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Degree of Mechanization in Paddy Cultivation: A Review of Available Data From 2018-2022

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ABSTRACT

Mechanization plays a crucial role in paddy cultivation, however mechanization in Bhutan has rarely been studied. This study aimed to determine the degree of mechanization for different paddy production operations in Bhutan. The degree of mechanization was computed based on the available secondary data. It serves as a quantitative indicator for assessing the extent of mechanization of agriculture operation. The findings showed that the degree of mechanization in paddy production was highest for threshing (69%) followed by land preparation at 67% and milling at 63%. Other operations like weeding, transplanting and reaping were still done predominantly using manual power which is very laborious and cost intensive. The weeding operation exhibited the lowest mechanization at 0.05%, followed by transplanting at 6% and reaping at 19%. There is need to intensively promote mechanization in rice farming.

Keywords: *Mechanization degree; Paddy cultivation; Agriculture operations*

1 Introduction

In Bhutan, rice is the main food crop and is essential to daily life, culture, custom, and religion (Ghimiray et al., 2008). Rice constitutes the most prevalent cereal in the country's dietary intake, despite its lower production volume compared to other cereals (Ghimiray et al., 2008). Rice is grown in 9495.31 ha, with a total production of 40,081 MT of rough rice, with the national average yield at 4.2 MT/ha (NSB, 2021). Rice self-sufficiency ranged between 34.7% and 51.03% (Tashi, Dendup, Ngawang, & Gyeltshen, 2022). This indicates that more than half of rice consumed is imported primarily from India to cover the deficit. If the current production and consumption trends continue, the ratio of rice self-sufficiency is likely to decline steadily in the coming years (Shrestha, 2004; Tashi et al., 2022). Reverting to fallow land, implementing improved high-yielding varieties, increasing irrigation, implementing

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improved plant and soil management techniques, implementing labour-saving technologies, promoting upland rice, and rice double cropping are possible ways to increase production. However, limited arable land to increase rice self-sufficiency is a bigger challenge in Bhutan. The main cereal crops cultivated in Bhutan encompass paddy, maize, wheat, barley, buckwheat, millet, and quinoa. Paddy takes the lead in annual production, yielding an impressive 54,088.41 MT, followed closely by maize with an annual output of 40,964.62 MT(NSB, 2021). Rapid urbanization and migration of agricultural labour to other jobs, and high labour wages are some of the emerging challenges for sustainable rice production as well as food security.

Labour shortages and high labour charge are most pressing issue in paddy cultivation. Farm mechanization has been identified as a significant measure to address this issue. Agricultural mechanization can simply be defined as the use of any machine to accomplish a task or an operation involved in agricultural production (Odigboh, 2000).

For centuries, Bhutan relied on traditional manual farming with hand tools and oxen. Mechanization began in 1964 with Japanese expert Dasho Keiji Nishioka introducing modern techniques (Dorji & Penjore, 2011). With strong support from government and continued Japanese grant support for effective promotion of farm mechanization, the Agriculture Machinery Centre (AMC) was established in 1983. Grants played a vital role in farm mechanization. Farm equipment, which are received as grant aid, were sold to farmers or provided through government hiring services with a subsidy rate of 55-73% approved by the government. The proceeds are either used for agriclture development or for the procurement of other farm machinery to supply to the farming community. The subsidy component includes cost price, transportation, installation, technical backstopping, training, lower interest loan, tax waiver (Thinley, Wangchen, & Sakurai, 2011). Bhutan received two Kennedy Round (KR) Grant aids for overs 25 years starting from 1984, General Grants in 2016 and 2019, and Japanese Non Project Grant Aids in 2008 and 2010. Around 3,423 power tillers and 5,078 other machines were acquired under these grants.

The engagement of private sector has boosted mechanization through enhanced access to farm machinery sales and repair services. The most popular private agricultural farm firm, Ms Sherub Enterprise started the sale of hand tools and small cultivators as early as 1995. Since then, numerous new private enterprises have emerged since 1995, expanding the market considerably. The government has continuously partnered with private farm machinery

suppliers with free certifiction of various machineries and has excampted taxes on all kinds of agricultural machineries. The government also partners with banks to provide affordable loan at low interest rates for farmers to buy agricultural machinery.

Agriculture mechanization reduces drudgery, increases the safety and comfort of the working environment; it enhances productivity, cropping intensity and production. It increases income for agricultural workers and improves social equality and overall living standards. If properly used, mechanization also conserves and properly utilizes natural resources and reduces the cost of production. It allows for timely farm operations and produces better quality agricultural commodities.

The statements above emphasize how important mechanization is for farming. In Bhutan, using machines has helped paddy cultivation in recent decades. Machines save labour and make working conditions better for farmers. Having such benefits, mechanization has potential to attract young people to take up paddy cultivation in Bhutan.

While mechanization plays a pivotal role in agricultural production, there has been limited exploration of the scope of mechanization specifically in paddy cultivation within Bhutan. This knowledge gap underscores the importance of investigating the degree of mechanization in paddy cultivation in Bhutan. The degree of mechanization serves as a quantitative indicator for evaluating the progress of mechanization implementation in farmlands. It is defined as the ratio of the mechanized area achieved to the total cultivated area (Almasi, S. Kiani, & Loui-mi, 2000). The degree of mechanization also implies the extent to which a particular operation within the crop production system is mechanized (e-Krishi-Shiksha, 2022).

This study aimed to determine the mechanization degree for paddy cultivation in Bhutan. By knowing mechanization degree and its trend, it permits to assess the level of adoption among the cultivators. Moreover, such a study would be useful for evaluating the progress of mechanization in rice cultivation and seek improvement in productivity and efficiency, besides assisting the government to formulate relevant policies.

2 Materials and method

The computation of the degree of mechanization in paddy cultivation and its trends was conducted utilizing available secondary data. The machinery inventory data was obtained from AMC, covering the period from 1982 to 2016. Until 2016, AMC managed the sales and national hiring of farm machinery. Subsequently, the Farm Machinery Corporation Limited

(FMCL), a state-owned enterprise, took over these responsibilities. The data collection process involved examining FMCL's sales and hiring reports from 2016 to 2022, along with sales records from prominent private farm machinery dealers in the country for the years 2018 to 2022.

2.1 Degree of Mechanization

Degree of mechanization implies the extent to which a given operation in the crop production system is mechanized. Degree of mechanization is the ratio of mechanization area accomplished to the total area to be cultivated (Almasi et al., 2000; Ghadiryanfar, Keyhani, & Akram, 2009; El Pebrian & Mohiddin, 2021).

The formula of mechanization degree is expressed in percent (%) as:

$$\mathrm{DOM} = \frac{\mathrm{CAF}*\mathrm{N}*\mathrm{Cap}*\mathrm{H}*\mathrm{D}}{A*R} * 100 \quad \text{---------- ----------1}$$

CAF- Crop area factor defined as ratio of crop area to total area
DOM – degree of mechanization
N – number of machines in the state
Cap – effective field capacity of the machine, acre/hr.
H – hours of daily work
D – number of days available for performing the operation in a year
R – replications of the machine required
A – crop area, acre

Main assumptions for determining the degree of mechanization for paddy cultivation in Bhutan are:

1. The estimation of the degree of mechanization did not consider the hand tools and animal power used, as they are the basic implements of farmers who rely on manual labour.
2. Each machine replication frequency (R), machine capacity (CAF), working days (D) and life of machine have been generalized based on information collected from National hiring scheme report, farmers, and researchers, as reflected in (Table 1).
3. One working day means eight working hours.
4. The total paddy area (total wet land) amounting to 58569.25 acre (NSB, 2018) was used in this calculation.

5. Degree of mechanization degree of irrigation, pest control and drying has not been worked out due to data limitation.
6. The machinery employed for land development included tractors and power-tillers only.
7. All recorded machines for land development were assumed to be used for paddy cultivation.

Paddy degree of Mechanization was calculated and discussed with respect to these agriculture operations namely Land preparation, Transplanting, Weeding, Reaping, Threshing and Milling.

3 Result and Discussion

3.1 Land preparation

The method of land preparation for rice cultivation in Bhutan is similar to many other Asian rice growing countries. Land preparation typically involves ploughing to till the soil, harrowing to break the soil clods into smaller mass and incorporate plant residue, and puddling to create soft, flooded layer before transplanting rice by churning and tilling the flooded field. Machines used for these three operations involve engine powered tractor, power tiller and mini tiller with specific implements like mould board or disc plough for ploughing, harrow or rotavator for harrowing and rotavator for puddling. Since most of the mini tiller in the country are used for dry land cultivation, it has not been considered in this study. Table 1 presents the details of operations in rice cultivation, while Figure 1 shows the area cultivated and harvested from 2017-22.

Operation/Machines		Field Capacity (ac/hr.)	Daily Working (hrs.)	Working Days Per Year (days)	Replication	Machine Life
Tillage	tractor private hiring	0.30	8	30	3	10
	power tiller private hiring	0.10	8	10	3	10
	tractor govt. hiring	0.10	8	70	3	10
	power tiller govt. hiring	0.30	8	70	3	10
Plantation	transplanter	0.30	8	20	1	6
	direct seeder	0.30	8	30	1	6
Weeding	manual weeder	0.11	8	2	2	10
Harvesting	Reaper	0.30	8	20	1	6
	combine harvester	0.30	8	30	1	10
Threshing	power thresher (kg/hr.)	275	7	25	1	10
	pedal thresher (kg/hr.)	50	7	30	1	10

	combine threshing capacity (kg/hr.)	350	7	30	1	10
Milling	power rice mill (kg/hr.)	150	8	10	1	10
	indigenous rice mill (kg/hr.)	240	8	7	1	10

Table 6. Field capacity, daily working, working day per year, replication and life for different machine used in paddy cultivation

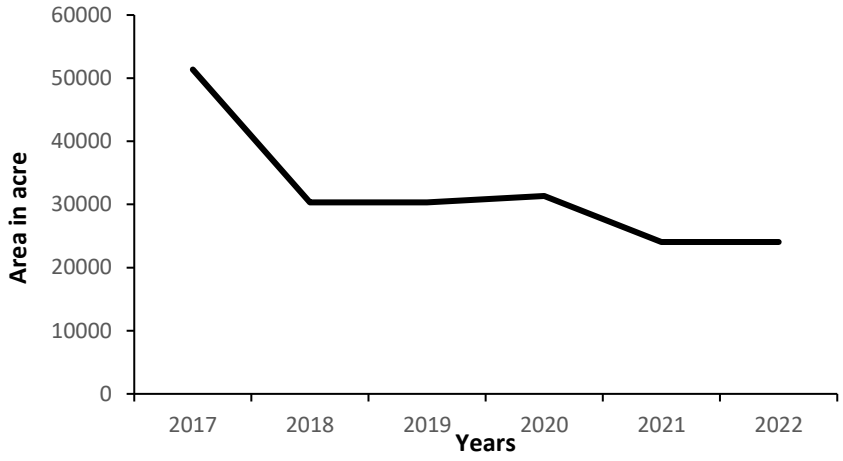

Figure 8. Total paddy harvested area over years

Currently, the degree of mechanization for land preparation stands at 67% (Figure 2). The degree of mechanization in land preparation during paddy cultivation is among the highest, comparable to the mechanization observed in threshing and milling operations. This can be attributed to the widespread availability of power tillers, with an average annual sale of 590 units by private companies. Additionally, the availability of both tractors and power tillers for hire service facilitated by FMCL as well as private hiring service further contributes to high mechanization.

Figure 2 clearly shows that power-tiller is widely used compared to tractor. Because of Bhutan's rugged topography, rice fields are generally narrow terraces (Ghimiray et al., 2013), therefore power tiller and Mini tiller are more suitable compared to tractor. Due to its small turning radius and simple maneuverability for power tillers, they operate better and are more accurate on mountains than four-wheel tractors (Sakai, 2000).

Similarly, degree of mechanization for land preparation has a higher percentage compared to other operation in country like Sri Lanka 100% (Gamlath, Gunathilke, & Chamara, 2018) and Philippines 62% (Malanon & Cruz, 2018).

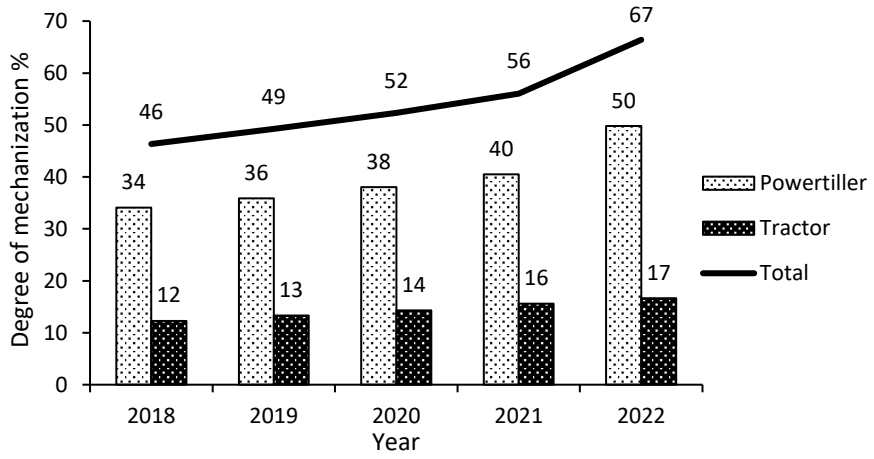

Figure 2. Degree of mechanization of paddy land preparation over years

In Bhutan, mechanization for land development in paddy cultivation has not been fully optimized. Small land holding, undulating topography, socioeconomically vulnerable farmers, limited repair and maintenance service and spare parts availability are major obstacles that stand in the way of the widespread adoption of land development mechanization.

3.2 Transplanting

In Bhutan paddy is transplanted either manually at random or in lines, or by using transplanter machine. Rice is also established by directing seeding using a drum seeder. Degree of mechanization for paddy transplanting stands at a very low level of 6% (Figure 3). This suggests there are very few numbers of engine operated rice transplanter (148) and drum seeders (48) at present. Machine transplanting is mostly done by farmers in Paro, Wangdue and Punakha (DoA, 2019). Transplanters are highly labour effective compared to other methods with reduced labour of 6-man days per acre of field (Dixit, Khurana, Singh, & Singh, 2007).

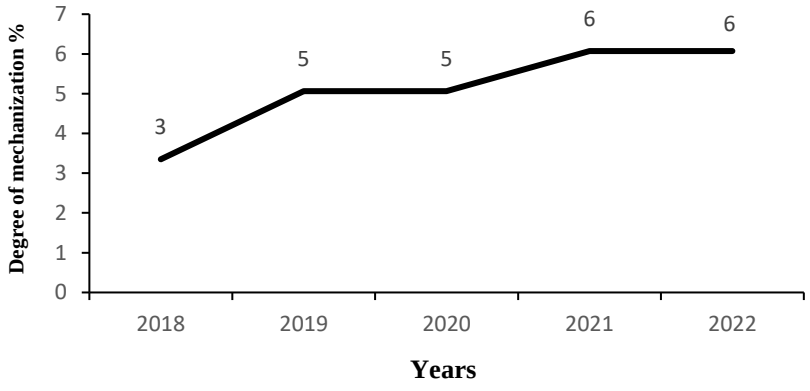

Figure 3. Degree of mechanization for paddy transplanting

Direct seeding of rice is a process of establishing a rice crop from seeds sown in the field rather than by transplanting rice seedlings from the nursery (Akhgari & Kaviani, 2011). There is a cost advantage of 53% for drum seeding ($163/ha) compared to manual line transplanting with reduced labour of 15.5-man days (Dendup & Chhogyel, 2018). Despite the proven labour efficiency and benefits of line planting provided by these machines, they have not gained popularity within the country. The low adoption rate is attributed to its newness and cost factor, resulting in slower adoption. Additionally, farmers who have adopted this technology encounter challenges in maintaining initial irrigation water levels and managing weeds, as reported in their feedback. Transplanting paddy is considered one of the most labour-intensive operations in paddy cultivation. Labour requirement and cost of operation is 33-man days at $ 345/ha for manual line transplanting while it is 29-man days at $306/ha for manual random transplanting (Dendup & Chhogyel, 2018). Scarcity of labour during peak season of transplanting is another major issue.

Based on information gathered from farmers and researchers in Bhutan, the limited adoption of agricultural machines can be attributed to several factors. These include deeply ingrained traditional farming practices and the mindset of farmers, a shortage of trained operators and mechanics, as well as the government's limited provision of machines for hiring. Moreover, long waiting times or unavailability of these machines during peak planting seasons contribute to their restricted usage. Additionally, the machines may not be suitable for small, stoney, irregularly shaped farms, making them less appealing to farmers. Finally, the lack of availability of these machines in the local market also impedes their widespread adoption.

3.3 Weeding

Weeding is uprooting of unwanted plants grown along with paddy in the fields. On average, Bhutanese farmers weed twice in a rice season. The current weed management practices by farmers includes physical, cultural, chemical, and integrated methods (Tshewang, Sindel, Ghimiray, & Chauhan, 2016). In Bhutan, the use of machines or mechanical weeders for weeding purposes is minimal. Among the limited options available, there are manual mechanical tools like the cono weeder, and engine-operated weeders. The availability of these machines is notably limited, with as few as 31 cono weeders and only three power weeders in circulation.

Currently, the level of mechanization in paddy weeding stands at only 0.05% (Figure 4), despite the introduction of mechanical weeders in the early 1990s. However, user adoption has

remained very low till date and has not increased. The low adoption of weeders in Bhutan is mainly due to the paddy plantation method, which is mostly done manually with random planting. The mechanical weeder requires line planting which otherwise damages the crop plants. The paddy transplanter and drum seeder are suitable for planting in straight lines, however their adoption is also low as shown in Figure 3.

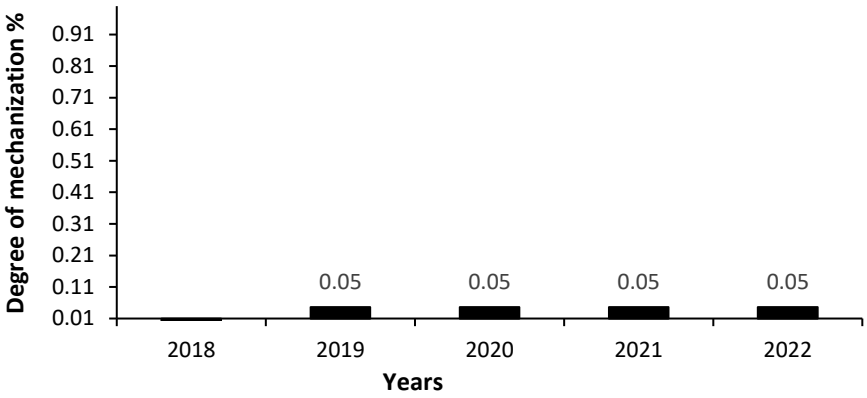

Figure 4. Degree of mechanization for weeding operation in paddy cultivation

Furthermore, in Bhutan, herbicide is most widely used to control weeds in rice. For more than two decades, it has been in use, and its application has consistently increased over time. Generally, there has been extensive adoption of herbicides in rice production systems throughout Asia due to higher profitability (Tshewang et al., 2016). Similar studies conducted in Philippines and Sri Lanka revealed that the degree of mechanization for paddy weeding is remarkably low, standing at only 1% in the Philippines (Malanon & Cruz, 2018) and 2.94% in Sri Lanka (Gamlath et al., 2018). The key reasons for their limited mechanization are due to the factors outlined above. The implementation of row planting or use of transplanter is essential to encourage the use of mechanical weeders which will reduce the labour required in weeding operation as well as reduce the use of herbicides.

3.4 Reaping

The harvesting operation involves cutting of the paddy after it is matured. The harvesting is done both manually using sickles and by use of machine. Harvesting machines such as combine harvester and walk-behind power reaper are used by the farmers. Among these, the walk-behind reaper is particularly valued and commonly owned by individual farmers due to its practicality and efficiency in smaller-scale farming. On contrast, the combine harvester is typically only owned by government hiring services.

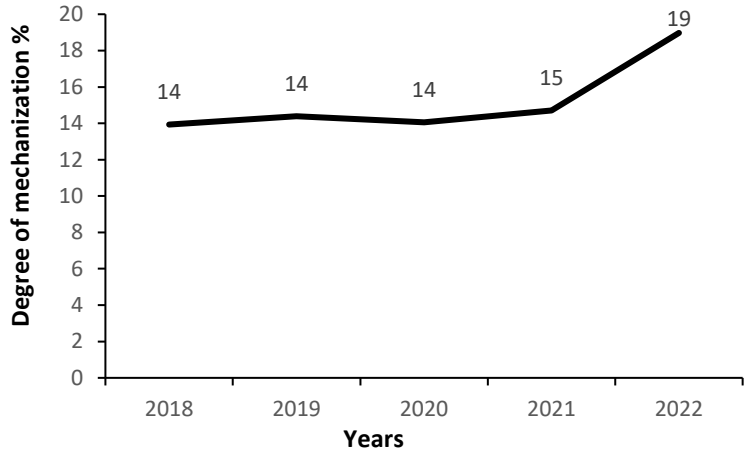

Figure 5. Degree of mechanization for harvesting operation in paddy cultivation

The data presented in Figure 5 indicates constant paddy mechanization degree in harvesting for past three years from 2018 to 2020 and a modest increase only in the year 2022. With the available harvesting machines in the country reaper (176) and combine (37), the current degree of paddy mechanization in harvesting has reached 19%. The low degree of machination in paddy harvesting is because the use of combine harvester in Bhutan is limited due to small terraces, sloppy fields and expensive hiring charges and machines cost. The walk behind reaper is also not much feasible in small and sloppy fields.

The issue can be addressed by promoting affordable hiring services for harvesting machinery like combines and ensuring their availability during peak seasons to marginal farmers and by ensuring the availability of small reapers feasible for small terraces and sloppy fields. Developing paddy fields suitable for bigger machines such as combines and reapers can also pave the way for increased mechanization in the future.

3.5 Threshing

Threshing involves detaching the grains from the panicles. In Bhutan, the machines used for threshing include the pedal thresher, power thresher, and the threshing unit of a combine harvester. The combine harvester is owned only by FMCL and hire charges are high.

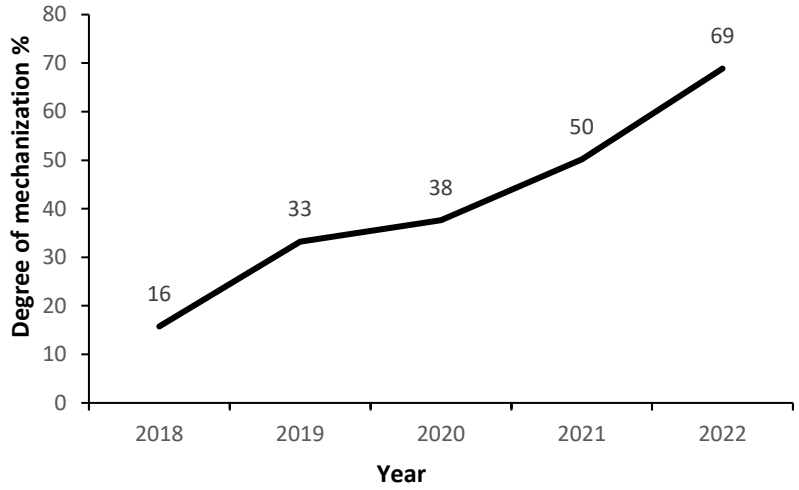

Figure 6. Degree of mechanization for threshing in paddy cultivation

Figure 6 indicates that the level of mechanization in paddy threshing reached 69% in 2022, showing a steady increase over the past five years. The significant rise in the number of machines since 2018 is due to the entry of five new private suppliers in the market. Prior to that, only two companies were selling pedal and power threshers. However, the efficient use of mechanized threshers in paddy farming has not been fully achieved, and in certain regions of the country, especially in the southern areas, traditional methods of threshing paddy are still the preferred choice.

According to Figure 1, there is a consistent decrease in the overall cultivated area over time, with only 41% of the total wetland being cultivated in 2021. At the current stage of cultivation, the existing machines (power thresher: 819, pedal thresher: 584) are sufficient to achieve full threshing mechanization, with a mechanization degree of 168%.

3.6 Post-harvest Milling

In Bhutan, various types of power rice mills are used for rice milling operations. Lately, electrically operated compact rice mills have been gaining popularity due to their easy availability, efficiency, and affordability. Before this, the custom hired Engelberg screw type rice mills were in use.

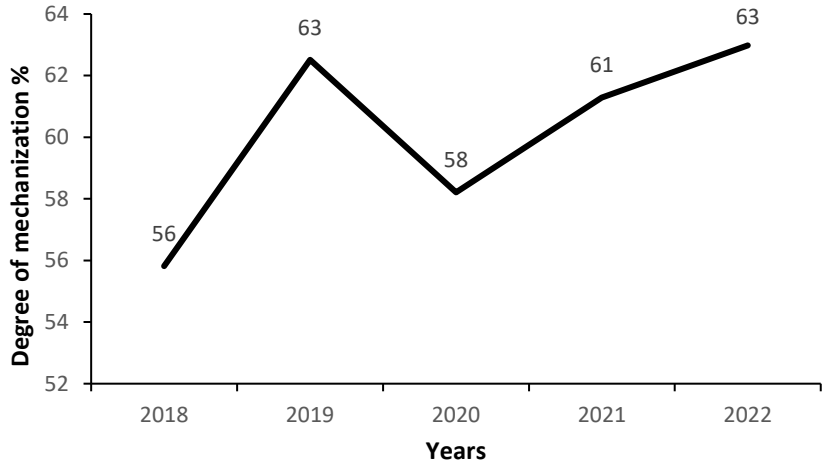

Figure 7. Degree of mechanization in milling for paddy cultivation

The advantages of using machines over traditional methods, such as mortar and pestle, are significantly higher in terms of capacity, labour reduction, total milling output, and decreased operational costs. Consequently, rice mills are becoming increasingly popular among farmers.

At the current stage of cultivation (24055 acre), existing machines are adequate, resulting in a mechanization level of 153%. If paddy cultivation covers the country's total wetland (58569.25 acre), the degree of mechanization in rice milling operations stands at 63% as shown in Figure 7.

4 Conclusion

Mechanization of paddy cultivation operations has been promoted for almost four decades since it was first introduced in the 1980s. This study delved into the implementation of mechanization in paddy farming in Bhutan, investigating the current degree of mechanization. Paddy is the only crop in the country where nearly all agricultural operations deploy machinery. Operations such as land preparation (67%), threshing (69%) and milling (63%) were more mechanized compared to reaping (19%), transplanting (6%) and weeding (0.05%). Similar observations were made in Asian countries like Sri Lanka and Philippines. Over the past five years, a noticeable and gradual increase in the degree of mechanization has been observed. This shift is attributed to the easy access and increased sales of machines like power tillers, power threshers, and rice mills.

Numerous private companies entered the market since 2018 to sell farm machinery. As of now, we have nine well-established private companies that are successfully running and providing quality farm machinery. In terms of operations with high potential for mechanization,

transplanting (6%), weeding (0.05%) and harvesting (19%) were the three next labour-intensive farm operations that are expected to be affected by the diminishing farm labour. Hence, intensive promotion of mechanization for these three operations is an urgent need to enhance the degree of mechanization, and to minimize farm labour shortages. The effort requires a strong collaboration between relevant agencies such as research and academic institutions, farm machinery manufacturers, dealers and related government agencies to create mechanization technologies from technical, economical, geographical, topographical and agronomic aspects.

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