SAARC J. Agric., 22(1): 153-167 (2024) *DOI: https://doi.org/10.3329/sja.v22i1.73728*

PERFORMANCE EVALUATION OF SELF-PROPELLED RICE TRANSPLANTER FOR IMPACT STUDY ON RICE CULTIVATION

A. Deres[*1] and M. Katahira[2]

[1]Ethiopian Institute of Agricultural Research, Fogera National Rice Research and Training Center
[2]Yamagata University Faculty of Agriculture Tsurouka, Japan

ABSTRACT

Rice is cultivated through mechanical transplanting or direct seeding methods worldwide. Our investigation focused on evaluating the performance of mechanical transplanting and surveying yield, and yield components. The study was conducted at the Yamagata University Faculty of Agriculture at the Takasaka Farm. A Kubota (NSU-87) transplanter with 'Heanuki' rice seedlings was used. We evaluated the performance of the transplanter by the ratio of the effective field capacity (hah-1) to the theoretical field capacity (hah-1). The average field capacity and efficiency of the eight rows of self-propelled paddy transplanter was 0.184 ha/h and 76.6%, respectively, with an area of 0.024 ha at an average operating speed of 1 km/h. The average planting depth (30.36 mm), number of seedlings per hill (3.66), number of seedlings per square meter (102.16), and hill-to-hill distance (15.09 cm) were surveyed and measured. The average grain yield (5.5 tons/ha) was calculated. The average values of (411.2) panicles per square meter, (68.4) grains per panicle, (89.6) percent of filled grains, and (22.25) 1,000-grain weight were obtained. Kubota type (NSU-87) transplanter was satisfactory, at the parameters of fieldwork capacity, fieldwork accuracy, grain yield, and yield components. A self-propelled transplanter is essential for rice cultivation, and it is recommended for saving the amount of seed, ease (weed control and field monitoring), easy operation system, and better crop stand establishment.

Keywords: Fieldwork capacity, Grain yield, Plant growth, Transplanter, Yield components

[*] Corresponding author: asnakewderes@gmail.com

Received: 31.05.2024 *Accepted: 12.06.2024*

INTRODUCTION

Rice serves as a primary food source for over half of the world's population. Rice cultivation is a complex process that involves multiple steps to produce the final product. Currently, rice cultivation is performed in different systems worldwide. The two most important cultivation methods are direct seeding and transplantation where young rice plants grown in nurseries are planted in puddled soils (Pandey et al., 2000, p. 3).

Various types of transplanters are currently employed in Asia for establishing rice crops. Mechanical rice transplanters come in different capacities, such as 4 rows, 6 rows, and 8 rows, which vary based on the type of work they perform (Manikyam et al., 2020). A mechanical rice transplanter significantly decreases the manual work resulting in a higher density of plants and a reduced water depth (1-2 cm) during the transplantation process in the nursery (Haider Z et al., 2019). By taking advantage of the latest advancements in rice production machinery, farmers can make more informed decisions that benefit their livelihoods and the planet. By utilizing the benefits of transplanting in conjunction with precision agriculture and drone technology, farmers can continue to improve their crop management practices and ultimately increase their overall productivity and profitability (Dixit et al., 2007). Kanai (1979) stated that most planters in Japan are designed for the use of rice plants whose roots are composed of soil. Mechanical rice transplanting is the process of transplanting young seedlings using a self-propelled machine, and the seedlings are grown in a mat nursery (Rickman et al., 2015).

Wei et al. (2017) reported that extensive mechanization efforts have been made to achieve high rice yields, which has contributed to reducing labor requirements and improving production efficiency. As the agricultural sector continues to face challenges such as labor shortages and the aging of farmers, it becomes crucial to invest in technologies that can improve production and productivity. Research on the performance evaluation of rice transplanting machines and their effects on field capacity, operational systems, and labor needs is crucial for the sustainable future of rice farming.

MATERIALS AND METHODS

Study area and the study equipment

This study was conducted in Tsurouka City, Yamagata Prefecture, Japan, where rice is grown once in a year during May to October. The experiment was performed at the Takasaka farm station at the Yamagata University.

The self-propelled rice transplanter equips with a Seedling Feed Stopper, Float, Planting Fingers, and Side marker to ensure precise and efficient transplanting. It is capable of planting seedlings at a consistent depth, which is essential for uniform growth and maturity. In addition to its precision planting capabilities, the transplanter is designed for efficiency, allowing farmers to quickly transplant large areas of paddies. It has a 30 cm row spacing and 2.4 m width (Figure 1).

Figure 1. Self-propelled (Kubota NSU-87) transplanter

The main components of the rice transplanting machine

(1) Seedling Rack

(2) Seedling Mat Stopper

(3) Seedling Feed Stopper

(4) Float

(5) Planting Fingers

(6) Side marker

Seedling preparation

A self-propelled rice transplanter requires seedlings grown in the tray-type nurseries. The fertile soil was used for growing the seedlings. The soil was sieved and placed as a single layer in the tray. Water was regularly sprinkled on trays for good germination, and the trays were maintained under atmospheric conditions. The ‘Haenuki’ Japanese rice variety was grown in a thin layer of 30 cm × 60 cm × 3 cm soil in seedling boxes in a greenhouse. The seedlings were carefully monitored for growth and health, ensuring they were strong and ready for transplanting. Once the seedlings were at the optimal stage for transplanting, they were carefully removed from the trays and placed into the transplanter for planting in the field (Figure 2).

Figure 2. Rice Seedlings

Soil moisture content (mc %)

The moisture content of the experimental field was recorded before and after plowing at dry soil conditions (paddy). We randomly selected three sample plots before and after plowing then collected the soil sample at each sample plot and weighed. The samples were kept oven dry at 105℃ for one day and weighed. The soil moisture content is calculated by using the following equation as a percentage of the dry soil weight,

$$\text{Mc \%} = \frac{Mass\ of\ water}{Mass\ of\ dried\ soil} \times 100 \quad \ldots\ldots 1$$

Field preparation

The experimental field was prepared by using a power tiller and irrigated before initial puddling. Before transplanting, the field was flooded and puddled, after that, the excess water was removed through drainage. The depth of the standing water was 4–8 cm during the initial puddling. The field was left for 5–6 days after initial puddling with water to decompose the previous crop residues. The final puddling was performed with the same power tiller. After the final puddling, the field was left for three days to settle the soil and regain its strength.

Soil pulverization ratio

Soil pulverization ratio is the ratio of the soil weight fraction composed of soil clods less than or equal to 25 mm which passes from the sieve mesh of 25 mm to the total weight of clods produced by plowing. After plowing, it was randomly selected three sample plots and soil samples on the experimental field Khadr (2008). The procedure was to weigh the total weight of each collected soil sample and sieve by 25 mm diameter of sieve mesh. It recorded the weight of greater than 25 mm diameter and less than or equal to 25 mm diameter of soil clod. It is an important method to determine the soil pulverization ratio. The soil pulverization ratio was calculated which was noted in Khadr (2008).

$$\text{Soil pulverization ratio} = \frac{Mass\ of\ clods\ \leq 25mm\ daimeter}{Total\ weight\ of\ sampling\ clods} \times 100 \quad \ldots\ldots 2$$

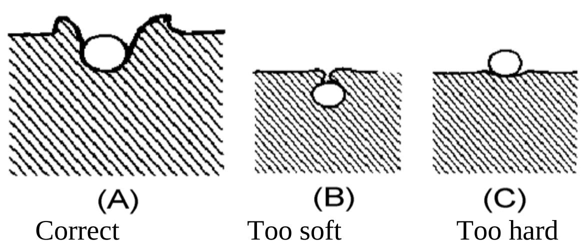
Soil hardness

It is essential to ensure the soil hardness is optimal for the best performance of the transplanting machine and overall fieldwork efficiency. Soil hardness is an indicator of the soil's compaction status; large pores are necessary for water and air movement to allow roots and organisms to explore the soil. A soil hardness tester was used to measure the soil hardness depth (mm) and pressure (kg/cm^2) of the experimental field before and after puddling (figure 3).

Figure 3. Soil hardness tester

Soil penetration

The correct soil hardness is crucial for the successful transplanting of seedlings. If the field is too hard, the seedlings will struggle to take root and may not survive. Conversely, if the field is too soft, the seedlings may not be able to establish themselves properly, leading to poor rice posture and soil return. After puddling, the soil penetration of the field was measured by using a Golf ball-type instrument. A golf ball is a circular shape and it weighs 45.95 g as shown in figure 4. The weight of the golf ball is crucial in determining the depth of the sunk ball after being dropped from a one-meter height. The results of the experiment will help determine the impact of different field conditions on the growth and development of the seedlings. Proper preparation of the field will ensure reliable and consistent data for analysis.



https://www.yanmar.com/media/th/com/maintenance/catalog/100492.pdf

Figure 4. Golf ball type soil hardness tester

Figure 2. 5b Diagrammatic status of soil hardness

The performance of the transplanting machine

Fieldwork efficiency

The performance of an agricultural machine is measured by the rate and quality at which the operations are accomplished (Hunt, 1979). There are many different parameters reflecting machine performance, such as field capacity, efficiency, and fuel consumption**.**

Operational speed (km/h)

The operational speed is the time elapsed between the observed departure times at the involved stops. The operational speed (km/h) of the planter was measured by using a GPS logger instrument attached to the planting machine.

Effective field capacity, ha/h

The effective field capacity is the performance of the actual rate of land or crop processing in a given time based on the total field time. The effective field capacity is the ratio of the actual area covered to the total time taken. Therefore, the effective field capacity of the transplanter is calculated by the following equation: (Hunt, 1979),

Effective field capacity, hah-1 $=\frac{\text{The total area covered,ha}}{\text{Total time is taken,h}}$ ………………………...3

Theoretical field capacity, ha/h

The theoretical field capacity of an implement is the rating of field coverage that would be obtained if the machine is performing 100 percent of the time at the rated forward speed and always covering 100 percent of the rated width. The theoretical field capacity of the transplanter was evaluated. The planting width (m) and operational speed (km/h) of the planter were measured.

Therefore, the theoretical field capacity is calculated by the following equation: (Hunt, 1979);

Theoretical field capacity, hah-1= $Width\ (m) \times Speed(km/h)$ …………………………………4

Field efficiency, %

The field efficiency is the ratio of the effective field capacity to the theoretical field capacity, expressed as a percentage.

Therefore, the field efficiency is calculated by the following equation: (Hunt, 1979);

Field efficiency, % $=\frac{\text{Effective field capacity,(ha/h)}}{\text{Theoretical field capacity,(ha/h)}} \times 100$ …………………………….5

The field working accuracy of the transplanting machine

Test checkpoints

Three test checkpoints were randomly selected in the experimental field, and the working accuracy of the transplanter was evaluated. Each checkpoint contained 10 hills laid on two rows (5 hills per row).

Planting depth of the seedlings

The depth of transplanting was measured by uprooting the seedlings immediately after transplanting. The seedlings were held close to the puddled soil surface for uprooting. The distance from that point to the tip of the root was measured by a scale to determine the depth of transplanting. Ten randomly selected observations were taken to determine the depth of transplanting.

Rice seedlings per hill

The number of seedlings per hill was measured by directly counting the number of seedlings picked by the planting finger and transplanted in the field per hill after transplanting. Ten hills were randomly selected for observation, and the average was determined to represent the number of seedlings per hill.

Paddy hills planted or planting rate: hills/m^2

The number of paddy hills per sample area was counted directly by the number of seedlings picked by the planting finger and transplanted in the field per sample area after transplanting and converted to the number of hills per square meter.

Hill-to-hill distance

The hill-to-hill distance was measured using a metric scale after transplanting. Ten hill observations were randomly selected from the three sample checkpoints, and the mean was calculated to represent the hill spacing.

Missing hills

A hill without seedlings is called a missing hill. The missing hills were checked at the test checkpoints, and the average values were calculated. The percentage of missing hills was calculated by taking the ratio of the total number of missing hills to the total number of paddy hills planted in a square meter area, as expressed in the following equation (Islam and Rahman, 2014):

Missing hills, **%** $= \frac{Number\ of\ missing\ hills\ per\ m^2}{Total\ number\ of\ hills\ per\ m^2} \times 100$ ………………………………6

Floating hills

Seedlings that are either floating on the surface or just placed on the surface of the mud are called floating hills. The number of floating hills in the square-meter area was calculated from the average of all the readings.

The percentage of floating hills was calculated by the following equation (Islam and Rahman, 2014):

Floating hills, % = =$\frac{Number\ of\ floating\ hills\ per\ m^2}{Total\ number\ of\ hills\ per\ m^2} \times 100$ ……………………………7

Buried hills

Seedlings that are completely buried under the soil after transplanting are called buried hills. The number of buried hills in a square-meter area was calculated from an average of all the readings. The percentage of buried hills was calculated by the following equation (Islam and Rahman, 2014):

Buried hills, % = =$\frac{Number\ of\ buried\ hills\ per\ m^2}{Total\ number\ of\ hills\ per\ m^2} \times 100$ ……………………………….8

Planting efficiency

Planting efficiency is an important measure of the success of a transplant operation. It provides valuable information on the overall effectiveness of the planting process and can help identify areas for improvement. This data is crucial for ensuring the sustainability and productivity of agricultural practices. It is the ratio of the number of hills with seedlings (planted + floating + buried) to the total number of hills expressed as a percentage1.

It was calculated by the following equation (Islam and Rahman, 2014):

Planting efficiency, % = $(1-\frac{Number\ of\ missing\ hills\ per\ m^2}{Total\ number\ of\ hills\ per\ m^2}) \times 100$ …………………….9

Yield and yield component investigation

Measuring grain yield

To estimate the grain yield of the experiment, three subtest plots were randomly chosen during the harvesting stage. Sixty hills were harvested per subtest plot for the determination of yield and yield components.

Measuring yield components

Panicle number per unit area

The number of fully mature panicles in the experimental test plot area was counted and converted to panicle numbers per square meter. The number of fully exerted and grain-bearing panicles at maturity is called the panicle number per unit area.

Number of grains per panicle

The number of grains per panicle was counted at 5 hills per test plot sample.

Percentage of filled grains

The proportion of filled grains to all grains is called the percentage of filled grains. To estimate the percentage of filled grains in the experiment, all test samples were threshed, and the filled grains (F) were separated from the unfilled grains (U) by using the salt-water solution method with a hydrometer (specific gravity of 1.06). The filled (F) and unfilled (U) test sample grains were counted. This measurement is important for determining the overall quality and potential yield of the rice crop. Additionally, it can provide valuable information on factors such as weather conditions, pest damage, and nutrient availability that may affect grain filling in the plants. Monitoring and analyzing the percentage of filled grains can help farmers make informed decisions to improve their crop management practices and optimize their harvest. Therefore, the percentage of filled grains could be calculated by the following equation:

$$\text{Percentage of filled grains} = \frac{\text{Number of filled grains}}{\text{Number of filled grains} + \text{Number of unfilled grains}} \times 100 \quad \ldots\ldots\ldots..10$$

The weight of 1,000 brown rice grains

The weight of filled grains is commonly reported based on 1,000 grains. The weight of the 1,000 brown rice grains was measured by a weight balance, and the average values (grams) were taken.

Data analysis

The soil moisture content, soil pulverization ratio, soil hardness, soil penetration, fieldwork efficiency, fieldwork accuracy, grain yield, and yield component data were recorded and organized in Microsoft Excel 2016. Data generated from the experiment was subjected to statistical software JASP 0.18.3.0. The above parameters were analyzed by descriptive statistics and the T-test at $p < 0.05$ was considered to be significantly different.

RESULTS AND DISCUSSION

Soil and field conditions

Plowing and tilling of land is done to predetermined levels that allow rice plants to develop a good root system. The experimental field area was 0.024 ha and well prepared by Kubota and Iseki types of tractors with rotary tillers. Soil moisture content (mc %) before and after plowing, soil pulverization ratio (%), soil hardness, and soil penetration were measured. Before transplanting, the field was flooded and puddled, the excess water was removed through drainage. The depth of the standing water was 4–8 cm during the initial puddling.

Moisture content %

It was observed the average moisture content (35%) at plowed and unplowed (30%) of the experimental field in the dry condition, and the result did not show a significant difference (Table 1).

Table 1. The average moisture content before and after plowing

	Group	N	Mean	SD	Cv	P -value
Weight moist soil (g)	Plowed	3	123.713	23.101	0.187	0.106
	Unplowed	3	95.577	3.907	0.041	
Weight dried soil (g)	Plowed	3	91.373	15.107	0.165	0.119
	Unplowed	3	73.24	4.785	0.065	
Weight water (g)	Plowed	3	32.34	8.051	0.249	0.107
	Unplowed	3	22.337	2.221	0.099	
Mc %	Plowed	3	0.35	0.035	0.099	0.287
	Unplowed	3	0.307	0.05	0.164	

The values are the means (n=3), Mc, Moisture content, (SD) standard deviations, Cv, coefficient of variance, Student's t-test at $P < 0.05$

Soil Hardness (SH) T-Test: There are statistically significant differences between the puddled and un-puddled conditions with more than two times soil hardness observed in the puddled condition (29.66 mm) compared to the un-puddled condition (14.5 mm) as shown in Table 2.

Pressure (Pr) T-Test: There is a significant difference in the pressure exerted by the rice transplanter between the puddled and un-puddled conditions, with more than ten times the pressure observed in the puddled condition (31.66kg/cm^2) compared to the un-puddled condition (2.96 kg/cm^2) as shown Table 2.

Soil penetration T-test: There is a significant difference in soil penetration between the two conditions, with two times higher soil penetration observed in the puddled condition (16.33 mm) compared to the un-puddled condition (7.33) as shown in Table 2.

Table 2. The effect of soil cultivation on the performance of the rice transplanting machine

	Group	N	Mean	SD	Cv	P -value
Soil Hardness (mm)	Puddled	3	29.66	1.528	0.051	< 0.001
	Un puddled	3	14.5	2.291	0.158	
Pressure (kg/cm^2)	Puddled	3	31.66	7.638	0.241	0.003
	Un puddled	3	2.96	1.002	0.338	
Soil penetration (mm)	Puddled	3	16.33	2.082	0.127	0.009
	Un puddled	3	7.33	2.517	0.343	

The values are the means (n=3), Mc, Moisture content, (SD) standard deviations, Cv, coefficient of variance, Student's t-test at $P < 0.05$

Soil pulverization ratio

The experimental land was prepared by tractor with rotary tiller implement. It was collected the average soil sample (6.91 kg) from this (1.4 kg) soil particle size greater than 25 mm diameter and (5.51kg) soil particle size less than or equal to 25 mm diameter as shown in Table 3. The presence of a significant amount of soil particles less than 25 mm in diameter indicates that the soil may also have good drainage properties. It was obtained the average soil pulverization ratio (79.89%). This result is closely supported by Bozbey and Garaisayev's (2010) soil pulverization levels studied and “Fine pulverization” was defined as 80-90% with soil samples passed through a 25 mm diameter sieve mesh.

Table 3. Soil pulverization ratio

Descriptive statistics	Total sample weight (kg)	Soil particle Size >25 cm diameter (kg)	Soil particle size ≤ 25 cm diameter (kg)	SP%
Mean	6.91	1.4	5.51	79.89
Standard Deviation	0.58	0.32	0.35	0.03
Minimum	6.25	1.05	5.2	76.22
Maximum	7.35	1.7	5.9	83.2

Sp% mean Soil pulverization ratio

Fieldwork efficiency of the transplanting machine

The experiment was performed under wet (puddled soil) field conditions with Kubota NSU-87 transplanting machine. The machine has eight rows, a 2.4 m planting width, and a 30 cm row spacing. The actual field capacity (ha/h) of the machine is the ratio of the covered area (ha) to the total time taken (hr.), and the theoretical field capacity (ha/h) refers to the planting width (m) with the average operating speed (km/h). It was observed (0.184 ha/h) actual field capacity and (76.66%) fieldwork efficiency with an average operating speed of 1 km/h in Table 3.4. The field efficiency result is almost similar to Nenavath Manikyam et al. (2019) field efficiency of a self-propelled rice transplanter at 75.16%. Field efficiency might be influenced by the downtime during operation as well as the skill and experience of the operator. Our finding is supported by Oduma et al. (2015), who reported that the field efficiency of machines is affected by field conditions, frequent breakdowns, and other downtime during operation.

Table 4: Fieldwork efficiency of the transplanting machine

Items	Observation
Area, ha	0.024
Planting width, b(m)	2.4
Total working time, Tw(h)	0.13
Average operating speed, V(km/h)	1
Field efficiency	
C = Area /Tw	0.184
Ct = b×v	0.24
η = C/Ct ×100%	76.66%

η, Efficiency (%), C, Field capacity (ha/h), Ct, Theoretical field capacity (ha/h)

Fieldwork accuracy of the transplanting machine

Paddy transplanting was performed using a self-propelled eight-row paddy transplanter. The number of seedlings transplanted per hill, the number of seedlings per square meter, hill-to-hill spacing (cm), and the depth of the transplanted seedlings (mm) in the three subtest plots were measured and observed the missing, floating, or buried hills per square meter. The age of the nursery (mat type) was 26 days. We observed the average number of seedlings planted per hill (3.66), the number of paddy seedlings planted/ square meter (102.16), the hill-to-hill spacing (15.09 cm), and the seedling planting depth (30.36 mm) as shown in Table 5.

These findings suggest that the spacing and depth of transplanted seedlings in our study align closely with the results of previous research conducted by Nenavath Manikyam et al. (2019) who found the average hill-to-hill spacing (15.2 cm) and seedling depth (25-30 mm). Overall, the consistency in seedling spacing, depth, and age further supports the notion that these parameters play a crucial role in achieving optimal yields in rice paddy fields. However, we did not observe missing, floating, or buried hills per square meter in the experimental test plots, which indicates that the machine is efficient and effective, and this demonstrated that the transplanting machine was able to consistently plant seedlings at the desired depth, ensuring that they had the best chance of establishing themselves in the field. The results of this evaluation confirmed that the machine was operating with a high level of accuracy and precision, meeting the requirements for successful transplanting in the experimental field.

Table 5. Working accuracy of the transplanting machine

Descriptive statistics	Planted/hill	Planted/m^2	Hill spacing (cm)	Hill depth (mm)
Mean	3.66	102.16	15.09	30.36
Std. Deviation	0.516	14.442	0.94	3.66
Minimum	3	80	13.88	26.2
Maximum	4	116	16.61	37

The effect of the transplanting method on yield and yield components

Grain yield (kg/ha)

Grain yield was sampled from 60 hills per test plot in three subtest plots in the experiment. The average grain yield was adjusted to 15% of the Japanese standard grain moisture content. The maximum grain yield was obtained (5.7 tons/ha) and the minimum grain yield was recorded (5.2 tons/ha) as shown in Table 3.6. It was observed the average grain yield (5.5 tons/ha).

Yield components

The number of panicles per square meter, the number of grains per panicle, the percentage of filled grains, and the weight of 1000 grains are shown in Table 3.6. The average yield component data were collected from the growth test plots, i.e., 20 hills per test plot with three replications. It recorded the maximum number of panicles per square meter, number of grains per panicle, percentage of filled grains, and 1000-grain weight 446.2, 77, 93, and 22.5 respectively. It was observed the average number of panicles per square meter (441.2), the average number of grains per panicle (68.4), the average percentage of filled grains (89.6), and the average 1000-grain weight (22.25 grams) as shown in Table 6.

Table 6. Effect of the transplanting method on the yield components

Descriptive Statistics	Yield (ton)	Panicle/m^2	Grains/ Panicle	% Filled grains	1000 Grains Weight (gram)
Mean	5.5	411.2	68.4	89.6	22.25
Std. Deviation	202.861	25.691	5.313	0.035	0.247
Minimum	5.2	378.7	62.1	85.5	21.9
Maximum	5.7	446.2	77	93.0	22.5

CONCLUSION

A self-propelled eight-row paddy transplanter (Kubota: NSU-87) was used for transplanting. The average field capacity and field efficiency of the eight rows of self-propelled paddy transplanters were 0.184 ha/h and 76.66%, respectively.

The fieldwork capacity and working accuracy of the transplanting machine might be influenced by the operating system (operating speed), seedling age, field and soil conditions, etc. The average grain yield (5.5 tons/ha) was obtained. In conclusion, the performance of the mechanically self-propelled paddy transplanter was found to be efficient and quite satisfactory in terms of fieldwork efficiency and accuracy.

REFERENCES

Abeels, P. F. J., Auernhammer, H., Balsari, P., Billot, J. F., Blary, D., Bourarach, E. and Wilkinson, R. (1999). Plant Production Engineering. In the CIGR Handbook of Agricultural Engineering (Vol. III of VI, p. 5),.

Bozbey, I., and Garaisayev, S., (2010). Effects of soil pulverization quality on lime stabilization of an expansive clay. Environmental Earth Sciences, 60:6, 1137-1151.

Dixit, A., Khurana, R., Singh, J., and Singh, G. (2007). Comparative performance of different paddy transplanters developed in India: A review. Agricultural Reviews, 28(4), 262–269.

Haider Z, Pros and Cons of Mechanized Transplanting in Basmati Rice - A Case Study. Journal of Rice Science. 2019; 1(1): 1-9

Hunt, D. R. (1979). Farm power and machinery management.4th Edition. Second printing. The Iowa State University Press.

IRRI. (2007). Rice Production Manual, 14.

Islam, A. K. M. S., and Rahman, M. A. (2014). BRRI-Syngenta Tegra transplants under public private partnership approach. An unpublished research report submitted to the Tegra program, Syngenta Bangladesh Limited.

J Kalita, P Ahmed and N Baruah. Puddling and its effect on soil physical properties and growth of rice and post rice crops: A review. J Pharmacogn Phytochem 2020; 9 (4):503-510.

J. R. Murray, J. N. T., and B. B. B. (2006). Planters and their Components Types, attributes, functional requirements, classification, and description. Australian Centre for International Agricultural Research, ACIAR Monograph No. 121.

Jugović, M., Ponjičan, O., and Jakišić, T. (2020): The effect of rotary tiller and other machines for tillage on the soil structure aggregates. Agriculture and Forestry, 66 (1): 251-260.

Kader, K.A. (2008). Effect of some primary tillage implements on soil pulverization and specific energy. Misr. J. Agric. Eng., 25(3): 731-745.

Kanai, B. K. (1979). Performance of Rice Transplanters as Evaluated by the National Test in Japan, 1978–1981.

Kumar, V., and Ladha, J. K. (2011). Direct seeding of rice. Advances in Agronomy (1st ed., Vol. 111). Elsevier Inc.

Manikyam, N., Guru, P.K., Naik, R.K. and Diwan, P. 2020. Performance evaluation of self-propelled rice transplanter. Journal of Pharmacognosy and Phytochemistry 9(1): 980-983.

Murray J. R., Tullberg J. N., andB. B. B. (2006a). Planters and their components Planter and Their Component, 142–154.

Nenavath Manikyam, Prabhat Kumar Guru, RK Naik and Pushpraj Diwan (2019). Performance evaluation of self-propelled rice transplanter

Pandey, S., and Velasco, L. (2004). Trends in Crop Establishment Methods in Asia and Research Issues. Rice Is Life: Scientific Perspectives for the 21st Century, Proceedings of the World Rice Research Conference.

Prasanthkumar, K., Saravanakumar, M., Asokan, D. *et al.* Effect of Puddling Techniques on Puddling Quality of Silty Loam Soil. *Agric Res* **10**, 215–222 (2021).

Pandey, S., Velasco, L., andFukai, S. (2000). Economics of direct seeding in Asia: patterns of adoption and research priorities. Direct seeding: research issues and opportunities.

Ravi, S. B. (2018). Standardize selective mechanization for enhancing the productivity and profitability of rice. International Journal of Current Microbiology and Applied Sciences, 7(03), 1820–1826.

Rickman, J. F., Mussgnug, F., Khanda, C. M., Satpathy, S. D., Parida, N., Singla, K., and McDonald, A. (2015). Operational Manual for Mechanical Transplanting of Rice.

Saiful Islam, A. K. M., Islam, M. T., Rabbani, M. A., Rahman, M. A., and Ziaur Rahman, A. B. M. (2015). Commercial mechanical rice transplanting under a public-private partnership in Bangladesh. Journal of Bioscience and Agriculture Research, 6(1), 501–511.

Van Nguyen, N., and Ferrero, A. (2006). Meeting the challenges of global rice production. Paddy and Water Environment, 4(1), 1–9.

Wei, H., XU, K., Huo, Z., Xing, Z., Zhang, H., Zhou, G, and Qian, H. (2017). Comparison of yield traits in rice among three mechanized planting methods in a rice-wheat rotation system. Journal of Integrative Agriculture, 16(7), 1451–1466.

Xangsayasane, P., Phongchanmisai, S., Vuthea, C., Ouk, M., Bounphanousay, C., Mitchell, J., and Fukai, S. (2019). A diagnostic on-farm survey of the potential of seed drills and transplanters for mechanized rice establishments in Central Laos and Southern Cambodia. Plant Production Science, 22(1), 12–22.

Yoshikawa, Y. (2010). Can Japanese agriculture overcome dependence and decline? 日本の農業は依存と衰退を克服できるか. Japanese, Can Overcome, Agriculture, 8(26).