniaina et al., 2018) and is partly associated with the low germination rate of the seeds although the vertical feed setting of the transplanter was set at 16 mm. They were not different between the types of the seedlings although that of the arrayed seedlings on a scratched and on a

pressed coco-peat appeared slightly larger than that of the broadcast seedlings (Figure 5.3). This might be due to the lower density in seeds of the arrayed seedlings as compared to the broadcast seedlings.

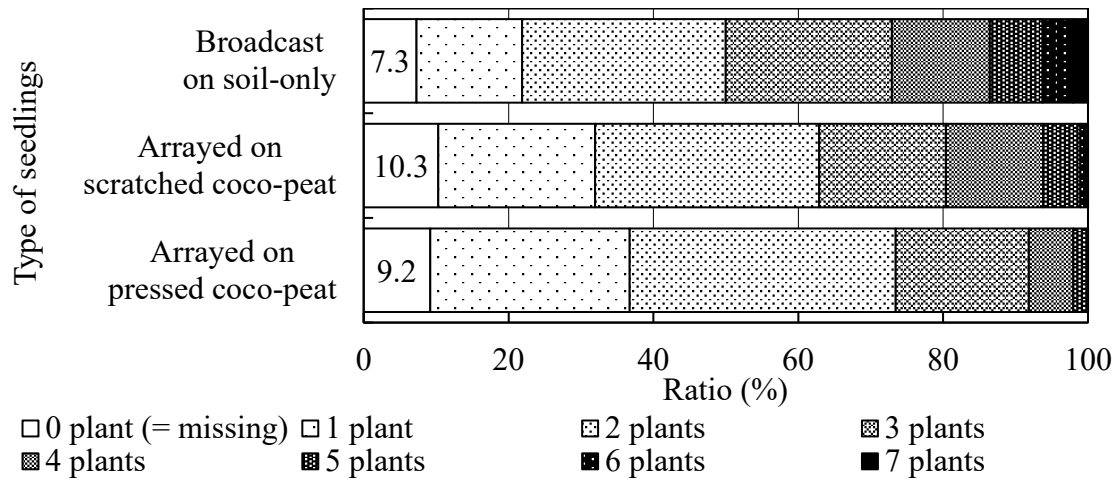


Figure 5.3 Number of plants per hill at transplanting

The hill mortality was low ($< 2\%$) and was not different between types of the seedlings. They tended to decrease with the percentage of the singular plants per hill at transplanting. This percentage of hill mortality is far lower than the 19% in the 30-rows arrayed seedlings transplanted with the 30-feed rice transplanter investigated at harvest (Andoniaina et al., 2018). The broadcast seedlings presented the lowest percentage of the single plant per hill and a zero hill mortality, whereas both of the arrayed seedlings had a larger percentage of single plant per hill and presented a hill mortality over one percent. These hill mortality are lower than what was found in the 26-rows arrayed seedlings at 13 mm vertical feed investigated upon harvest that was over 6% (CHAPTER 4). This difference was may be due to the early investigations (12 DAT) and to the wider vertical feed that might have reduced the percentage of the singular plants at transplanting.

The depths of planting were not different between the seedlings and they were between 2 to 4 cm which is in line with the standard depth for transplanter (Kanai, 1980). The

averages lodging angles of the plants were 31° from the vertical as calculated from Table 5.2, which was probably associated with the wide hole left by the tines on the soil after the insertion of the plants of the seedling into the soil. However, all the seedlings plants were recovered in 12 DAT (Figure 5.4).

Table 5.2 Hills investigation

Type of seedlings	Broadcast on soil-only	Arrayed on scratched coco-peat	Arrayed on pressed coco-peat
Missing hills at 12 DAT (%)	8.4	10.3	10.2
Hill mortality (%)	1.2	0.0	1.1
Depth of planting (cm)	2.7 (0.6)	2.9 (0.5)	2.5 (0.6)
Plant lodging angle ($^\circ$)	38.4 (17.8)	22.9 (14.6)	32.7 (14.2)

Numbers in brackets are standard deviations.



Figure 5.4 The transplanted seedlings, 12 DAT.

5.4. Conclusion

- 1) The rice transplanter with the free-pivot suspension performed a slippage average of

10.7% in a varying hardpan depth of the soil pan. The slippage tended to increase with the depth of the hardpan.

- 2) The plant number per hills ranged from one to three and the missing hills at transplanting were 8.9% on the average.
- 3) The hill mortality was less than 2% which is partly attributed to the wide tines of the conventional planting mechanism and to the large vertical feed setting that lowered the number of singular plants at transplanting.
- 4) The planting depth was between 2 to 4 cm and the lodging angle of the planted seedlings was 31° from the vertical which was recovered 12 DAT.
- 5) The arrayed seedlings were not different from the broadcast seedlings when transplanted with the free-pivoting suspension rice transplanter.

CHAPTER 6. CONCLUSIONS AND FUTURE PROSPECTS

6.1. General conclusions

This research has been done with a view to benefiting small-scale farmers in rice farming. It is a combination of two correlated techniques that are rice transplanter and rice mat seedlings. A prototype of rice transplanter with a simplified structure has been made along with a seed-saving mat seedling namely one-wheel two-row walk-behind rice transplanter with free-pivoting suspension and arrayed seedlings, respectively. Series of experiments were carried out and the results are summarized as follows:

- 1) A prototype of one-wheel two-row rice transplanter has been developed with a free-pivoting suspension as a simplification of its suspension mechanism. The mass of the transplanter was significantly light (54 kg) and the suspension mechanism satisfied the function required for a height control mechanism. The body of the transplanter was maintained stably near the horizontal while the wheel was, with a 98 N additional weight on it, allowed to freely encounter the soil pan up to 16 cm deep. This resulted in a reduction of slippage of the wheel of 52% and a stable pitch angle of the planting mechanism near the horizontal. The prototype of the transplanter transplanted seedlings in a varying soil pan of the field with a wheel slippage average of 10.3% and a lodging angle of the plant of 17°.
- 2) The arrayed seedlings with 30-rows allow a 40% saving of seeds over the broadcast seedlings and a longer lifespan of the plant thanks to the low density of the seeds. The combination of the 7 mm vertical feed and the 30 lateral feed reduced the number of mat per area to 46%. However, this has indirectly induced a large percentage of hill mortality (19%) during the growth period of the plants although the missing hill at transplanting was low (4.4%). This large hill mortality affected negatively the

grain yield and was partly attributed to the narrow and sharp tines of the planting mechanism for high-density seedlings.

- 3) In 26-rows, aside from the 40% seed saving, the arrayed seedlings covered the same planting area per nursery tray as that of the broadcast seedlings with no differences in grain yield. The use of conventional rice transplanter with 26 lateral feed resulted in a low percentage of hill mortality ($> 5\%$) which was associated mainly with environmental conditions. The planting test on the 7 mm, 10 mm, and 13 mm vertical feed settings revealed that the percentage of missing hills decreased with the increase in the vertical feed where the 7 mm was not suitable for both the arrayed and the broadcast seedlings due to a large number of missing hills at transplanting. In the arrayed seedlings, this large number was attributed to the lower density of the seeds, the varying distances between the plants along the same array, and the deformation of the mat that interacted with the tines wider than the spacing of the arrays. The vertical feed of 13 mm was the most favorable setting whereas the 10 mm was acceptable in terms of missing hills at transplanting.
- 4) The trial of the arrayed seedlings on the free-pivoting suspension of transplanter was carried out in a varying soil pan of the field under 16 cm- deep. The rice transplanter achieved a low slippage of 10.7% that tended to increase with the increase of the depth of the hardpan. The rice transplanter achieved a slightly large percentage of the missing hill at transplanting (9%) but also a low hill mortality ($<2\%$). The planting depth of the seedlings was within the standard requirement in transplanting, whereas, the plant lodging angle was 31° but recovered 12 days after transplanting. The arrayed seedlings were not different from the broadcast seedlings when they were transplanted with the free-pivoting suspension of transplanter.

6.2. Future prospects

Walk-behind rice transplanters are by far useful in rice farming. They give small-scale farmers access to mechanical transplanting. One-wheel two-row walk-behind rice transplanter helps to preserve land for not being abandoned due to shortage of labor in those rice fields where small machines only can be introduced and used (i.e. hilly lands, terrassery, etc.). Besides, small size and low-cost rice transplanter can be used to initiate farmers that are still practicing traditional transplanting (i.e. manual) but want to adopt mechanical transplanting, so that they can start from using a small machine and later upgrade to a large one. Moreover, the rice transplanter with the free-pivoting suspension is light in weight (54 kg) while satisfying the functions as a rice transplanter and, therefore, is easy to transport.

However, although the slippage of the free-pivoting rice transplanter was within the acceptable range of slippage ($<15\%$), yet, further improvement is still necessary to obtain a better performance of its mobility. It was proven in CHAPTER 2 that the heavier the weight on the wheel, the lesser the slippage. In this study, a weight of 98 N gives a slippage average of 10%. Therefore, it is plausible that with a weight heavier than the 98 N would result in a slippage lower than that found here. However, the capacity of the engine is still to be considered as the total weight of the machine, in that case, would increase. Another possible way to reduce the slippage of the rice transplanter is to design a lug of wheel wider than the actual one so that the interaction between wheel and soil will be enhanced and the slippage minimized.

The arrayed rice mat seedlings have been developed and allowed 40% saving of seeds while maintaining the same coverage of area as that of the broadcast seedlings as described in CHAPTER 3 and CHAPTER 4. The sowing in arrays was possible thanks to

the coco-peat mat that could be shaped to have an arrayed furrows on it where seeds were maintained straight in line. In the tray, the coco-peat mat occupied approximately 30% of the volume of the tray. This is equivalent to 30% less in soil used on the arrayed seedlings compared to the broadcast seedlings. Therefore, this is contributing indirectly to preserving soil-landscape in places where those soils are taken from and in the rice fields where they are brought to during the period of transplanting.

On the other hand, improvements are still to be done in the future such as reducing the large percentage of missing hills at transplanting on a small vertical feed setting. One of the solutions would be the arrangement of the seeds to the same orientation in the furrows of the coco-peat mat to unify the distances between plants of the seedlings. This would eliminate the large distance (along the array) between plants and thus reduce the percentage of missing hills at transplanting. Subsequently, with uniform distances between plants of the seedlings in the tray, the use of a smaller vertical feed would be possible which in turn would reduce the number of mats used per area of planting. Furthermore, as discussed in CHAPTER 4, the causes of the missing hill to occur were the misalignment of the tines to the seedlings plants due to the deformation of the mat and the width of the tines that was wider than the spacing of the arrays which resulted in an unstable number of plants being picked up including zero plant. As a solution, the misalignment would be reduced by adding guides around the position where tines pick up plants of the seedlings, this would maintain a uniform spacing of the arrays during transplanting operation, thus improving the alignment of tines to seedlings. Besides, designing tines of a width similar to the lateral feed i.e. the pitch of the furrows, with the consideration not to increase plant mortality in the narrow clearance would potentially stabilize missing hills, especially at a small vertical feed, even when the mat is laterally

deformed to cause misalignment of the furrows and the tines.

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