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Design and Fabrication of an Autonomous Rice Transplanter

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ABSTRACT

The goal of this study was to create a prototype of an automatically guided rice transplanter using a Pixhauk flight controller, 3DR telemetry, Raspberry Pi, Tof sensor, gyro sensor, and other GPS navigation sensors to determine the field performance of that machine. GPS was used to obtain data such as location, direction, and speed, whereas machine vision can provide a navigation line. The next position of the transplanter can be determined using feature points extracted from the navigation line. The controller area network bus complies with the actuator control command and data communication protocols. Electrical actuators control steering and transmission based on a vehicle's location in a field. The percentage of missing, buried, and floating hills was observed to be 1.6%, 1.4%, and 3.0%, respectively, as the maximum values were found in clay soil at T_1. Over time, percentages of losses decreased, and the lowest percentage of losses was given. The lowest percentage of missing, buried, and floating hills was found at 0.8%, 0.2%, and 0.8%, respectively, in clay loam soil at T_5. Planting efficiency improved, and losses decreased as treatment levels upgraded. Clay loam soil in T_5 had the highest planting efficiency percentage (88%), whereas clay soil in T_1 had the lowest (61%) proportion. The findings indicated that T_4 and T_5 enhanced rice output by decreasing the losses incurred during seedling transplantation. The study suggested that the developed rice transplanter might be suitable for planting rice seedlings to establish meaningful mechanization through precision agriculture technology.

INTRODUCTION

Throughout the world, millions of small-scale farmers cultivate rice across millions of hectares, and numerous landless laborers who work on these fields for a living also include rice among their important crops. Rice is responsible for 15% of human protein and 21% of global energy consumption per person (Gnanamanickam, 2009). Although rice has a low protein content, it has a high nutritional quality rating for protein in comparison to other cereals. Fiber, vitamins, and minerals are still present in rice, despite the fact that milling removes all components except carbohydrates. In the future, the rate of increase in rice production must be at least as high as the rate of population growth, if not higher. The main focus of agriculture or farming extends beyond crop cultivation and includes the economic advancement of farmers and laborers. Rice is a labor-intensive crop and requires about 139 person-days ha−1 (Rahman *et al.*, 2008). One of the growing issues with rice production is the timely availability of manpower and water for several rice activities. Transplanting means moving or transplanting 15 to 21 days aged seedlings from one place to another place either manually or mechanically (Karthik *et al.*, 2018). In Asia, transplanting is the most popular and simple technique for establishing crops, particularly paddy. In Bangladesh, farmers still use manual transplanting as their best way to transplant.

To improve both the quantity and quality of rice produced, small-scale farmers must also have access to an affordable and user-friendly rice transplanter. Bangladesh is now moving to a great challenge to feed and adequately cherish the millions of growing populations. Every year two million people are assimilated in the country and lands are decreasing by 80,000 ha annually (Haque, M.M 202will the population is estimated to reach 215.4 by 2050 (Kabir *et al.*, 2015). The need for clean rice grain by 2050 has been prominent to reach 47.2 million tons at an expected per capita income growth rate of 2% (Kabir et. al., 2016). Farmers need to produce more crops with limited land resources to meet the rising demand. The major cereal crops that are growing in Bangladesh are rice, wheat, maize, jute, and pulses.

In Bangladesh, rice is grown in three seasons: Boro (Dec-April), Aus (April-July), and Aman (Aug-Nov). Approximately 10.8 million hectares, or 77% (10.71 Mha) of all planted lands are produced on an area of 48 million Mt (BBS, 2011). One of the most crucial tasks in the rice field during the rice-growing season is transplanting. Various methods exist for transplanting seedlings in the main field, including manual, mechanical, or throwing techniques. In Bangladesh, growing rice usually involves transplanting seedlings into thick, puddled soils. Manual labor is used primarily in transplant operations. Manual transplantation of paddy is a labor-intensive and time-consuming process. It typically involves around 250-300 man-hr ha-1, which accounts for around 25% of the total labor requirement for rice production (Haider *et al*, 2019). According to reports, there is a 25% reduction in yield every month when transplanting is delayed and a 70% reduction in production every two months that it is

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delayed (Rao & Pradhan, 1973). In contrast, mechanical transplanting has several advantages in which seedlings can recover very fast, and vigorously and increase planting capacity, uniformity in spacing, and plant density, while reducing time, cost, and power.

The mechanical rice transplanter was initially created in Japan during the 1960s. In Bangladesh, BRAC's Agriculture and Food Security Programme and GBK (Golden Barn Kingdom) introduced a walking-type mechanical rice transplanter. It was then tested in various project locations to evaluate its performance in both the rainy and dry seasons of 2012 and 2013, respectively (Islam *et al.*, 2015). In mechanical transplanting, the operator is also needed and it of course, must be a skilled person. Regarding the drawback, there is an urgent need for a labor- and money-saving technique of rice transplantation that doesn't decrease productivity (Tripathi *et al.*, 2004).

The development of innovative technologies, such as autonomous rice transplanters, plays a crucial role in satisfying the need for poverty reduction and contributes to worldwide efforts in this respect. Autonomous robot systems are employed in diverse applications. Agriculture is increasingly utilizing additional off-road machinery, such as tractors. Combine harvesters and orchard mobile devices are commonly utilized in an automated manner. In contrast, being guided along a specified path or following a predetermined route to do manufacturing duties. Nagasaka *et al.* (2004), Nagasaka *et al.* (2009, 2013), and Sun *et al.* (2010) studied the autonomous navigation systems of rice transplanters. Most studies utilize either rear seat support or a real-time kinetic (RTK)-global navigation satellite system (GNSS) located at the transplanter's front end to determine the transplanter's precise spatial position. Researchers have analyzed the precision of navigation control in rice transplanters. Zhang *et al.* (2006), He *et al.* (2019), and Oksanen and Backman (2013) developed steering control systems specifically for rice transplanters. Li *et al.* (2018) and Eaton *et al.* (2009) researched techniques for tracking rice transplanters' navigation route.

Guo and Hu (2013) and Huang *et al.* (2019) examined the speed of rice transplanters and the control systems for steering at the end of the field. Consequently, the exact positions of the vehicle cannot be determined. Hu (2016) and Li and Zhao (2011) researched correcting the placement of objects by analyzing how the attitude of a vehicle changes in response to this challenge. These solutions effectively mitigate the placement inaccuracy resulting from the body inclination of agricultural gear. Zhao *et al.* (2016) and Huang *et al.* (2019) employed Kalman filters in agricultural machinery, specifically rice transplanters and high-clearance sprayers, in paddy fields. The purpose was to determine the location and velocity of RTK-GNSS receivers, thereby enhancing the stability and precision of placement. On the other hand, a rice transplanter's navigational skills are assessed based on tracking accuracy. The body's relative attitudes and the way a rice transplanter is utilized differ during the process. A rolling direction-definable self-leveling system based on profiling is integrated into a rice transplanter's tool. (ISEKI, 2012; Koschel, C. *et al.*, 2009). Consequently, when a rice transplanter passes an uneven paddy field, the angle of inclination increases, causing the implement's centerline to deviate from the body's midline, leading to a positioning error. A rice transplanter's moving track is incompatible with that of a transplanter. A paddy field's muddy lower layer is irregular, moist, and slippery. The narrow design of rice transplanter wheels leads to inadequate grip on muddy paddy fields, increasing the possibility of skidding. The navigation accuracy of a rice transplanter's body does not necessarily indicate the total navigation accuracy of transplantation.

In this proposed autonomous rice transplanter can be operated remotely by using IoT-based software. It will be controlled by a GPS tracking system and will follow the field map (with the exact location of hills and tillers) which will be provided by the software. In the above discussion, the study set out to accomplish the following objectives: To design and fabricate a prototype of an autonomous rice transplanter. And to investigate the field performance of autonomous rice transplanters.

LITERATURE REVIEW

Basir *et al.* (2021) examined the correlation between rice yield (measured in gm m-2) and four mechanical rice transplanting parameters: seedling density in the tray, missing hill percentage, floating hill percentage, and seedling number per hill. They also constructed an Artificial Neural Networks (ANN) model to forecast yield based on these transplanting parameters. When compared to manual rice transplanting procedures, these devices require an average labor input of 11.2 man-hr ha-1, saving 94.4 percent labor. Less or one labor can operate the transplanter when employing an automatic transplantation procedure, lowering labor costs and increasing transplanting efficiency.

Krishnan *et al.* (2017) created a prototype out of locally available materials. The new prototype saved more than 80% over commercially available equipment in terms of cost. According to studies conducted with this prototype, the semi-automated procedure saves labor effort by 17% and transplantation time by 17%. The machine is constructed using commonly available off-the-shelf bicycle components, which can be easily repaired by farmers, ensuring its reliability and durability. They can use different methods to pull the machine, including manual pulling, ox pulling, and so on, as well as automated machinery and mobile robots. The map of the paddy field will be a lot easier to identify, traverse, and monitor if they utilize a GPS tracking device with this prototype.

Kumar *et al.* (2021) designed a machine around a four-bar chain mechanism that will be controlled by pedals. Again, human work is required to move the machine, but crops will be cultivated automatically, therefore the name Semi-Automatic Machine Rice Cultivating Machine.

When compared to the traditional way of cultivating rice by hand, the proposed design will not only boost crop productivity but also reduce human labor effort. The proposed design necessitates human effort, which can be avoided by using an engine rather than a handle.

Nagasaka *et al.* (2018) created a new rice transplanter that's guided by the Global Positioning System (GPS). The GPS antenna is 1.5 meters tall with a 0.4-meter front offset from the vehicle's front axle. The controller area network (CAN) bus complies with the actuator control command and data transmission standards. The forward speed was set to 0.5 m/s to maintain accuracy. R.M.S. 0.03 m or 0.04 m of deviation from the desired path. However, a rice transplanter may travel at a maximum speed of 1.6 m/s. The control method can be enhanced to adapt speedier operations in future development.

Pakshaweera *et al.* (2016) designed a paddy transplanter comprising a planting tray, a mechanical arm, and a carrier that can support the weight of the mechanical arm and the planting tray. This research is being carried out in order to reduce the constraints of existing paddy transplanting technologies and to incorporate a new design that is more suitable for paddy fields in wet zones. If they use a GPS tracking gadget, it will be much easier to find, navigate, and track the map of the paddy field.

Saiyed *et al.* (2018) focused on the design and manufacture of autonomous rice transplanting machine for small-scale Indian rice farmers. To make their work easier and more precise, they can use a variety of link mechanisms to streamline the cultivation process, lowering costs and labor costs. There are four rows of these seedlings will be planted. The space between these rows of rice seedlings will be 20cm horizontally, and 15cm to 18 cm vertically. It will be much easier to discover, navigate, and track the map of the paddy field if they utilize a GPS tracking device.

Siddique *et al.* (2018) used commercial simulation tools to design and simulate a transplanter simulation model (AMESim). In comparison to the results of the simulation, the PID controller performed comparatively better. It was also discovered that HST was roughly 71.82 percent efficient. The horizontal control system requires the development of a control algorithm as well as field testing for validation.

Xiang *et al.* (2018) used RTK-GNSS and IMU as navigation sensors and developed an automatically guided rice transplanter. To test the performance of the autonomously guided rice transplanter, experiments were carried out. The lateral and heading errors were less than 10 cm and 5 degrees, respectively, in case of flat-out path. Experiments were carried out to validate its abilities in both following straight paths and turning at headlands. Straight tracking was shown to be reliable, with RMS errors of less than 0.06 m for lateral offset and 3.0 degrees for heading direction, respectively. And the appropriate processes for headland turning were followed automatically. Future research will focus on further analyzing the newly constructed automatically guided rice transplanter and attempting to find antidotes to longitudinal track slip and lateral skid during paddy field operations.

Yang *et al.* (2018) described the seedling separation device with reciprocating seedling cups and the entire automatic plug seedling transplanter's control system. According to the research, the special strategic path seedling is planar, and a control system for it has been developed. The main focus will be on the precise design of the three essential parts of the seedling separation device: the transplanting device, the seedling device, and the seedling cup. The linear driving motor and drive cylinder regulate the reciprocating motion as well as the opening and closing mechanism of the mobile seedling cups. The method of converting positioning error into the number of pulses is used to correct the positioning error of linear transmission devices. The measurement result shows that positioning error at 25000 Hz frequency remains between 0.2 mm and 0.8 mm, proving the method's feasibility; data from the success rate test shows that the success rate decreases as the rate of seedling separation increases, but the overall success rate can reach more than 95%, proving the method's rationality.

Yin *et al.* (2019) incorporated a new controller into the Kubota SPU-68C rice transplanter. Afterward, an automated steering control experiment was conducted using the modified transplanter under two conditions: linear tracking and headland turning, to assess the transplanter's automatic steering influence in a variety of steering angle situations. The variance was deemed to be acceptable with the new controller and modified transplanter, as it had a maximum promontory turning deviation of 11.5 cm, a maximum linear tracking deviation of 7.5 cm, and an average deviation of less than 5 cm. The greatest heading deviation was 3°, and the average heading deviation was 5°. The average heading deviation was 2°. The rice transplanter's automatic steering control at various angles is a beneficial method for enhancing the control precision of the autonomous navigation process. This effectively reduces the rice transplanter's lateral and heading deviation during operation.

Zhou *et al.* (2018) discovered that the automatic steering control of the rice transplanter effectively minimizes the machine's lateral and heading deviation during the automatic navigation process at various steering angles. This helps to improve the precision of the automatic navigation control and can meet the agronomic needs of the rice transplanter's field service.

MATERIALS AND METHODS

Study Location

The experiment was conducted at the Agricultural and Biosystems Engineering Laboratory, Department of Farm Power and Machinery, Faculty of Agricultural Engineering and Technology, Sylhet Agricultural University, Sylhet-3100 (Latitude: N 24°54'33.1" and Longitude: E 91°54'07.2"), Bangladesh.

Design Consideration

To design an autonomous rice transplanter some considerations should be taken. The design considerations are as follows:

1. The autonomous rice transplanter should be lightweight for easy transportation.
2. Raw materials should be available locally.
3. Trained labor should be available.
4. Materials should be suitable for working conditions in service.
5. The cost of the materials should be low.
6. Easy to operate.
7. Safety of operation.
8. Capacity of the transplanter.

Fabrication Procedure of Rice Transplanter

A solar system generates 500 watts of electricity and charges a 12-volt vehicle battery, which powers this equipment. The Pixhawk was the robot's principal control system. Xt60 connections and power modules linked the power source to the Pixhawk and ESC. Servo connectors connected the electric speed controller to the Pixhawk's main device. The electric speed controller allowed to adjust the speed of each motor. Bullet connectors connect each motor and control the motor's spinning in the opposite direction. The motor linked to the traced chassis. A 3DR GPS and compass kit communicated with Pixhawk via note.

The note was always a great practice to twist the wires together to reduce interference. Telemetry was also offered as an alternative control mechanism for UAVs (Unmanned Aerial Vehicles). It allowed powerful ground station software to be utilized on a computer, smartphone, or tablet. A buzzer generates an audible signal that indicates the UAV's performance. This machine is primarily used for agriculture. This machine's main function is rice transplanting. The structure of this machine determines whether or not the field condition is adequate. The CAN bus connects the building to the rice transplanter and the Pixhawk. There is also an inbuilt measurement unit that aids in measuring field conditions. (Figure 1)

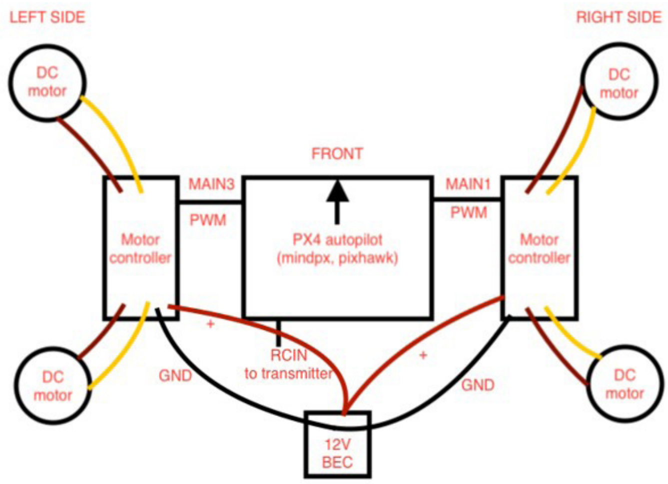

Figure 1: Diagram of the Automated Rice Transplanter

Design and Treatment

This experiment was carried out following the Randomized Complete Block Design (RCBD) and the following treatments were done.

T_1= Treatment no. one when mat thickness was 2.5 cm and clay soil

T_2= Treatment no. two when mat thickness was 2.00 cm and clay soil

T_3= Treatment no. three when mat thickness was 1.75 cm and clay loam soil

T_4= Treatment no. four when mat thickness was 1.45 cm and clay loam soil

T_5= Treatment no. five when mat thickness was 0.8 cm and clay loam soil

Machine Performance Test

To find out the performance of the machine, some specifications of the machine should be determined.

Forward Speed

By following the equation, the forward speed of the machine was determined (Hunt, 1995).

$$S= D/T\times 3.6 \quad (1)$$

Where,

S= Forward speed of the machine, km/hr

D= Distance covered by the transplanter, m

T= Time required to cover the distance, sec

Theoretical Field Capacity

The theoretical field capacity of the machine can be determined by the following equation (Hunt, 1995).

$$TFC= (W\times S)/C \quad (2)$$

Where,

TFC= Theoretical Field Capacity, ha/hr

W= Rated width of implement, m

S= Speed of travel, Km/hr

C= Constant (Its value is 10)

Effective Field Capacity

The effective field capacity of the machine can be determined by the following equation (Hunt, 1995).

EFC= A/T (3)

Where,

EFC= Effective Field Capacity, ha/hr

A= Total Covered Area, ha

T= Total time of operation, hr

Field Efficiency

The field efficiency of the machine can be determined by the following equation (Hunt, 1995).

Ef= EFC/TFC×100% (4)

Where,

Ef= Field Efficiency, %

EFC= Effective Field Capacity

TFC= Theoretical Field Capacity

Transplanting Performance

No. of Hill Per Unit Area

A square quadrant measuring 1m x 1m was utilized to determine the hill density, which refers to the number of hills planted within a square meter. The count of hills inside the square quadrant area was determined for three randomly selected places in the field during each replication. The mean of the data was utilized to compute the quantity of hills within a square meter area.

Seedlings Per Hill

The number of seedlings planted per hill was determined by randomly counting the number of seedlings at three different sites within the field for each replication. The count was done at the level of individual hills. A mean of all the data was computed to determine the number of seedlings per hill.

Hill to Hill Distance

The hill-to-hill distance was determined at three specific locations in the field for each replication by measuring the distance between two randomly selected hills. The separation between the hills was quantified using a flexible measuring tape, and the distance was calculated by taking the mean of all the measurements.

Percentage of Missing Hill

The term "Missing hill" refers to a hill that does not have any seedlings. A square quadrant measuring 1m×1m was employed to calculate the overall quantity of hills and the number of hills that were absent. The data was gathered from three randomly chosen locations inside the square quadrant in each replication. A mean value was computed for the number of hills and the number of missing hills in a square meter area.

The subsequent equation was employed to calculate the percentage of missing hill:

Percentage of missing hill (%) = (No. of missing hills)/(Total hills) ×100 (5)

Percentage of Floating Hill

Floating hills are characterized by the presence of plants that either float on the surface or are directly planted on the saturated soil surface. Data was gathered from three distinct locations in the field within a square quadrant of 1m x 1m for each repetition. The density of floating hills in a square meter area was determined by computing the mean of all the hills.

The percentage of floating hills was calculated using the following equation:

Percentage of floating hill (%) = (No. of floating hills)/(Total hills) ×100 (6)

Percentage of Buried Hill

A buried hill refers to plants that are completely submerged in the soil upon transplantation. The number of submerged seedlings within a square meter region was tallied utilizing a square quadrant measuring 1m x 1m.

The percentage of buried hills was calculated by employing the following equation:

Percentage of buried hill (%) = (No. of buried hills)/(Total hills) ×100 (7)

Transplanting Efficiency

Transplanting efficiency is the number of hills standing with seedlings (without the missing, floating and buried) to the total number of seedlings.

Transplanting efficiency was determined by using the following equation:

Transplanting efficiency (%)

= (Total hills-No.of(missing+floating+buried)hills)/(Total hills) × 100 (8)

RESULTS AND DISCUSSION

Controlling Systems

The controlling system of the automated rice transplanter is shown in Figure 2. A small skillful person can control this rice transplanter. The onboard electronics consist of an inertial measurement unit and autopilot unit, known as pxIMU, as well as an onboard computer vision processing unit, referred to as pxCOMEx. This device allows for convenient remote control of the rice transplanter from a designated location. The Pixhawk served as a flight

Figure 2: Controlling system of Automated Rice Transplanter

controller that translated control inputs from either a human or a computer pilot into control signals for the motor. This was made possible by its built-in sensor arrays, which consisted of an accelerometer, barometer, and compass.

Performance of Machine

Machine performance was assessed by measuring forward speed, theoretical field capacity, actual field capacity, and efficiency. The figures display the values for forwarding speed, theoretical field capacity, actual field capacity, and efficiency.

Forward Speed

The forward speed of the machine was calculated for each treatment. The field was changed for every treatment but the area was fixed for each treatment. In T_1 the forward speed was so poor because the thickness of the seedling mat was 2.5 cm and the soil was clay type. Which made the machine move very slowly (1.2 km/hr). Then the forward speed was increased gradually for T_2, T_3, T_4, and T_5. Because the thickness of the seedling mat was decreased to 2 cm, 1.75 cm, 1.45 cm, and 0.8 cm respectively. The values of forward speed for T_1, T_2, T_3, T_4, and T_5 were 1.2, 1.3, 1.45, 1.49, and 1.57 km/hr respectively (Figure-3).

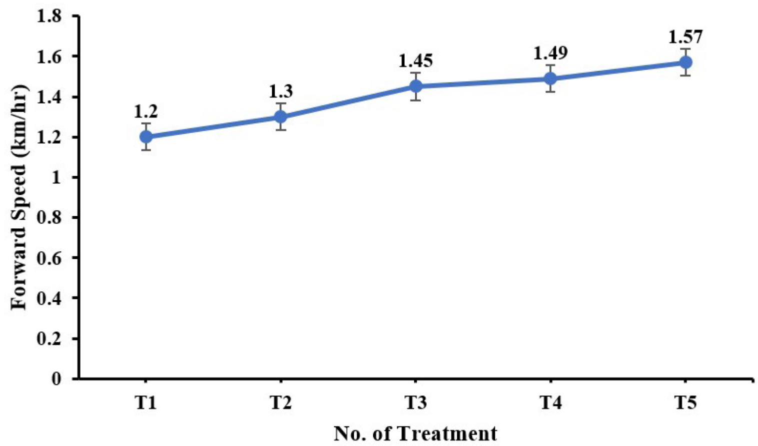

Figure 3: Forward speed of Rice transplanter

Theoretical Field Capacity

Figure 4 shows that as the thickness of the seedling mat for T_1, T_2, T_3, T_4, and T_5 were increased than the theoretical field capacity also increased and the values were 0.2, 0.25, 0.28, 0.30, 0.32ha/hr. respectively.

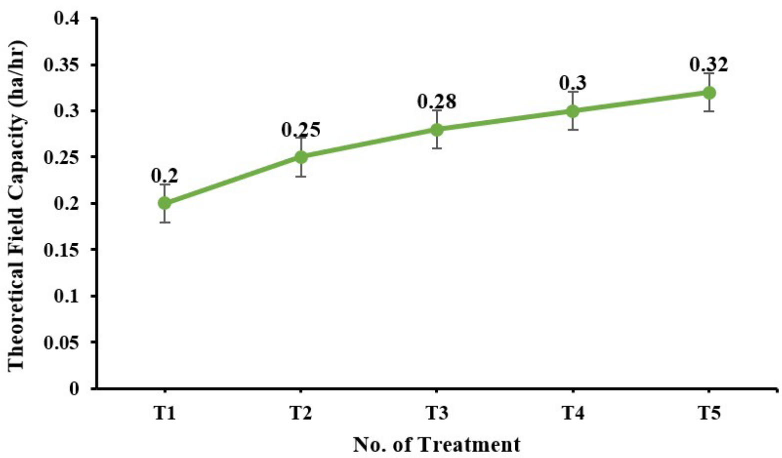

Figure 4: Theoretical Field Capacity of Rice Transplanter

Effective Field Capacity

Similar to the theoretical field capacity, the effective field capacity of the machine also significantly varied for the thickness of the seedlings mat. Figure 5, showed that when the mat thickness decreased than the effective field capacity increased. The actual field capacity of T_1, T_2, T_3, T_4, and T_5 were 0.12, 0.15, 0.18, 0.20, and 0.21 ha/hr respectively.

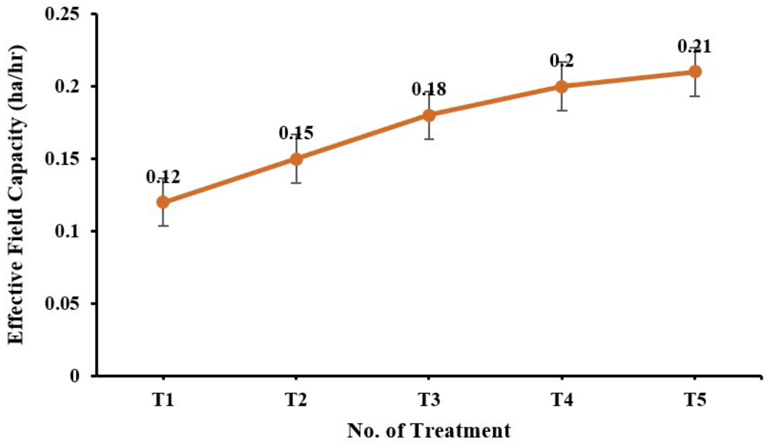

Figure 5: Effective Field Capacity of Rice Transplanter

Field Efficiency

Figure 6, it was shown that the field efficiency of the machine significantly varied with the mat thickness, and for T_1, T_2, T_3, T_4, and T_5 the field efficiency was found 65%, 67%, 71%, 74%, and 77% respectively.

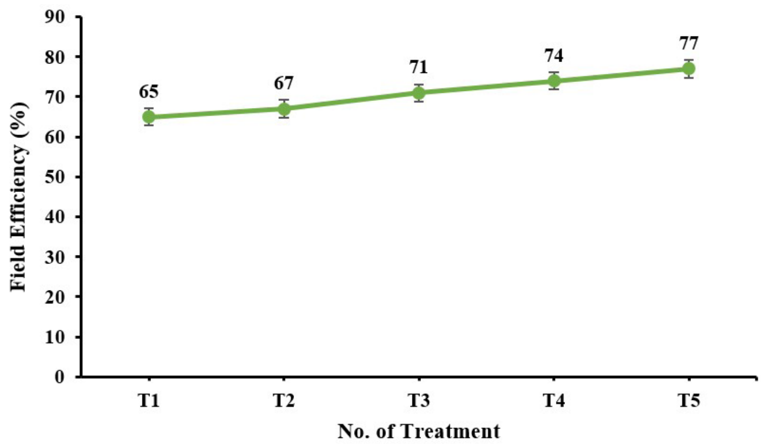

Figure 6: Field Efficiency of Rice Transplanter

Transplanting Performance

The transplanting performance of the machine was determined by using the percentage of missing hills, floating hills, and buried hills.

Percentage of Missing Hill

Figure 7, shows that the percentage of missing hills significantly varied for the seedling's mat thickness. The highest percentage of missing hills (1.60%) was found

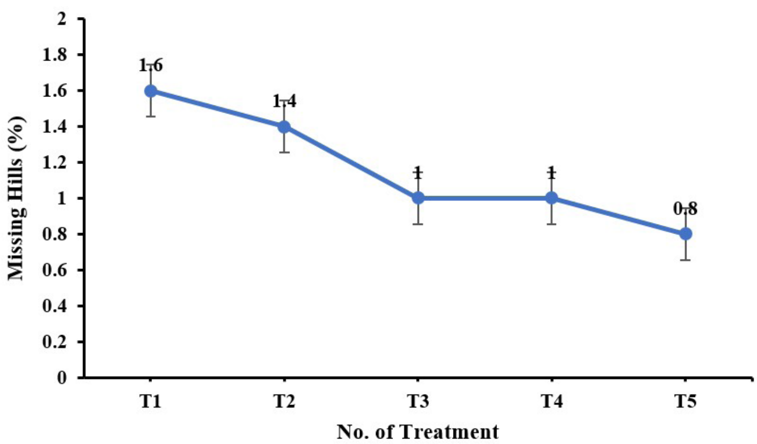

Figure 7: Percentage of missing hills

in T_1 and 1.4% in T_2 because of clay soil. On the other hand, 1.0%, 1.0%, and 0.8% were found for T_3, T_4, and T_5 respectively where the soil was clay loam.

Percentage of Floating Hill

Irrigation water influenced the floating hills of transplanting. Because of the high-water level initially in the field, the number of floating hills increased. With the passage of time and the dropping water level in the field, the floating mound was observed to progressively diminish. Figure 8, showed that for T_1, T_2, T_3, T_4, and T_5, the percentage of floating hills were found 3.0%, 2.6%, 2.2%, 1.5% and 0.8% respectively.

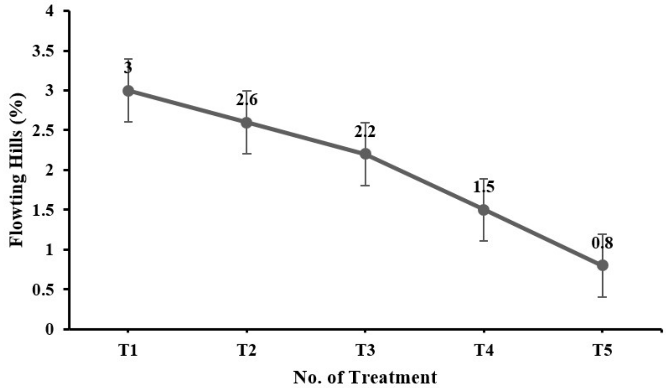

Figure 8: Percentage of floating hills

Percentage of Buried Hill

Figure 9, shows that the percentage of buried hills due transplanter wheel was lowered with the treatment. It was happened due to a perfect algorithm setting for path detection of the machine and the soil variety. Percentage of buried hills were 1.4%, 1.2%, 0.8%, 0.6%, and 0.2% for the treatment T_1, T_2, T_3, T_4, and T_5 respectively.

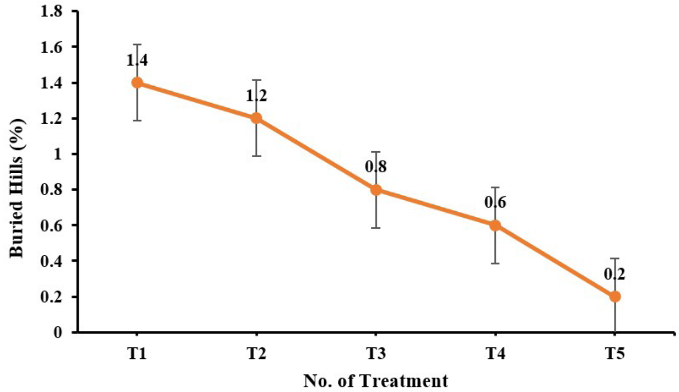

Figure 9: Percentage of buried hills

Transplanting Efficiency

From Figure 10, it was found that T_5 gave the highest number of planting efficiency (88%) in clay loam soil. Followed by T_4 and T_3 gave 82% and 76% respectively for the same soil texture. On the other hand, the lowest efficiency (61%) was found in clay soil and also for T_2.

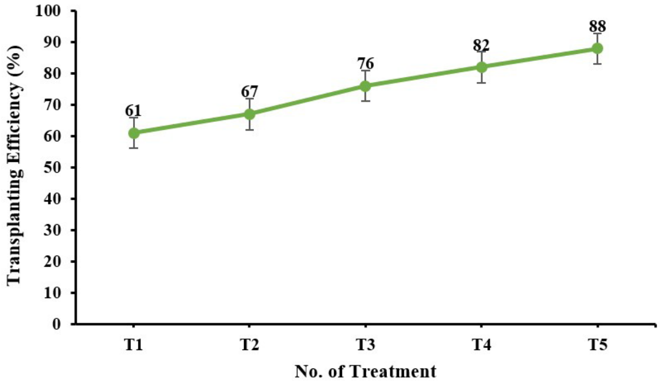

Figure 10: Transplanting Efficiency of the Rice Transplanter

DISCUSSION

In this study, the proportion of missing, floating, and buried hills in clay soil was determined to be 1.6%, 3.0%, and 1.4%, respectively, at the earliest period when the mat thickness was 2.5 cm. As time went on, the value of losses reduced. In clay loam soil, the values for missing, floating, and buried hills were, respectively, 0.8%, 0.8%, and 0.2%, with a mat thickness of 0.8 cm. In clay soil, the planting efficiency was at least 61%, while in clay loam soil, it reached a maximum of 88%. The absence of hills was dependent upon the inability to choose and plant seedlings in the appropriate location. Because of the initial period, the thickness of the seedling mat was high as a result, soil attached to the head of the picker, and flowing water made turbulence when picking the plant causing the seedling to become resistant to its placement. On the other hand, buried hills mainly depended on the dagame of seedlings due to machine wheels during the transplanter's operation. Water in the field is responsible for floating hills. Finally, the study showed that the planting efficiency depends on the factors of buried hills, missing hills, and floating hill losses. In this experiment, the maximum transplanting efficiency was 88.0% for T_5 in clay loam soil with a seedling mat thickness of 0.8cm. The remarkable field performance of rice transplanter is very important in developing a rice transplanter. It also showed that, field performance was extremely influenced by the forwarding speed, effective field capacity, and theoretical field capacity of the studied rice transplanter. In this study, it was found that the maximum forward speed, effective field capacity, and theoretical field capacity at optimum conditions were 1.57km/hr, 0.21 ha/hr, and 0.32 ha/hr respectively when the seedling mat thickness was 0.8cm and soil was clay loam type. This result showed better similarity to the report of an effective field capacity of 0.21 ha/hr and a theoretical field capacity of 0.27 ha/hr (Kumar *et al.*, 2020). This experiment also showed a field efficiency of 77%, which justifies the report of 75% (Karthik *et al.*, 2018) and 83.22% (Ganapathi *et al.*, 2015). Another result showed that accepted field efficiency for newly developed manual-operated rice transplanter might be in the range of 44-52% (Pal *et al.*, 2018).
Many parameters are involved to evaluate the performance of the forward motion manual rice transplanter.

CONCLUSION

In this experiment, simulations and field experiments were performed to verify the effectiveness of the automatic steering control system. An autonomous guidance system for a rice transplanter was established that could travel along straight paths through the target field using a navigation map predetermined based on field spatial information. The results of this study suggest that the field performance of autonomous rice transplanter was significantly influenced by the soil type and seedling mat thickness. When the seedling mat was very thick and the soil was clay, the forward speed, theoretical field capacity, and effective field capacity were decreased. However, the following parameters were increased when the mat was not very thick and the soil was clay loam. On the other hand, field efficiency was not greatly influenced by the mat thickness and the type of soil. It also found in this experiment that transplanting efficiency was varied significantly with the mat thickness and the soil type. There were also some other factors that influenced the transplanting performance, which were the water level in the field and the control of the machine wheel. The percentage of missing, floating, and buried hills was increased when the soil was clay-type and the mat was thick. With the passing of time, this rate decreased when the mat was not very thick and the soil was clay loam.

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REFERENCES

Basir, M. S., Chowdhury, M., Islam, M. N., & Ashik-E-Rabbani, M. (2021). Artificial neural network model in predicting yield of mechanically transplanted rice from transplanting parameters in Bangladesh. *Journal of Agriculture and Food Research, 5,* 100186. https://doi.org/10.1016/j.jafr.2021.100186

BBS (Bangladesh Bureau of Statistics) (2011). *Year Book of Agricultural Statistics, Bangladesh.*

Gnanamanickam, S. S. (2009). Rice and its importance to human life. In *Biological control of rice diseases* (pp. 1-11). https://doi.org/10.1007/978-90-481-2465-7

Guo, N., & Hu, J. (2013). Variable universe adaptive fuzzy-PID control of traveling speed for rice transplanter. *Transactions of the Chinese Society for Agricultural Machinery, 44,* 245-251.

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

Haque, M. M. (2021) Technology Transfer in Agro-Based Industry of Bangladesh: Opportunities, Challenges and Options. *The International Journal of Engineering and Science (IJES), 10*(10), 38-52. https://doi:10.9790/1813-1010013852

Hu, L. (2016). *Agriculral machinery based on GNSS navigation attitude calibration study* (Doctoral dissertation, Master Thesis, Shanghai university of engineering science, Shanghai, China).

Huang, P., Zhang, Z., Luo, X., Liu, Z. E., Wang, H., Yue, B. B., & Gao, W. W. (2019). Development of external acceleration identification and attitude estimation system of field working vehicle. *Transactions of the Chinese Society of Agricultural Engineering, 35,* 9-15.

Islam, M. S., Rashid, M. M., Ahmed, A., & Abid-Ul-Kabir, M. (2015). Transplanting rice seedling using machine transplanter: A potential step for mechanization in agriculture. *Good Practices, 10*(July 2015).

Kabir, M. S., Salam, M. U., Chowdhury, A., Rahman,

N. M. F., Iftekharuddaula, K. M., Rahman, M. S., & Biswas, J. K. (2015). Rice vision for Bangladesh: 2050 and beyond. *Bangladesh Rice J, 19*(2), 1-18.

Karthik, A. V., Bhat, A. S., VB, M. K., Karanam, P., & Verma, R. (2018). Design and fabrication of hybrid rice seedling transplanter. *International Journal of Computational Engineering Research (IJCER), 8*(2), 26-36.

Koschel, C., Spangenberg, R., & Lang, E. (2007). U.S. Patent No. 7,159,952. Washington, DC: U.S. Patent and Trademark Office.

Krishnan, R., Vishnu, R. S., Mohan, T. H., & Bhavani, R. R. (2017). Design and fabrication of a low-cost rice transplanting machine. In *Technological Innovations in ICT for Agriculture and Rural Development (TIAR)* (pp. 14-17). IEEE. https://doi.org/10.1109/TIAR.2017.8273678

Kumar, R. (2021). A Step towards Increasing Paddy Cultivation by Mechanical Transplanting Mechanism. *Recent Advances in Thermal Engineering, 1*(1).

Li.,Y & Zhao,Z. (2011). Positioning correction method based on Kalman filter for agricultural vehicle. *Agricultural Equipment & Vehicle Engineering, 49*(9), 3-9.

Nagasaka, Y., Saito, H., Tamaki, K., Seki, M., Kobayashi, K., & Taniwaki, K. (2009). An autonomous rice transplanter guided by global positioning system and inertial measurement unit. *Journal of field robotics, 26*(6-7), 537-548. https://doi.org/10.1002/rob.20294

Nagasaka, Y., Tamaki, K., Nishiwaki, K., Saito, M., Kikuchi, Y., & Motobayashi, K. (2013). A global positioning system guided automated rice transplanter. *IFAC Proceedings Volumes, 46*(18), 41-46. https://doi.org/10.3182/20130828-2-SF-3019.00009

Nagasaka, Y., Umeda, N., Kanetai, Y., Taniwaki, K., & Sasaki, Y. (2004). Autonomous guidance for rice transplanting using global positioning and gyroscopes. *Computers and electronics in agriculture, 43*(3), 223-234. https://doi.org/10.1016/j.compag.2004.01.005

Oksanen, T., & Backman, J. (2013). Guidance system for agricultural tractor with four-wheel steering. *IFAC Proceedings Volumes, 46*(4), 124-129. https://doi.org/10.3182/20130327-3-JP-3017.00030

Pakshaweera, D. K. P., Guruge, C. G. T., Dhanushke, D. S. J., Fernando, W. S. P., & Wijesinghe, W. L. P. K. (2016). Automated Paddy Transplanter. In *Proceedings in Engineering, Built Environment and Spatial Sciences,* 9th International Research Conference-KDU, Sri Lanka.

Rahman, M. B., Hossain, S. M. A., Biswas, J. C., Islam, S. A., Sarkar, A. B. S., & Rahman, M. A. (2008). Studies on the performances of wet-seeded and transplanted Aman and Boro rice. *Eco-Friendly Agric. J, 1,* 18-25.

Rao, M. V., & Pradhan, S. N. (1973). Cultivation practices. *Rice production manual, ICAR, 71,* 95.

Saiyed, M. T., Shaikh, M. F., Sharma, M., Sharma, R., & Solanki, C. (2018). Automatic Rice Transplantation Machine. *International Journal of Scientific Research in Science, Engineering and Technology (IJSRSET), 4*(4), 1231-1234.

SEKI. (2012). Iseki PZ-60/80 high-speed riding type rice transplanter. *Agricultural Machinery, 20,* 73-74.

Siddique, M. A. A., Kim, W. S., Beak, S. Y., Kim, Y. J., & Choi, C. H. (2018). Simulation of hydraulic system of the rice transplanter with AMESim software. In *2018 ASABE Annual International Meeting* (p. 1). American Society of Agricultural and Biological Engineers. https://doi:10.13031/aim.201800981

Sun, H., Slaughter, D. C., Ruiz, M. P., Gliever, C., Upadhyaya, S. K., & Smith, R. F. (2010). RTK GPS mapping of transplanted row crops. *Computers and Electronics in Agriculture, 71*(1), 32-37. https://doi.org/10.1016/j.compag.2009.11.006

Tripathi, S. K., Jena, H. K., & Panda, P. K. (2004). Self-propelled rice transplanter for economizing labor. *Indian Fmg., 54,* 23-25.

Xiang, Y. I. N., Juan, D. U., Duanyang, G. E. N. G., & Chengqian, J. I. N. (2018). Development of an automatically guided rice transplanter using RTK-GNSS and IMU. *IFAC-PapersOnLine, 51*(17), 374-378. https://doi.org/10.1016/j.ifacol.2018.08.193

Yang, Q., Xu, L., Shi, X., Ibrar, A., Mao, H., Hu, J., & Han, L. (2018). Design of seedlings separation device with reciprocating movement seedling cups and its controlling system of the full-automatic plug seedling transplanter. *Computers and Electronics in Agriculture, 147,* 131-145. https://doi.org/10.1016/j.compag.2018.02.004

Yin, J., Zhu, D., Liao, J., Zhu, G., Wang, Y., & Zhang, S. (2019). Automatic steering control algorithm based on compound fuzzy PID for rice transplanter. *Applied Sciences, 9*(13), 2666. https://doi.org/10.3390/app9132666

Zhang ZhiGang, Z. Z., Luo XiWen, L. X., Zhou ZhiYan, Z. Z., & Zang Ying, Z. Y. (2006). Design of GPS navigation control system for rice transplanter. *Transactions of the Chinese Society of Agricultural Machinery, 37*(7), 95-97. http://www.agro-csam.org/njxb/

Zhao, R., Hu, L., Luo, X., Zhou, H., Yuan, Q., & Zhang, M. (2016). Prediction of transplanter attitude in field based on ARMA. *Transactions of the Chinese Society of Agricultural Machinery, 47,* 8-12.

Zhou, S., Shi, H., Guo, L., Guo, W., Jin, H., & Zhou, J. (2018). Autonomous guidance for rice transplanter fusion of machine vision and global positioning system. In *2018 ASABE Annual International Meeting* (p. 1). American Society of Agricultural and Biological Engineers. https://doi.org/10.13031/aim.201800912