Commercializing mechanical rice transplanter in Bangladesh: A review

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Abstract: Labor scarcity, especially during peak periods, significantly challenges Bangladesh's agriculture. The widespread adoption of mechanical transplanting in rice cultivation holds the potential to address this challenge. Commercializing this technology could open significant opportunities for small and marginal farmers, ultimately bolstering food security in Bangladesh. This review paper assesses the economic feasibility of mechanical transplanting compared to manual methods. The study involved an extensive literature review of relevant research literature, journals, conference papers and academic presentations to gather and analyze pertinent data. Manual operated transplanters, particularly the riding type are well suited for small scale farmers due to their user friendliness and higher field capacity. Eight row transplanters are recommended for more significant operations or business oriented farms, surpassing their four and six row counterparts in field capacity, efficiency and operational speed. Within the category of walking type transplanters, the six row variant is more fuel efficient than its four row counterpart which excels in functional utility. Mechanical transplanting is a cost effective and advantageous practice in Bangladesh, delivering higher yields at a reduced cost. The availability of an affordable and accessible transplanter is imperative in the Bangladeshi context.

Keywords: rice transplanter, mechanization, commercialization, seedling.

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1 Introduction

About 135 million people reside in Bangladesh, where rice is the main sustenance staple. It plays a pivotal role in the country's agricultural landscape, contributing to nearly half of rural employment, providing approximately two-thirds of the nation's total calorie intake and accounting for roughly half of an average individual's protein consumption. The rice industry is a cornerstone of Bangladesh's economy, generating one-sixth of the nation's total income and half of the agricultural GDP (https://knowledgebank-brri.org). Nearly all the 17 million farming families in the country cultivate rice (BBS, 2017). Over the past three decades, an area of 10.5 million hectares has been dedicated to rice cultivation. In terms of both land area and rice output, Bangladesh ranks fourth globally, trailing behind China, India and Indonesia (Hussain, 2023). Agriculture contributes to 77.07% of

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the world's rice production, with boro rice accounting for 48.97% (Munnaf et al., 2014). In Asia, where rice is a dietary staple for over 560 million people, more than 90% of rice is consumed (Walling et al., 2009). Rice being Bangladesh's primary crop occupies a substantial 74.85% of the country's agricultural acreage (BBS, 2017). As one of the leading paddy-growing nations in Asia, Bangladesh ranks fourth in this regard (Kabir et al., 2015). The agricultural sector played a significant role in the country's economy in the fiscal year 2016-2017, contributing 13.41% to the national GDP (BBS, 2017; Nath et al., 2016).

Using a self-propelled rice transplanter, an operator and an assistant can accomplish the same amount of work in approximately 25 to 40 man-days ha^{-1}, significantly improving compared to manual transplantation methods (Abares, 2012) . In contrast, mechanical transplanting with a four-row walking transplanter requires only 9 to 11 man-h ha^{-1}, while manual transplanting consumes 123 to 150 man-h ha^{-1} (Islam et al., 2016a). In Bangladesh, a new technology known as mechanical transplantation has emerged, offering numerous advantages over traditional practices. This method reduces transplantation costs and labor requirements (Sarkar et al., 2019). Hand and machine transplanting necessitate between 123 and 150 and 9.0 to 10.5 man-h ha^{-1}, respectively, constituting 19 to 22 and 1.65 to 2.00 of the total labor input for rice cultivation (Islam et al., 2016b). A rice transplanter can cover an area of 10,000 m^2 day^{-1}, whereas a single worker can manually plant only 700 m^2. Mechanical transplantation requires 1.4 man-days ha^{-1}, while manual transplanting demands 25 man-days ha^{-1}. Therefore, the financial feasibility of employing a mechanical rice transplanter should be evaluated to facilitate the expansion of service based businesses centered around mechanical transplanting, ensuring the sustainable utilization of transplanters for bespoke hire operations. Although mechanical transplanting is not widely adopted in Bangladesh, its commercialization is crucial (Nath et al., 2022; Huda et al., 2019). It particularly appeals to marginal farmers and presents numerous opportunities for small scale farmers to access commercial mechanical rice transplanting services. Several research conducted on rice transplanter and listed in Table 1.

The key solution to addressing labour shortages during rice production's peak and regular seasons lies in mechanization (Nath et al., 2017). Among the crucial agricultural tasks, planting and harvesting crops demand significant labour inputs. To produce one hectare of rice, 156.2 man-days of labour were required with 44.5 man-days or 28.24% of the total allocated to seeding, raising and transplanting (Rahman et al., 2021b). Manual transplanting in rows necessitates approximately 400 man-h ha^{-1}, constituting 30% of the overall effort for rice production (Islam et al., 2014). While mechanical transplanters have been developed at an institutional level in Bangladesh, many farmers rely on imported transplanters. The scarcity of labour during the busiest transplanting season coupled with the increasing availability of rice transplanters is prompting policymakers to reconsider their stance on the expanded use of machinery in rice cultivation. This review article delves into the challenges and solutions regarding commercialising mechanical rice transplanters and the nuances of various transplanting techniques. Some farmers are adopting the rice transplanter the Bangladesh government provides for their fields. Therefore, gaining insights into the current utilization of rice transplanters in rice production is crucial for understanding the potential acceptance of this technology in Bangladesh. This information will prove valuable to the decision makers responsible for shaping the country's policies.

2 Methodology

The objective of this study was to assess the economic feasibility of mechanical transplantation in comparison to manual transplantation. To gather and evaluate relevant articles, various search engines were employed. This extensive approach ensures a thorough examination of the available literature and provides a robust foundation for the comparative analysis of mechanical and manual transplantation methods.

Table 1 Published information on rice transplanting in Bangladesh context

Types of work	Objectives/ Activities	Findings	References
Rice Transplanting Mechanization in Bangladesh: Way to Make it Sustainable	To examine the problems associated with different rice transplanting methods, critical technological gaps in adoption of mechanical transplanters and suggests future research policy to make transplanter more users friendly.	Inexpensive and ease of operation type rice transplanter need to be designed for Bangladesh conditions.	(Hossen et al., 2022)
Financial analysis for custom hire busines of mechanical rice transplanter in Bangladesh	Analyze the financial per- formance of mechanical transplanter for customer service providers and to analyze the profitability of mechanical rice transplanting business with hybrid and inbred rice varieties.	Rice transplanter can be a great opportunity for custom hire business as well as entrepreneurship development not only for inbred rice but also for hybrid varieties.	(Sarkar et al., 2020)
Commercial mechanical rice transplanting under public private partnership in Bangladesh	To reduce the seedling tray requirement and increase the field capacity of mechanical transplanter; to identify the constraints of commercial service of mechanical transplanting and to suggest possible solution to overcome the problem.	Tray requirement in each plot can be reduced by adjusting plant to plant space and seedling density setting. Various factors affected the field capacity i.e. plot size and shape, land preparation, land leveling, water height, plot to plot distance etc	(Islam et al., 2015)
Validation of walking and riding type rice transplanter in different location of Bangladesh	To validate the rice transplanter to the end users, to observe yield performance of mechanical transplanted rice compared to traditional practices and to increase labor efficiency and reduce human drudgery	Entrepreneurship development for seedling rising might be solved the problems of mechanical transplanter popularization in Bangladesh.	(Hossen et al., 2018b)
Impact of Mechanical Transplanting on Rice Productivity and Profitability- Review	Scrutinizes the affirmative and deleterious impression on yield and economic of mechanized rice production.	Mechanized transplanting can be used magnificently as an economic, practicable and alternative opportunity for attaining higher productivity and curtail the cost of farming as the traditional rice transplanting needs more workforce.	(Saha et al., 2021)
Mechanical Rice Transplanting in Bangladesh: Current Situation, Technical Challenges, and Future Approach	The problems associated with various rice transplanting methods, significant techno-logical gaps in the adoption of mechanical transplanters, and future research thrust areas aiming at improving the usability of transplanters	Bangladesh needs an inexpensive and user-friendly rice transplanter. Farming operations could ben-efit from a low-cost, semi-automatic rice transplanter, which could help address labor shortages while also saving money.	(Rahaman et al., 2022)

3 Present status of transplanting

3.1 Manual transplanting

In Bangladesh, manual transplantation remains the predominant method for planting rice. This labor intensive process entails individuals standing in waterlogged fields, bending and stooping for extended periods to transplant rice seedlings into the soil manually. It is estimated that approximately 250 to 300 man-hours are required to manually transplant a hectare of rice, encompassing activities such as nursery raising, uprooting of seedlings and transplanting (Hossen et al., 2018a). Remarkably about 95% of the land in Bangladesh is subjected to manual transplantation, underlining its widespread prevalence.

However, manual transplanting comes with its own set of challenges. The process is time consuming and costly and can hinder the maturation of crops due to the stress endured by laborers (Luvisi et al., 2016). An ergonomic study conducted by Karunanithi et al. (2001) revealed that male and female workers expend significant energy during manual transplanting, ranging from 72% to 87% for males and 83% to 89% for females mainly when working in muddy fields. Moreover, the frequent changes in posture required during manual transplantation can lead to musculoskeletal issues among workers.

Studies have also highlighted the prevalence of musculoskeletal disorders among rice farmers engaged in manual transplanting. For instance, low back discomfort affects a significant proportion of Thai rice farmers with an incidence rate of 83.1% among 344 farmers aged 20 to 59 (Keawduangdee et al., 2015). This underscores the physical toll that manual transplantation can exact on agricultural workers.

Manual transplanting is most suitable in areas where labor is abundant and in smaller rice fields. It is a method well suited for fields with uneven terrain and fluctuating water levels. However, it is essential to note that depending on soil type, manual transplantation can require between 123 to 150 man-h ha^{-1}, covering tasks from nursery raising to seedling, uprooting and transplanting (Islam et al., 2016b). Across Asia, manual planting remains a common practice, often involving a workforce of 25 to 30 individuals per hectare of rice. This method finds its niche in regions where labor is readily available and in smaller, more manageable rice fields.

3.2 Mechanical transplanting

Farmers in Bangladesh are increasingly showing interest in adopting mechanical rice transplantation with approximately 300 mechanical transplanters now accessible across the country according to data from the Bangladesh Bureau of Statistics (Haque et al., 2019). The primary objective behind the availability of these transplanters is to showcase the benefits of mechanical transplantation to farmers. A Research by Islam (2016) further supports the feasibility of mechanical transplantation, demonstrating its successful implementation in Bangladesh on a smaller scale, utilizing four-row transplanters at various locations.

A study conducted by Kabir et al. (2015) delved into the commercially viable performance of a 6-row trip on a transplanter, revealing that approximately 92% of trays were required for mechanical transplanting, with 2% allocated for gap filling and 6% for the pocket area. Moreover, Islam (2016) compared hand and machine transplanting, revealing that the former required between 123 and 150 man-h ha^{-1}, while the latter only required 9.0 to 10.5 man-h ha^{-1}. This drastic reduction in labor hours accounting for 19 to 22 times less than that of manual transplanting highlights the efficiency gains associated with mechanical transplantation.

In terms of yield, mechanical transplantation proved to be advantageous, producing a higher number of effective tillers per hill compared to manual transplantation. Specifically, mechanical transplantation yielded 15 effective tillers per hill instead of the 13.67 achieved through manual transplanting (Manjunatha et al., 2009). This higher tiller count contributed to an overall better grain yield, attributed mainly to a more significant number of panicles per square meter.

While mechanical transplantation is a promising solution in Bangladesh, it is essential to note that it may only be suitable for some soil conditions. For instance, dry or excessively muddy soil may pose challenges. Additionally, it is worth considering the financial aspect, as the cost of acquiring mechanical transplanters can be prohibitive for smaller or economically disadvantaged farmers. Figure 1 indicates that there are roughly 300 rice transplanters currently available in Bangladesh, providing a snapshot of the current landscape of mechanical transplantation in the country.

Both non-puddled and puddled conditions are suitable for the application of mechanical rice transplanters, as indicated by Hossen et al. (2018b) . However, despite this versatility, less than 5% of all paddy fields in Bangladesh currently utilize mechanical transplanters as reported by (Hossen et al., 2018b). This relatively low adoption rate highlights the need for further promotion and awareness surrounding the benefits of mechanical transplantation.

One of the primary motivations for implementing mechanical transplantation was to address the labor shortage in agricultural operations. According to Islam (2016), this method leads to a substantial reduction in labor requirements, saving approximately 61%, and also results in an 18% reduction in overall expenditure when compared to manual transplantation. These findings underscore the potential economic and labor-saving advantages associated with mechanical transplanting.

Numerous studies and investigations have demonstrated the successful application of transplanters in the agricultural landscape of Bangladesh. The Department of Agricultural Extension (DAE) and various Non-Governmental Organizations (NGOs) have played a significant role in deploying many rice transplanters. Specifically, DAE has employed these machines in 32% and 34% of their operations, while NGOs, Bangladesh Agricultural Development Corporation (BADC), Bangladesh Rice Research Institute (BRRI), and Bangladesh Agricultural Research Institute (BARI) have utilized rice transplanters in 14%, 10%, and 5%, of their respective operations as depicted in Figure 2. This data highlights the growing adoption and utilization of transplanters in the agricultural sector.

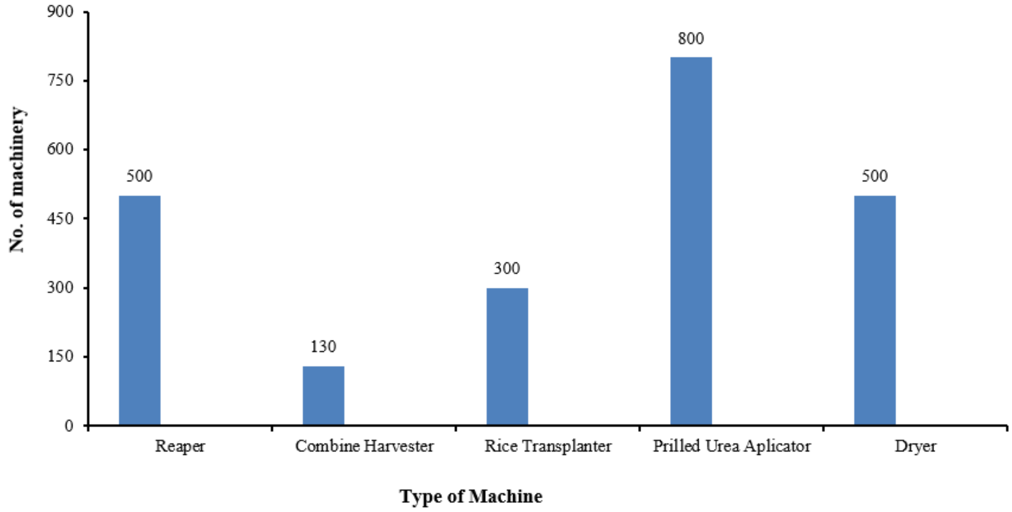

Figure 1 Present status of farm machinery in Bangladesh (Rahman et al., 2021a)

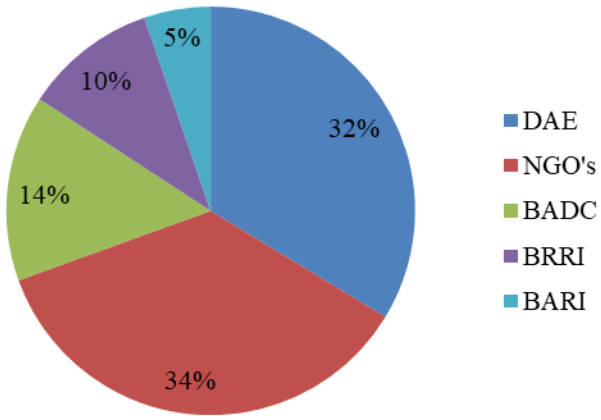

Figure 2 Status of rice transplanter used in Bangladesh (Awal et al., 2019)

The self-propelled walk behind type and the four-wheel type transplanters have significantly improved grain yield, surpassing manual practices by 9.3% and 6.7%, respectively (Hossen et al., 2022). This indicates that mechanical transplanting not only requires considerably less time but also reduces the labor intensive nature of the process. DAE has been running government subsidy programs that have contributed to a considerable increase in the use of precision rice transplanters at the farmer level in Bangladesh. Mechanical rice transplantation is becoming more and more popular because of these efforts. Maintaining training programs around the country that are focused on producing competent operators is essential to further ensuring the success of this technology. Moreover, several well liked rice transplanter types have been recognized by the subsidy program and are being encouraged to be used by more farmers.

4 Classification of transplanting technology-based on power sources

4.1 Manually operated transplanter

According to Kumar et al. (2017) manually operated transplanters are powered by either humans or animals and are well-suited for planting mat-type seedlings on puddled soil in row formations. These transplanters can accommodate anywhere from two to ten rows. The machine comprises a picker arm for planting seedlings, a float, a tray to hold the seedlings and a mechanism for indexing the tray (Kamruzzaman et al., 2014). The operator moves the machine forward while the picker extracts a group of two or three seedlings and plants them in the soil. Typically, the mechanism maintains a fixed row spacing of 200 mm.

This locally manufactured machine comes for 55 USD ha^{-1} and has operational expenses of 15 USD ha^{-1}, as opposed to the 46 USD ha^{-1} for hand transplantation. Workers often complain of back pain, although the machine tends to function smoothly over time. The transplanter is compact enough to be manually operated and is designed explicitly for transplanting bare root plants without mud. Its lightweight structure makes it easy to operate and maintain. It is recommended for small scale farmers to consider using this type of transplanter.

4.2 Self-propelled transplanter

There are two types of self-propelled transplanters: i) Walk-behind type (Figure 4) and ii) Riding- type (Figure 5). According to Hossen et al. (2018a), the average field capacity for the walking and riding types of transplanters was found to be 39.42 and 90 decimal ha h^{-1}, respectively. Both types utilize mat type seedlings.

Recent 4-row walk behind tractors manufactured by Mahindra Tractors are equipped with a transmission system, a 4-stroke single cylinder gasoline engine and a planter that plants seedlings at a depth of 50 mm, 300 mm apart, with a planting pitch of 160 ~ 210 mm. The machine can achieve a planting speed of 0.45~0.85 m s^{-1} and weighs 180 kg. The same manufacturer also produces a 6-row riding type transplanter with the following specifications: 300 mm row spacing, 180 ~ 240 mm planting pitch, 20 ~ 50 mm planting depth, and available in both gasoline and diesel engine types. The overall weight of the machine is 830 kg. However, due to the significant depressions and mudflow created by the tractor wheels, as well as the absence of slopes, using a tractor for transplantation is often not the preferred method, accounting for nearly 50% of cases (Chaitanya et al., 2018).

It was observed that the field capacity of the riding-type transplanter exceeded that of the walking type. Both types of transplanters were effective alternatives for manual rice transplantation in Bangladesh. The choice between walking and riding type transplanters depends on specific field conditions. To enhance labor efficiency and reduce physical strain on workers, both types of transplanters are essential.

5 Based on the number of rows of the transplanter

5.1 Eight-row transplanter

According to Basir et al. (2019) an eight-row transplanter typically maintains a row spacing of around 300 mm, with hills spaced approximately 120 ~140 mm apart. Powered by a robust 178F diesel engine, this machine boasts enhanced capabilities. Achieving successful transplantation of a single paddy requires an area ranging from 0.5 to 0.7 ha. Similarly, to the 6-row transplanter, the eight-row counterpart exhibits a capacity of 0.15 ha h^{-1}. However, it tends to entail higher mechanical operation and labor costs (Kumar et al., 2017). The notable advantage of the eight-row transplanter lies in its ability to significantly reduce labor time, allowing two workers to complete all tasks efficiently. With its substantial capacity, this type of rice transplanter proves suitable for a wide range of fields. Its hanging suspension mechanism also makes it possible to modify the height of the rice transplantation to suit different field conditions and the planting area may be customized to fulfil particular customer’s needs.

5.2 Six-row transplanter

The six-row transplanter machine shares high efficiency and compatibility with the eight-row rice transplanter, especially when equipped with a 178F diesel engine. According to Mamun et al. (2013), the transplanter demonstrates a field productivity of 62.96%, a field capacity of 0.54 ha h^{-1} and a fuel consumption rate of 4.29 L h^{-1}.

Utilizing a six-row transplanter, one can cover an area of 0.04 to 0.05 ha h^{-1} with an expenditure of 40 to 50 man-h ha^{-1}, resulting in a yield increase of approximately 5% to 10%. This rice planter machine offers an adjustable depth range of 15 to 35 cm, row spacing of 20 to 25 cm, and an operating efficiency of 0.22 to 0.52 acres h^{-1}. The recommended planting depth is 0.7 and 3.7 cm (in 5 positions). On roads, the machine can achieve speeds ranging from 0.58 to 1.48 m s^{-1} (Munnaf et al., 2014). In terms of efficiency, the six-row transplanter machine is on par with the eight-row rice transplanter.

5.3 Four-row transplanter

In a different region of Bangladesh, the implementation of mechanical transplanting was met with success on a small scale, employing four-row transplanters that utilized 5.25 l ha^{-1} for each hectare of work. The field productivity of these rice planters ranged from 0.10 to 0.12 ha h^{-1}, with an efficiency rate falling between 64% and 70% (Islam, 2016). The four row transplanter, developed by CRRI demonstrates an effective field capacity of 0.025 ha/h at an operational speed of 0.47 km h^{-1} (Kumar et al., 2017). When compared to eight-row and six row transplanters, the performance of the four row transplanter in rice fields proved to be notably advantageous.

5.4 Two -row transplanter

The newly developed two-row rice transplanter boasts an adjustable row spacing of approximately 15~20 cm and is capable of efficiently transplanting seedlings aged between 20 and 25 days with a depth of up to 5 cm. Its operation requires two operators: one who walks behind the machine to fill the tray and another who walks in front to pull the transplanter along. For the transplanter turning and tray filling activities, time loss was 5% and 3%, respectively, allowing the machine to achieve a practical filing capacity of 0.2 ha day^{-1} (based on an eight-hour workday) (Nandede et al., 2017).The primary strengths of this two-row transplanter lie in its user friendly controls and straightforward design. Compared to traditional methods, farmers tend to favor this type of transplanter due to its efficiency and ease of use.

6 Research and development of rice transplanter in Bangladesh

In the 1960s, after an initial unsuccessful attempt in the nineteenth century, the Kubota firm successfully introduced the rice transplanter to Japan. Subsequently, in the following decades, especially in the 1970s and 1980s, there was a substantial surge in the development and utilization of rice transplanters. Although Bangladesh had been exploring mechanical technology since the 1960s, it was in the 1990s that mechanization rates began to increase significantly (Rahaman et al., 2022).

When the manual transplanter was first introduced, the BADC used it sparingly in their fields and refrained from employing it in farmer's fields (Islam, 2016). At the Farm Machinery and Postharvest Technology division of the BRRI, only a few research studies on manual transplanters have been conducted. They experimented with modifying a six row manually driven transplanter in collaboration with the International Rice Research Institute (IRRI) and compared it with BRRI's hand transplantation method (Syedul et al., 2000). However, during the initial phase, no suitable result was obtained.

Between 2014 and 2016, BRRI successfully developed a 4-row reverse pull-style manual rice transplanter. Although it required a significant amount of manual labor, the outcome proved highly effective. The commercial sector brought 400 mechanical rice transplanters to Bangladesh between 2009 and 2019 (Hossen et al., 2022). Through a government subsidy program, the DAE encouraged farmers to import mechanical rice transplanters, offering a subsidy rate of 70% in Bangladesh's haor and southern cyclone-prone regions and 50% in the rest of the nation (Kabir et al., 2015). Syedul et al. (2000) were the first to improve the 6-row manually operated rice transplanter designed by IRRI. They created a 5-row prototype, replacing the wooden skid with a G.I. sheet, resulting in a sturdier, lighter design with reduced sliding resistance. In 2008, the Farm Machinery and Postharvest Technology Division of BRRI launched a project to develop the technology under a government subsidy scheme. This innovation led to a forward-moving, manually operated rice transplanter. In 2019, BRRI made strides in improving power-operated rice transplanters. Additionally, BRRI embarked on a project to develop two walking-type rice transplanters (with spacings of 25 cm and 30 cm) under the SFMRA project in 2019.

7 Performance analysis of different mechanical transplanter

7.1 Field efficiency

Field efficiency is a crucial metric for evaluating rice planter performance in real-world conditions. Field efficiency is assessed by comparing achievable to theoretical field capacity (Kepner et al., 1978) For the walking type (4 rows) transplanter, the field efficiency ranges from 75% to 83.33%. Similarly, for the walking type (6 rows), it varies from 76% to 81%. The riding type (6 rows) transplanter exhibits field efficiency ranging from 71.23% to 74%. These values indicate the extent to which each transplanter model achieves its theoretical maximum output in practical field conditions. The field efficiency of 4-row, 6-row and riding transplanters is 76.11%, 78.66%, and 72.46%, respectively. A visual representation of the average field efficiency data can be found in Figure 3. This information serves as a valuable benchmark for evaluating the performance of different transplanter models in real world agricultural field.

7.2 Actual field capacity

Field capacity, a critical metric in agricultural machinery performance, represents the rate at which a machine would cover a field if it operated continuously at its designated forward speed and consistently covered its full width. The calculation of field capacity is based on Kepner et al. (1978) equation. In this context, the field capacity for the walking type (4 rows) transplanter ranges from 0.18 to 0.20 ha h^{-1}, for the walking type (6 rows) it ranges from 0.12 to 0.18 ha h^{-1}, and for the riding type (6 rows), it spans from 0.32 to 0.36 ha h^{-1}. These values signify the varying rates of field coverage achievable by each transplanter model under optimal conditions. When examining specific models, the average field capacity for the walking type 4-row, walking type 6-row, and riding type 6-row transplanters are 0.11 ha h^{-1}, 0.14 ha h^{-1} and 0.25 ha h^{-1}, respectively. A visual representation of the average actual field capacity data can be found in Figure 4.

7.3 Percentage of missing hills

The missing hill percentage which represents the ratio of the total number of hills without seedlings to the overall total number of hills is a critical metric in transplanting assessment. For the walking type (4 rows) transplanter, the missing hill percentage is 3.11%, while for the walking type (6 rows), it drops to 0.66%. In the case of the riding type (6 rows) transplanter, the missing hill percentage is slightly higher at 0.98%. These values indicate the extent of hills left without seedlings after transplantation. Among the different types of rice transplanters, riding type 6-row transplanters have the lowest average missing hill percentage of 0.98%. A visual representation of the average missing hill percentages can be found in Figure 5. This data provides valuable insights into the effectiveness of different transplanter models in achieving precise seedling placement.

7.4 Fuel consumption

The fuel consumption of transplanters is contingent on various factors such as plot size, shape, transplanting area, inter field movement, plot-to-plot distance and the distance between the machinery shed and the transplanting site. Specifically, the fuel consumption for the walking type (4 rows) is 5 L ha^{-1} while for the walking type (6 rows), it ranges from 4.25 to 4.5 L ha^{-1}. On the other hand, the riding type (6 rows) transplanter exhibits a higher fuel consumption, ranging from 16 to 19 L ha^{-1}. When considering specific models, the average fuel consumption for the walking type 4-row mechanical transplanter is 5.08 Lha^{-1}. In contrast, for the riding type, it stands at 16.75 Lha^{-1}. A visual representation of the average fuel consumption data can be found in Figure 6. These figures provide valuable insights for farmers and stakeholders to optimize resource usage in rice transplantation practices.

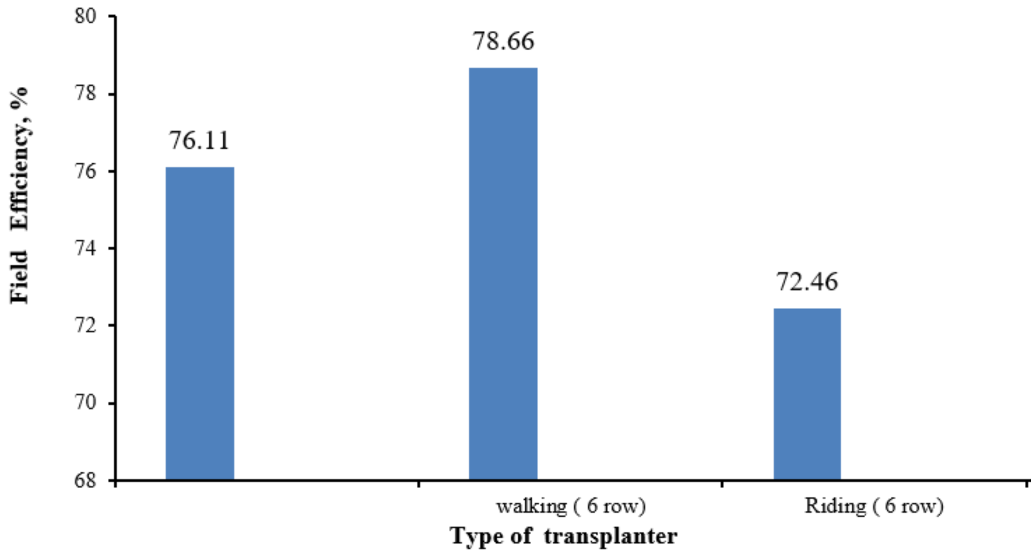

Figure 3 Field Efficiency of different types of the transplanter

8 Operating cost of rice transplanter

The primary fixed cost of a rice transplanter is its initial purchase price. The total operating costs for both the walking type (4 rows) and the riding type (6 rows) range from 52.73 USD ha^{-1} to 63.42 USD ha^{-1} and 26.21 USD ha^{-1} to 34.07 USD ha^{-1} respectively. Specifically, the average total operating costs for the walking type 4-row transplanter, walking type 6-row and riding type 6-row are 58.34 USD ha^{-1}, 46.47 USD ha^{-1} and 30.99 USD ha^{-1} respectively. Regarding effective utilization, the walking type 4-row, walking type 6-row and riding type 6-row transplanters are used for an average of 360 h yr^{-1}, 400 h yr^{-1} and 426 h yr^{-1} respectively. Variable costs are directly linked to the transplanter's usage and field capacity, with detailed cost breakdowns. According to (Munnaf et al., 2014) report, the manual cost amounted to 78.25 USD ha^{-1} (Figure 8). The average operating cost for a rice transplanter was 45.26 USD ha^{-1}.

9 Constraints and solution of commercialization of mechanical rice transplanting

9.1 Social constraint

The farmers often oppose adopting new technologies due to the influence of their socioeconomic culture. This training highlights, the need for comprehensive training and clear guidelines to enhance proficiency in managing rice transplanters. Addressing current trends, as well as the challenges in facilitating market access for farmers and entrepreneurs requires a more business-focused and demand driven approach. Overcoming hurdles related to the availability of post-sale services, local expertise and skilled mechanics is essential for successful adoption.

One significant barrier to entry is the cost associated with acquiring a rice transplanter, which is prohibitively expensive for the majority of rural farmers. This challenge highlights the necessity for government subsidies to make this technology accessible. The high price of transplanters remains a prominent obstacle to their widespread adoption.

Targeted intervention and support mechanisms are essential to ensuring that a broader agricultural community can realize the benefits of machine transplanting technology.

9.2 Institutional constraints

Rice transplanter technology is experiencing rapid advancements, particularly at the grassroots level, thanks in large part to the efforts of the Department of Agriculture Extension. To effectively educate farmers about these innovations, conducting adaptive trials and organizing field demonstrations for automated rice transplanting are highly effective methods. Notably, various organizations, including BRRI, BAU, GBK, BRAC, IRRI, BADC, and private groups, have orchestrated numerous field demonstrations aimed at introducing farmers to aspects such as transplanter performance, pricing, operational techniques, as well as repair and maintenance (Basir et al., 2019).

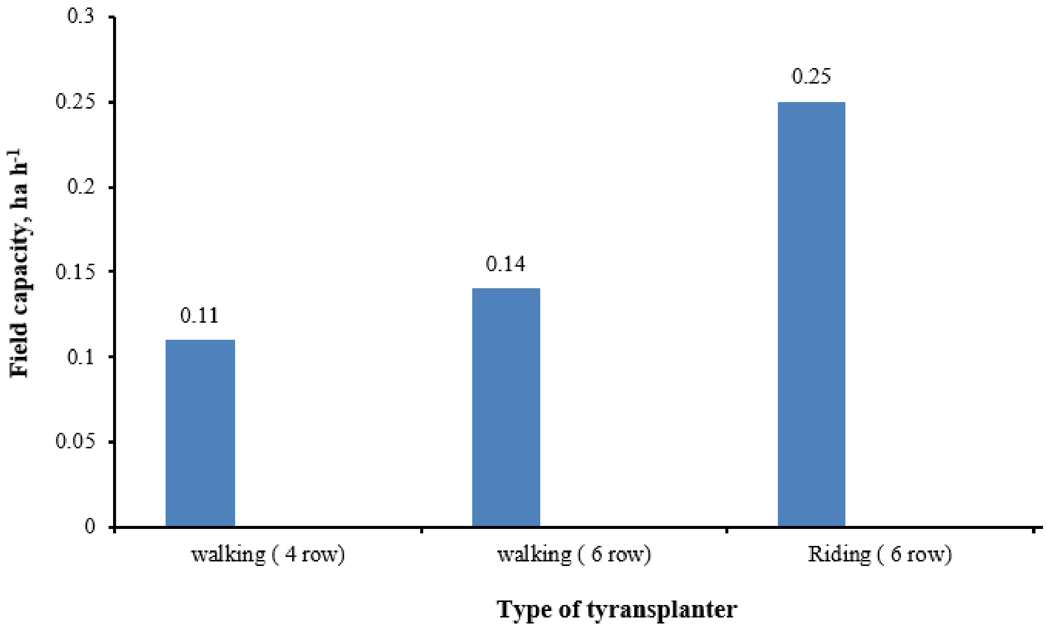

Figure 4 Actual field capacity of different types of the transplanter

To bolster the agricultural engineering sector, the Department of Agriculture Extension should prioritize the recruitment of qualified agricultural engineers, as there currently needs to be more skilled professionals in this domain. To facilitate the acquisition of rice transplanters, farmers have the option to seek loans from both private and public institutions or agricultural agencies. Moreover, these organizations may extend specialized hiring facilities, allowing farmers to access and utilize rice transplanters, ultimately contributing to their widespread adoption and utilization throughout Bangladesh (Hossen et al., 2022).

9.3 Land constraints

The effective operation of agricultural equipment hinges on the size and configuration of the land it uses. In our country, a significant portion of the land designated for transplanting purposes is relatively small in scale. Consistency in land size is a challenge frequently encountered. When selecting plots, it is imperative to factor in the accessibility of the machinery. The daily capacity for mechanical transplanting varied, contingent on several variables, including the distance between plots, the size of the plot, ground levelling, irrigation infrastructure, and the availability of seedling trays (Islam, 2016).

10 Solution

10.1 Synchronized cultivation

As per the recently instituted synchronized agricultural policy, it is now mandatory for synchronized farmers' groups to present at least one synchronized plot in a designated upazila within each district. This policy underscores the imperative of synchronized cultivation as the primary approach. Utilizing a rice transplanter proves to be a significantly more cost effective option than the traditional method, which incurs expenses of approximately 27~32 USD for transplanting seedlings on a hectare of land. Likewise, employing a combined harvester for rice harvesting costs 32~36 USD ha^{-1}, while manual processes involving cutting, transportation, and threshing by labor amount to roughly 164~182 USD ha^{-1} across various regions. Therefore, the adoption of mechanization for both planting and harvesting can yield substantial savings, ranging from 227~236 USD $acre^{-1}$.

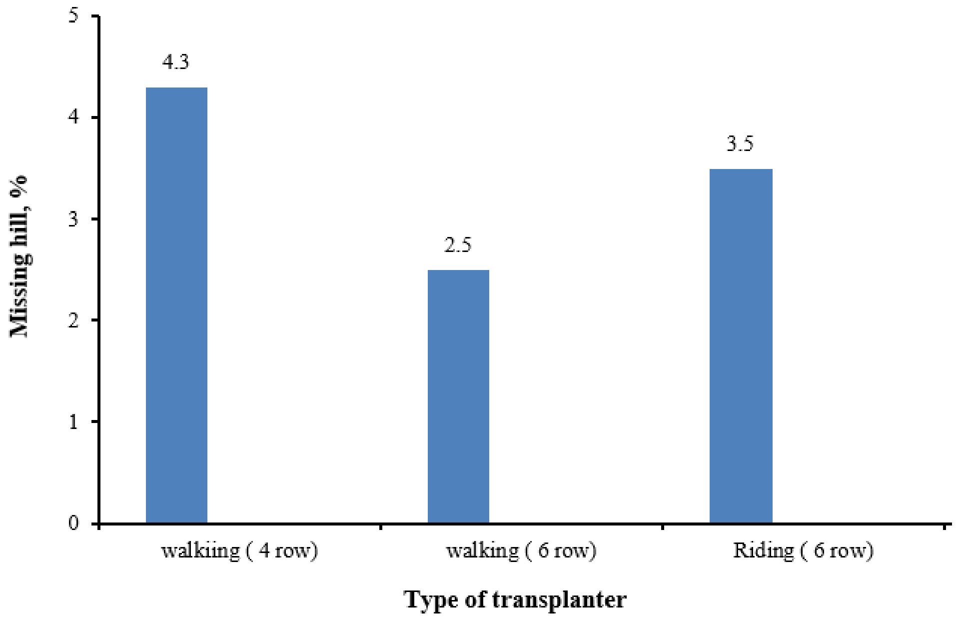

Figure 5 Percentage of the missing hills of different types of the transplanter

10.2 Management

The allocation of time during the transplanting process was contingent on the managerial coordination and the rapport between the transplanting crew and the farmers. Unfortunately, due to inadequate plot preparation, a substantial portion of the time was unproductively spent in idleness. Notably, the quantity of seedlings in the tray exhibited a negative correlation, while seedling population mortality showed a positive correlation. Regarding labor, mechanical transplanting necessitated 18 man-h ha^{-1}, whereas activities such as mat loading, machine transfer and cleaning required only 1.6 person-h ha^{-1}. It is worth noting that for optimal performance of a 4-row walking type rice transplanter, it is advisable to steer clear of small plots with an area of less than 250 m^2 (Islam et al., 2016a) .

10.3 Entrepreneurship development

Entrepreneurs venturing into this domain should be ready to invest in trays, effectively coordinate with fellow farmers and ensure the production of high quality seedlings that align with their specific requirements. However, in such situations, the entrepreneur's capacity to personally oversee seedling preparation may need to be improved. In instances where farmers express a desire to acquire plastic trays, the entrepreneur will facilitate the procurement process. Additionally, the business owner will offer equipment on a rental basis further supporting the operations (Islam et al., 2016b).

10.4 Mechanized village

In Bangladesh, mechanization plays a pivotal role in driving agricultural progress. The available arable land is diminishing at an alarming rate due to the relentless pressure of a growing population. For critical tasks like transplanting, harvesting, and threshing, the dependency on migrant labor has been significant. Moreover, there is a growing concern about the professional choices of the younger generation of farmers, which has implications for the future of agriculture in this region. To regulate and evaluate agricultural machinery, the government has implemented a national testing policy. The responsibility of standardizing agricultural hand tools and equipment falls under the purview of the Bangladesh Standard and Testing Institute. Both the BADC and the DAE are actively involved in the dissemination and promotion of agricultural machinery among farmers. Government-operated radio and television broadcasts feature prominently extension programs focused on agricultural machinery, helping to ensure that farmers have access to the latest information and resources to improve their agricultural practices.

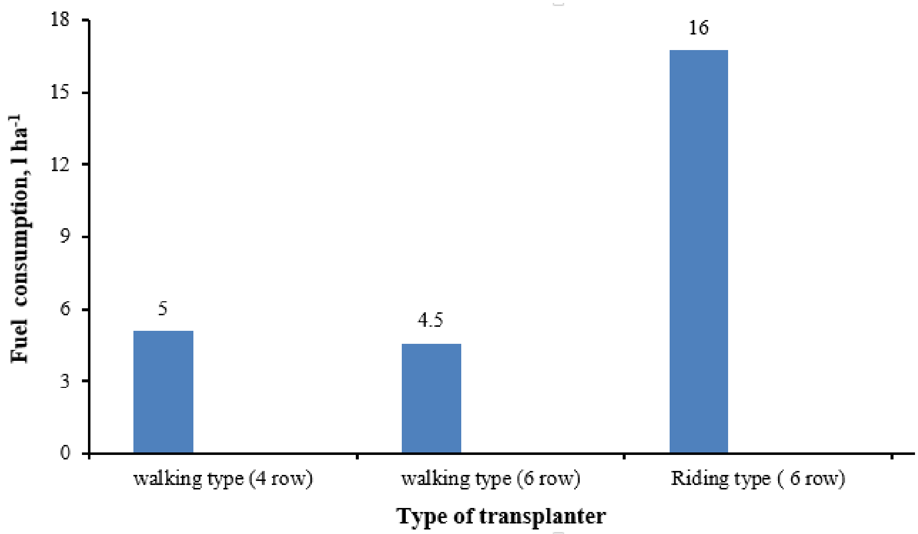

Figure 6 Fuel Consumption of different types of the transplanter

11 Way forward of sustainable rice transplanting system

11.1 Seedling raising technique

Farmers should be equipped with the skills and knowledge required to prepare seedlings in trays effectively. It is crucial to extend the training to the farmer level ensuring they receive comprehensive instruction in the proper care of seedlings. One notable challenge arises from the utilization of topsoil to create mat-type seedlings. To mitigate topsoil depletion during tray preparation, farmers can employ sustainable alternative growing media such as coir, vermiculite, and perlite. For research purposes, mat-type seedlings have been cultivated in various media. In a study by Paul et al. (2019), it was recommended that a mixture comprising 10% to 15% cow dung or rice bran, combined with both sandy loam and clay loam soil, proved suitable as a growing medium for obtaining excellent seedlings in the mat for mechanical transplanting. Hands on training in seedling raising techniques is essential to empower farmers in this regard. The widespread dissemination of seedling raising technology among farmers is key to the successful adoption of rice transplanters in the field.

11.2 Land size and shape

In the pocket areas, manual transplanting was preferred due to the plots uneven form and smaller size, which made it difficult for mechanical rice transplanters to navigate around them. These plots should be enlarged and reshaped with transplanter equipment. Furthermore, the plots raised location in relation to the country roads made it difficult for farm equipment to enter the fields smoothly. Accessibility for farm machinery can be greatly improved by putting land improvement measures into place such as building a dedicated farm road. This road construction maximizes the efficiency of agricultural machinery while simultaneously facilitating traffic. Using transplanter machines in conjunction with operational consolidation practices benefits entrepreneurs by ensuring a more streamlined and efficient operation.

11.3 Boost expertise and proficiency

According to Paul et al. (2016) while offering a sophisticated and knowledge dependent approach to rice production, the mechanical transplanter faces challenges in gaining acceptance among farmers. In vital agricultural regions of the country, it is imperative to select qualified individuals to provide comprehensive training on the functioning, fixing, and upkeep of rice transplanters. Owners and operators must thoroughly understand the machine's calibration, considering factors such as soil characteristics, including soil type, height, density and actual spacing between seedlings and the quantity of seedlings delivered in each stroke.

Establishing an effective communication link between farmers, operators, extension personnel, and investigators is essential to enhance mechanization efforts. It is crucial to assess the extent of farmers' accessibility to and engagement in technical training programs before introducing mechanization initiatives in agriculture. This proactive approach will help ensure that the adoption of mechanized techniques is not only viable but also beneficial for the farming community at large. The success of such initiatives ultimately hinges on a comprehensive understanding of the intricate interplay between technology and the agricultural ecosystem.

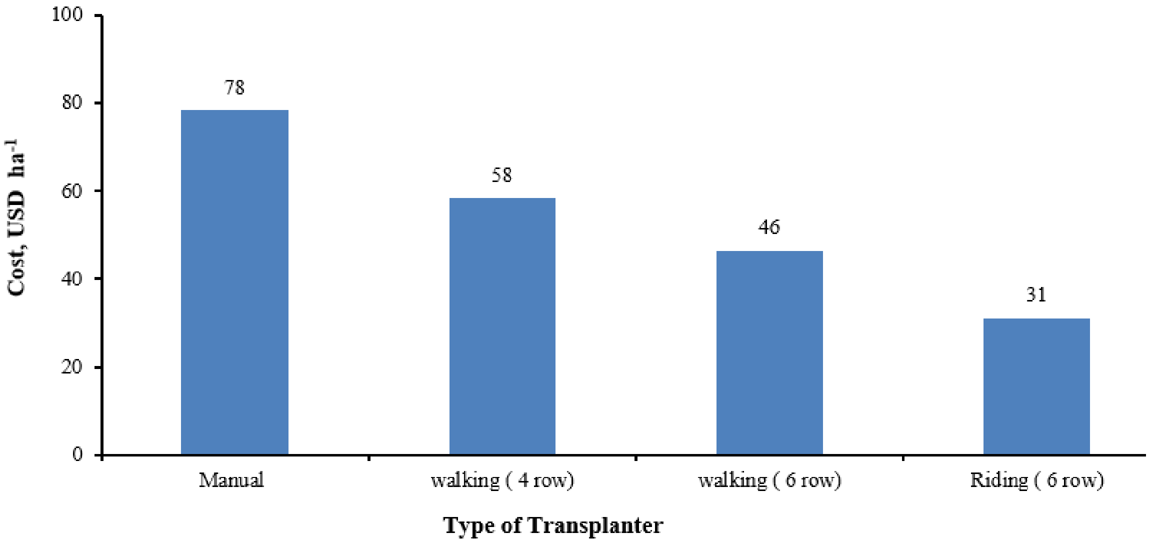

Figure 7 Operating cost of different types of the transplanter

11.4 Proper planning and creation

Agricultural machinery is characterized by its intricate and specialized design. In some instances, a one-size-fits-all approach may need to be revised as the functionality of some machinery hinges on the specific attributes of local agricultural inputs. Consequently, it becomes imperative to engineer and fabricate rice transplanters tailored to suit the prevailing soil type and regional conditions. A potential strategy to reduce costs lies in companies producing the machinery components, which could lead to a more affordable sale price (Hossen et al., 2022).

To ensure the longevity and effectiveness of rice transplanters, establishing a network of robust repair and maintenance facilities in every upazila, facilitated by agricultural extension services, is paramount. Moreover, establishing modern agro-machinery sales and service centers in each district's upazila is recommended to bolster the sustainability of mechanization efforts. This comprehensive approach will not only cater to the specific needs of the agricultural landscape but also contribute to the overall success and viability of mechanized farming practices.

11.5 Popularization activities

To effectively advance agricultural mechanization, it is imperative to coordinate initiatives by implementing appropriate guidelines and collaborative efforts between public and private sector entities. Initiatives like the National Agricultural Mechanization Policy 2020 and the 50%~70% equipment purchase subsidy represent significant steps forward. Systemic challenges must be addressed, including issues related to bank credit regulations, trade policies, quality standards and the provision of extension services.

In alignment with government policy and aimed at facilitating more accessible access to loans for farmers and small to medium-sized businesses, Bangladesh Bank has instituted the "Agricultural and Rural Credit Policy and Program for the FY 2014-2015." This policy limits the interest rates banks charge borrowers from small and medium-sized enterprises (SMEs). However, it is essential to acknowledge that this rate may only partially cover SMEs loan disbursement and collection costs (BBS, 2017). This aspect warrants further consideration to ensure the policy effectively supports the intended beneficiaries in pursuing agricultural mechanization.

12 Conclusion and outlooks

Adopting machine transplanting for rice cultivation is a promising and pragmatic choice from both technological and financial standpoints. Its potential to revolutionize production efficiency while minimizing farming costs cannot be overstated. Compelling evidence from recent studies underscores the urgency of transitioning towards mechanical rice transplantation in the current agricultural landscape. Moreover, synchronized cultivation is pivotal in driving entrepreneurship and commercialization in this domain.

It effectively highlights the importance of two key factors for ensuring the seamless integration of machine transplanting technology in Bangladesh: establishing service centers in every upazila for machinery upkeep and strategic credit distribution policies for small and medium-sized farmers. Additional measures like custom hiring centers, demonstrations, training programs, subsidies, model villages, and infrastructure development will amplify awareness and adoption of mechanical transplanting.

The ongoing collaboration between researchers from universities and research institutes is essential to keeping transplanting technology current and effective. By embracing mechanical transplanting, substantial reductions in labor costs and cultivation time for rice can be achieved. Developing an affordable, semi-automatic rice transplanter is not just a preference but an absolute necessity. Customizing these transplanters to suit the unique circumstances of Bangladesh will be pivotal in ensuring their widespread acceptance and success in this transformative endeavor.

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