ROYAL GOVERNMENT OF BHUTAN

DoA

Adoption of Labour-Saving Technologies in Southern Region (Samdrup Jongkhar, Samtse, Sarpang, Trongsa, and Zhemgang): An Empirical Evidence from a Household Survey

Agriculture Research and Innovation Division,
Department of Agriculture, MoAL
Thimphu; Bhutan

2024

Adoption of Labour-Saving Technologies in Southern Region (Samdrup Jongkhar, Samtse, Sarpang, Trongsa, and Zhemgang): An Empirical Evidence from a Household Survey

Authors

Ngawang	(Agriculture Research & Innovation Division)
Kentario Kawasaki	(Department of Agriculture)
Rinzin Wangchuk	(Agriculture Research & Innovation Division)
Chezang Dendup	(Agriculture Research & Development Centre -Samtenling)
Chimi Rinzin	(National Centre for Organic Agriculture – Yusipang)
Om Prakash Ghalley	(Agriculture Research & Development Centre -Samtenling)
Tshering Wangmo	(Agriculture Research & Development Centre -Samtenling)
Kinley Wangchuk	(Agriculture Research & Development Centre -Samtenling)

Coordination & Lead

Mr Rinzin Wangchuk
Mr Nawang
Mr Chimi Rinzin
NCOA and ARID

Published By:
Agriculture Research and Innovation Division (ARID)
Department of Agriculture
Ministry of Agriculture & Livestock
Tel# 02-322228/331316/336462/336186(F)

Funded by AFACI, RATES Project

Table of Contents

Executive summary

Technological innovation is crucial for improving agricultural productivity and meeting the nation's food security needs. Understanding the adoption rate of labor-saving technologies and the factors influencing their adoption is essential. This study utilized semi-structured and structured questionnaires to assess the current adoption status of labor-saving technologies and the factors affecting their adoption in five districts: Samdrup Jongkhar, Samtse, Sarpang, Trongsa, and Zhemgang. A total of 1,142 farmers were selected through a random proportionate sampling technique, and data were collected via face-to-face interviews. A probit regression was employed to analyze the data and adoption rates. The estimation results of the probit model suggest that the adoption of labor-saving technologies is particularly influenced by farm size, knowledge, and neighbors. A trend analysis indicated that power tiller and mini tiller adoption has drastically increased over time. The adoption rate of power tillers in the five districts was 33%, with Trongsa having the highest adoption rate compared to Samtse, which had the lowest. It is evident that power tillers and tractors are more commonly hired than self-owned across most districts. However, mini tillers show a higher rate of self-ownership, especially in Samtse and Trongsa. The data reveal a general preference for hiring machinery rather than owning it. A detailed analysis found that the primary factor influencing the adoption rate is the reduction of drudgery, accounting for 65% of the responses, the highest frequency reported by participants. Among non-adopters of power tillers, the main reason cited for not adopting was the cost, a consistent finding across all districts. Therefore, it is important for the government to establish and operate rental centers may be through FMCL for labor-saving machineries. *This would make these machines more accessible to small-scale farmers who cannot afford to purchase. While this study's adoption rates are based on the number of households, future studies should investigate adoption rates based on the area cultivated. Additionally, exploring the potential agricultural areas that can be brought under mechanization would be beneficial.*

Keywords: Technology; Adoption; Probit analysis; Hiring, Drudgery; Food security

.

Acknowledgments

Agriculture Research and Innovation Division would like to express our deepest gratitude to the **Asian Food and Agriculture Cooperation Initiative** (AFACI) project for their generous support and funding of this project. The financial support has been instrumental in the successful completion of the study on the adoption of agriculture technologies.

We are also thankful to the Department of Agriculture for granting us permission to carry out this important research. The support was essential in facilitating our study and enabling us to collect valuable data.

We extend our heartfelt thanks to the enumerators of ARDC-Samteling for their exceptional work in gathering high-quality data for this research. Your professionalism, diligence, and dedication have been crucial to the success of this project. We also would like to acknowledge Bhutan Construction and Transport Authority, MoIT and Farm Machinery Cooperation Limited, Paro for the administrative data, which was useful for the triangulation of survey findings.

Finally, we would like to express our profound appreciation to all the respondents who participated in the study. Your cooperation and willingness to share your experiences provided us with invaluable insights and significantly contributed to the success of our research.

Thank you all for your significant contributions and support.

Acronyms

AMTC	:	Agriculture Machinery and Technology Centre
ARDC	:	Agriculture Research and Development Centre
BCTA	:	Bhutan Construction and Transport Authority
DoA	:	Department of Agriculture
FMCL	:	Farm Machinery Cooperation Limited
GDP	:	Gross Domestic Product
KD	:	Kennedy Round
MoAL	:	Ministry of Agriculture and Livestock
MoIT	:	Ministry of Infrastructure and Transport
NSB	:	National Statistical Bureau
RNR	:	Renewal Natural Resources

1. Introduction

Technological innovation is crucial for improving agricultural productivity and meeting the nations' food security. But what is Technology? Technology can be defined as the utilization of scientific knowledge and instruments to address challenges and attain practical objectives. It includes the application of tools, methodologies, systems, and processes to generate, manipulate, transmit, store, and exchange information, or to manufacture goods and provide services. Today's global agricultural industry is highly efficient, largely due to labor-saving technologies. Despite challenges such as risky investments and seasonal outputs, technological advancements have significantly increased productivity, lowered production costs, reduced labor dependency, improved product quality, and enhanced environmental control (Gallardo & Sauer, 2018a). Labor-saving technologies impact labor demand and supply, influencing policy decisions. However, economic viability is essential for adoption. Factors influencing the adoption of these technologies include risks, investment costs, performance uncertainties, suitability for specific operations, and environmental conditions. Macroeconomic factors, such as labor supply structures and human capital, also play a role (Heinicke & Grove, 2001). The adoption of labor-saving technologies varies across agricultural sectors. While they have been successful for most annual crops like grains and cotton, they are less developed for specialty crops like fruits and vegetables.

As global populations continue to rise, there is an increasing pressure on the agricultural industry to enhance productivity and efficiency. Gallardo and Sauer (2018b) highlighted the significance of labor-saving technologies in addressing the challenges posed by labor shortages and the increasing demand for food. They argue that the adoption of such technologies is crucial for sustaining agricultural productivity and ensuring food security in the long run. Through a systematic literature review they found that economic considerations, including the cost-effectiveness of technology adoption, play a pivotal role demonstrating the positive correlation between economic incentives and technology adoption rates (Gallardo & Sauer, 2018b; Jones-Garcia & Krishna, 2021; Pingali, 2007).

Furthermore, the role of farmer characteristics and perceptions matters in technology adoption. Gallardo and Sauer (2018b) acknowledge the importance of understanding farmers' attitudes, beliefs, and risk preferences in predicting their likelihood of embracing new technologies.

The adoption of labor-saving technologies in agriculture has shown variability across different crops and landscape. For example the adoption and dissemination of machinery aimed at reducing labor have been successful in the case of annual crops such as grains and cotton, a similar trend is not observed in specialty crops like fresh fruits and vegetables (Gallardo & Sauer, 2018b).

Compared to the labor-saving technologies in crops, the dairy farming in in livestock sector has high progress in the substitution of labor which was further elevated by governmental regulations (Gallardo & Sauer, 2018b). According to Jones-Garcia and Krishna (2021) limited access to quality information, small landholding size, and lack of education are identified as major constraints to farmer adoption of sustainable intensification technologies. Pingali (2007) mentioned that mechanical technologies have helped alleviate power bottlenecks in land preparation, harvesting, and threshing operations, leading to increased agricultural productivity and reduced unit cost of crop production in densely populated countries in Asia.

Farmers' limited education and awareness, the modest scale of their farms, and the gender and ethnicity of the household head are identified as barriers preventing the adoption of otherwise advantageous agricultural technologies. The availability of farming-related information emerged as a frequently cited factor, being statistically significant in 64% of the studies. This was closely followed by the size of landholding (55%), the age of the farmer (53%), and their level of education (51%)(Jones-Garcia & Krishna, 2021).

A review carried out by Thuijsman et al. (2022) on the impacts of farming technologies on smallholder livelihood found that that better-off farmers benefit more from agricultural technologies, and they level of affordability also matters a lot in the technology adoption rate.

A study on adoption of power tillers in Bangladesh, was carried out using proportionately stratified random sampling in eight villages across four districts (n=267). It was found that the average growth rate of power tillers from 1993-2003 was 21.0%, with uneven distribution across regions. The study mentioned that credit availability significantly influences power tiller adoption, impacting cropping intensity. The study also argued that socio-political power and farm size were major determinants of acquisition of power tillers in Bangladesh. Other factors like irrigated area, small farm holdings, education level, and income surplus are associated with increased power tiller use. The study suggests credit support for farmers to promote widespread adoption and enhance crop production profitability (Quayum & Ali, 2012).

1.2. Capital replacing labor

In US farm labor has decreased significantly, while machinery use has doubled. Low labor costs historically slowed tractor adoption in US agriculture between 1910 and 1940 (Manuelli & Seshadri, 2014). As countries developed, higher wages led to a shift from labor to capital in agriculture. This shift increased the capital-to-labor ratio in agriculture faster than in other sectors (Herrendorf, Herrington, & Valentinyi, 2015). This shift could result in agriculture becoming more capital-intensive, reducing its share of employment.

Some of the economist debates whether labor was pulled out or pushed into agriculture due to change in the technologies. As per Gylfason and Zoega (2006) capital accumulation in urban areas raised wages and attracted agricultural labor, while technological advancements in agriculture sometimes pushed labor out of the sector. Today, the technologies in agriculture are advancing such as integrating mechanics, electronics, and computer systems that have led to the development of sensors and vision-guided devices, further improving automation and intelligence in agricultural machinery (Edan, Han, & Kondo, 2009).

1.3. Agriculture and technology adoption in Bhutan

Agriculture plays a significant role in Bhutan’s economic contributing approximately 15% to the overall gross domestic product (GDP). Specifically, the crop sub-sector constitutes around 6.81% of the total GDP, making up a substantial 46% of the agricultural GDP (NAS, 2023). Regarding the workforce Agricultural Sector accounted for approximately 43% of the population (NSB, 2022). Therefore, the performance of the economy of Bhutan in terms of output and employment still largely depends on the agricultural sector.

However, agriculture in Bhutan is challenged by many production factors. Labor shortage is one of the major constraints. Agricultural labor demographics are undergoing significant changes with an aging workforce in Bhutan. Younger generations are increasingly moving away from traditional farming jobs, resulting in a shortage of labor in the agricultural sector. For instance, the Population and Housing census of Bhutan 2017 recorded that 21.7% of the total population have migrated from rural areas to urban hubs (NSB, 2017). Further, data estimated by DoA (2022) mentioned that employment in agriculture sector has been declining by 1.4% annually and in 2022 only 43% was employed by agriculture.

Agriculture often requires a surge in labor during specific seasons, such as planting and harvesting. Traditional manual labor may not be readily available during these peak periods, leading to delays in crucial farming activities and potential losses in productivity. Furthermore, labor costs constitute a significant portion of the overall expenses in agriculture. The increasing scarcity of labor, combined with rising wages, is putting financial strain on producers. Implementing labor-saving technologies can enhance economic viability by reducing dependency on manual labor and increasing overall efficiency.

In Bhutan, the transition to mechanization began in 1964, when Japanese expert Dasho Keiji Nishioka introduced modern farming techniques. Farm equipment obtained through Japanese grants was sold to farmers or offered through government hiring services at a subsidized rate of 55-73%. Bhutan received two Kennedy Round (KR) Grant aids for over 25 years starting in 1984, General Grants in 2016 and 2019, and Japanese Non-Project Grant Aids in 2008 and 2010. Through these grants, approximately 3,423 power tillers and 5,078 other machines were acquired (Meghna, Kharka, & Sangay, 2024).

However, low usage of modern agricultural technologies and machines poses a significant challenge to the sector's productivity, commercialization, and competitiveness. Only about 22.5% of the total operational area (RNR Census 2019) is under some kind of farm mechanization while the remaining continues to be farmed under traditional practices. While the total potential area for farm mechanization is not assessed.

According to AMTC (2024), there are currently about 59 various types of farm machinery, including three types of power tillers, 33 types of mini tillers, and five types of combine harvesters certified by AMTC for use in Bhutan (Annexure 1). These machines are sold to farmers by FMCL and private firms within the country. Separate data was requested from the Bhutan Construction and Transport Authority (BCTA) on tractors and power tillers based on registration. Interestingly, the first power tiller (Kubota) in the country was owned by an individual named Namgay Zangmo in 1970, followed by Tshering Dorji in 1988. Similarly, the first ford tractor in the country, also owned by a private individual registered in 1989 (BCTA, 2024). Over the past five decades, it has been observed that the import of power tillers and tractors has steadily increased (Figure 1). Particularly, the import of power tillers saw a drastic increase starting in 2015, with 153 active units, up from 26 in 2014. However, there was a significant drop in numbers in 2019, a trend that was also observed for tractors. This drop in imports in 2019 can be attributed to the COVID-19 pandemic, which disrupted international trade.

As of June 2024, the country has a total of 1,661 active power tillers and 743 active tractors out of 3,945 and 933 registered, respectively. The status of the remaining machines is either cancelled, disposed, exported, or outstanding, according to BCTA records. The active machines are owned and utilized by both individuals and organizations, primarily to support agricultural activities across Bhutan.

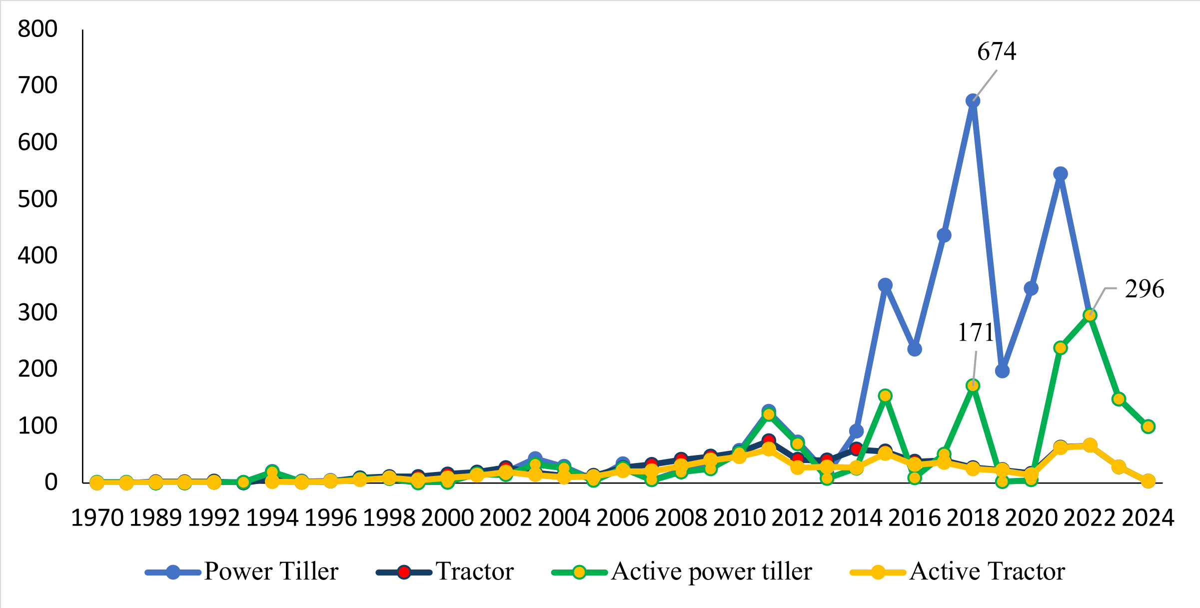


Figure 1: Trend umbers of tractors and power tillers in Bhutan (1970 - June 2024)

Source: BCTA, MOIT (2024)

The allocation of substantial public funds by governments towards agricultural technology research and development highlights its critical importance in streamlining processes and increasing production (Romanelli, Arriola, & Colaco, 2022). Understanding the adoption rates of agricultural technology is important as it directly impacts productivity, sustainability, and food security. By studying these adoption rates, we can gain valuable insights into the effectiveness of technological innovations in enhancing agricultural practices and outcomes (Ong, Rahim, Lim, & Nizat, 2022). Moreover, insights derived from studying technology adoption can inform policy-making processes, enabling governments and stakeholders to formulate targeted interventions, incentives, and support mechanisms. These measures can effectively promote the adoption of beneficial technologies and address barriers hindering their uptake. In doing so, governments can facilitate the integration of technological advancements into agricultural practices, thereby optimizing productivity and enhancing food security.

Despite the numbers of agriculture technologies that were made released in the field, there remains a gap in comprehensive studies on the adoption rates in Bhutan. To address this gap, the department through the Asian Food and Agriculture Cooperatives Initiative projects has initiated to assess the current state of technology adoption in Bhutan's agricultural sector, identify factors influencing adoption rates, particularly focusing on the labor-saving technologies (Table 2). These valuable insights can be garnered to inform future agricultural development strategies and initiatives in Bhutan.

1.4. Objectives

The objectives of the study are:

- Assessing the types and numbers of labor-technologies adopted by the farmers by five districts.
- Determining the factors influencing technology adoption among the five districts.

Table 2: Lists of technologies included for survey

#	Type of technology	Technology
1.	Labour-saving technologies	1. Power tiller 2. Tractor 3. Mini tiller 4. Thrashers 5. Hullers 6. Grass cutters 7. Rice millers
1	Protected cultivation Technologies	1. Greenhouse 2. Rain shelters
3	Plant Protection Technologies	1. Traps (pheromone, sticky and others) 2. Plastic mulch 3. Sprayers 4. Super grain bag
4	Organic Agriculture technologies	1. Composting 2. Fertilizer 3. Bio digester 4. Vermin compost 5. Sprinklers
5	Other technologies	1. Drip irrigation facility 2. Rainwater harvesting technology 3. Bhur Kambja1 (paddy varieties)

***Note**: The survey has collected data on major agricultural technologies; however, this analysis focuses on labor-saving technologies. Summary statistics for the other technologies are annexed at the end of this paper for interested individuals. The analysis of the remaining technologies will be published separately.*

2. Methodology

2.1. Study Sites

The research study covers five districts, that include 51 blocks (Figure 2) and further subdivided into 259 units called chiwogs. These districts are technically within the purview of the Agriculture Research and Development Centre, Samtenling, focusing on the transfer of agricultural technologies and outreach programs. They collaborate with District and Geog Agriculture offices to disseminate agricultural technologies in farmers' fields.

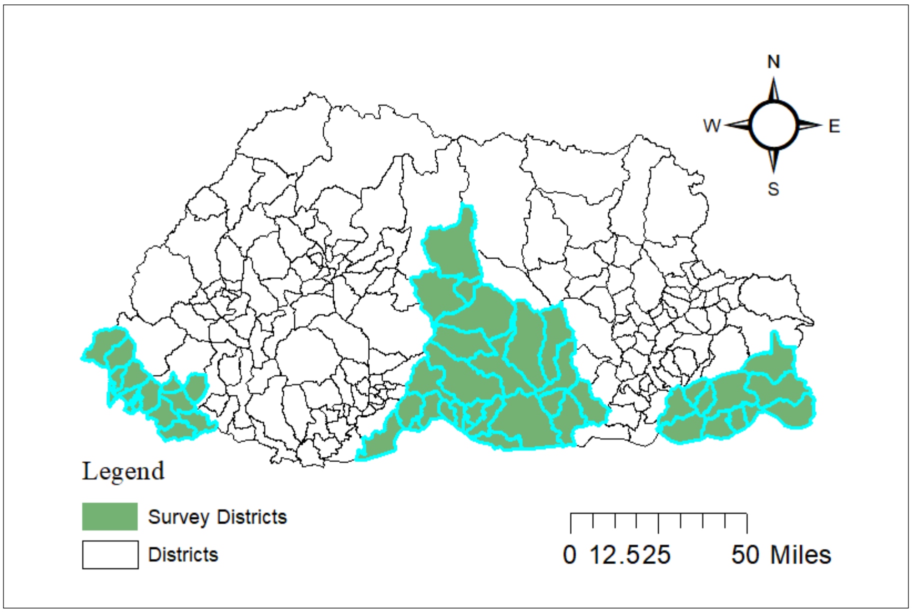


Figure 2: Survey districts included for data collection.

2.2. Study Population and Sample Selection

2.2.1. Sample and Data

The data collection was done in May and June 2024 covering 1340 households in five districts. The household's lists of the five districts were referred from the agricultural census 2022 of the National Statistical Bureau, Bhutan. The multistage sampling method was used to choose the respondents. The first sampling units consist of Primary Sampling Units (PSU) which comprise the 259 precincts (Chiwogs), while the Secondary Sampling Units (SSU) comprise the households (20,792). Proportional simple random sampling (PSRS) was used during both stages of sample drawing. The study used 50% sample intensity to derive the 130 PSU from 259 chiwogs. The final lists of 1340 (10% sampling intensity) households were selected for interview based on random proportional sampling.

To secure data quality during data collection, Kobo toolbox, an online free software was used. The questionnaire covered 5 sections that were related to household characteristics, land endowment, crop production, technology adoption rates and determinants of technology adoptions. Farmers were asked questions regarding decision-making in a household that makes crucial decisions in adopting the technologies. The major questions were focused on the use of agricultural technology, factors that affect adoptions.

The survey used both structured and semi-structured questionnaires for data collection. The approach also includes of the protection of participant privacy and the security of collected data.

The survey was conducted by the agriculture researchers of ARDC-Samtenling. The journey of this study that includes preparation of questionnaires, consultation with stakeholders, training of enumerators, mock sessions of the questionnaires, data collection, and processing to analysis were given in annexture 3.

2.3. Data Analysis

Data were analysed using MS 365, Stata and R programme. Both descriptive statistics and inferential analysis were done. Descriptive statistics includes frequency distribution, means, and percentages. Inferential analysis includes probit regression analysis and t-test. Probit regression analysis was performed to determine the influence of socio-demographic variables (Table 2) on the adoption of technologies. The findings from this survey were triangulated with the administrivia data for the validity and credibility.

In the probit model, the outcome (dependent) variable is a status of technology adoption y_i which equals to one if farm i uses the technology and zero otherwise. Our aim is to estimate the impacts of various household characteristics on technology adoption y_i. The household characteristics, compactly written as a vector $\mathbf{x}_i$, include age, education, farm size, altitude, and so on. See Table 2 for the detail. The probit model assumes $y_i = 1$ if $\mathbf{x}_i\boldsymbol{\beta} + u_i > 0$ and 0 otherwise. Here, $\boldsymbol{\beta}$ is parameters of interest and u_i is an error term following standard normal distribution. If an estimated parameter is positive (negative), that means the larger value of the variable increases (decreases) the probability of the adoption.

Table 2: Variables used for the probit analysis

	unit	mean	sd	min	max
Dependent variable (y)					
Power tiller	Yes = 1, No = 0	0.219	0.414	0	1
Mini tiller	Yes = 1, No = 0	0.075	0.264	0	1
Tractor	Yes = 1, No = 0	0.106	0.308	0	1
Thresher	Yes = 1, No = 0	0.039	0.195	0	1
Huller	Yes = 1, No = 0	0.104	0.306	0	1
Grass cutter	Yes = 1, No = 0	0.294	0.456	0	1
Rice miller	Yes = 1, No = 0	0.250	0.433	0	1
Independent variables (x)					
Cultivated area (owned + leased – fallow. The sum of wetland, dryland and orchard)	acre	3.216	3.947	0	81.5

Altitude	Meter	856.8	516.2	68.6	2642
Actual no. of family member working on farm		2.408	1.185	0	9
Share of literate family labor	share (0-1)	0.474	0.660	0	7
No. of season road is unusable		0.224	0.417	0	1
Wage rate	BTN/day	426.5	138.6	0	1000
Decision maker is head of family	Yes = 1, No = 0	0.784	0.412	0	1
Decision maker is male	Yes = 1, No = 0	0.567	0.496	0	1
Education of decision maker: Primary or Monk	Yes = 1, No = 0	0.184	0.388	0	1
Education of decision maker: Secondary or higher	Yes = 1, No = 0	0.060	0.238	0	1
Decision maker uses the smart phone	Yes = 1, No = 0	0.602	0.490	0	1
Decision maker is 40s	Yes = 1, No = 0	0.206	0.404	0	1
Decision maker is 50s	Yes = 1, No = 0	0.187	0.390	0	1
Decision maker is 60s	Yes = 1, No = 0	0.167	0.373	0	1
Decision maker is > 70	Yes = 1, No = 0	0.100	0.300	0	1

3. Results and Discussions

3.1. Demographic information and socio-economics features

The descriptive analysis shown that the survey coverage was 85% of the targeted sample size 1340 households and the non-response rate was very negligible. Among the five districts, Samtse had the highest participation rate at 36.6% of respondents, followed by Sarpang at 24%, Samdrup Jongkhar at 22.1%, Zhemgang at 9.9%, and Trongsa at 7.4% (Table 3). The proportional sampling strategy allocated more participants to districts with larger numbers of households.

Regarding age distribution, the majority (84.6%) of respondents were aged 19-64, with 15.3% in the over 65 age group and only 0.1% below 18 years old. In terms of gender, 58.9% of respondents were male, and 41.1% were female.

In educational qualifications, 61.3% had not studied, contrasting sharply with the 1% who had university-level education. Most families (94.9%) had 1-4 members working on the farm, with 4.4% having 5-8 members. Regarding literacy, 58.2% of families had 1-4 members who could read or write, while 40% had none, and 1.8% had 5-8 literate members. It is interesting to note that there is not much difference in term of gender respondents, where about 59% are male and the rest, 41 are female respondents.

Decision-making on technology adoption was primarily led by the head of the family (78.4%), which are true in Bhutanese culture. The family consensus influences 20.8% of cases, and a minimal 0.8% allowing anyone to decide.

Table 3: Distribution of sample size among 5 districts and socio-economic characteristics of the household

Variable		No. of HHs	Proportions (%)
Dzongkhag	S/jongkhar	252	22.1
	Samtse	418	36.6
	Sarpang	274	24.0
	Trongsa	85	7.4
	Zhemgang	113	9.9
Total		1142	100
Age	<18	1	0.1
	19-64	966	84.6
	>65	175	15.3
Gender	Male	673	58.9
	Female	469	41.1

Qualification	Not studied	700	61.3
	Nonformal-Primary Level	250	21.9
	High School - Higher Secondary	151	13.2
	University Level	11	1.0
	Lay Monk	30	2.6
Family member working on farm?	0	6	0.5
	1-4	1084	94.9
	5-8	50	4.4
	Above 8	2	0.2
How many of them can read or write?	0	457	40
	1-4	665	58
	5-8	20	1.8
	above 8	0	0.0
Who takes decision on tech adoption?	Head of the Family	895	78
	Family consensus	238	20.8
	Anyone	9	0.8

3.2. Regression Analysis

3.2.1. Influence of households' characteristics and adoption of labor-saving technologies.

The estimation results of probit model (Table 4) suggest that the adoption of labor-saving technologies is influenced especially by farm size, knowledge, and neighbors.

First, cultivated area (land size) significantly increase the likelihood of adopting all types of labor-saving technologies ($p<0.001$). This could be true because large scale farming can spread the cost of expensive technologies and make per-unit costs lower. These farmers can afford high-capital investments like tractors, or advanced farm machineries. In the literature, Ruzzante, Labarta, and Bilton (2021) found that land size, and land tenure positively correlate with the adoption of many agricultural technologies.

Knowledge also matters. We divide education into three categories: "Primary or Monk", "Secondary or higher", and the rest (i.e., no formal education). Compared to no formal education, farmers with "primary or monk" or "secondary or higher" educations are more likely to adopt technologies. Higher literacy among family labor also significantly favors the adoption of power tillers, tractors, grass cutters, and rice millers. Similar findings were reported by

Quayum and Ali (2012), Chang and Tsai (2015) and Zhou, Herzfeld, Glauben, Zhang, and Hu (2008). Usage of smart phone also positively affects the adoption of some technologies. Overall, these results suggest that knowledge is an important driver of technology adoption.

Lastly, technology adoption is strongly influenced by neighboring farmers. For example, if the outcome variable is power tiller usage, the variable "Share of farmers who uses same machines in the gewog" shows the share of farms using power tillers in the same gewog. The share of farmers using power tillers in a gewog has a coefficient of 3.82, with a highly significant z-statistic of 12.44, indicating a strong positive relationship with adoption rates. The trend and significance level are similar for all the technologies studied, including mini tillers, tractors, threshers, hullers, grass cutters, and rice millers. These results can be explained by the influence of social networks and peer learning. Research indicates that farmers are more likely to adopt new technologies if they observe their peers using them successfully (Nyambo, Luhanga, Yonah, Mujibi, & Clemen, 2022; Zhou et al., 2008). The positive relationships may reflect better accessibility (hiring) of machines in gewogs with higher user rates. Understanding these factors is crucial for designing effective interventions to promote the widespread and equitable adoption of technologies to boost production.

Apart from farm size, knowledge, and neighbors, other variables show insignificant or mixed effects for most cases. For instance, we hypothesized that age would negatively affect technology adoption. However, this is not the case in our study. We found that elderly farmers are not necessarily reluctant to adopt new technologies compared to young farmers. Probably, these results reflect severe labor shortage in Bhutan, which encourages all generations to adopt labor saving technologies.

Table 4: Probit analysis on HH characteristics and adoption patterns.

	Power tiller	Mini tiller	Tractor	Thresher	Huller	Grass cutter	Rice miller
Cultivated area (log)	0.259	0.210	0.142	0.175	0.378	0.313	0.373
	[4.16]***	[2.74]***	[1.71]*	[1.98]**	[4.41]***	[5.53]***	[5.88]***
Education of decision maker (no formal education = 0							
Primary or Monk	0.259	0.312	0.538	0.648	-0.088	0.400	0.154
	[1.72]*	[1.81]*	[2.54]**	[2.96]***	[-0.43]	[3.14]***	[1.09]
Secondary or higher	0.653	0.013	0.283	0.343	0.240	0.775	0.117
	[3.01]***	[0.04]	[0.90]	[1.11]	[0.88]	[3.93]***	[0.53]
	0.168	0.094	0.203	0.025	-0.024	0.142	0.171

Share of literate family labor	[2.09]**	[1.06]	[2.21]**	[0.28]	[-0.15]	[1.94]*	[2.23]**
Decision maker uses the smart phone	-0.072	0.268	0.503	-0.103	-0.024	0.323	0.148
	[-0.44]	[1.30]	[2.02]**	[-0.45]	[-0.12]	[2.23]**	[1.05]
Share of farms who use the technology in the same gewog	3.82	5.63	4.03	7.21	5.96	3.34	4.08
	[12.44]***	[8.59]***	[9.25]***	[6.51]***	[10.49]***	[10.89]***	[13.79]***
Age of decision maker (< 30s = 0)							
Decision maker is 40s	0.132	-0.066	-0.098	-0.339	0.355	0.067	0.286
	[0.71]	[-0.28]	[-0.31]	[-1.06]	[1.72]*	[0.40]	[1.50]
Decision maker is 50s	0.0911	0.145	-0.317	0.113	0.219	0.233	0.292
	[0.46]	[0.61]	[-0.95]	[0.39]	[0.95]	[1.36]	[1.52]
Decision maker is 60s	0.054	0.112	0.131	-0.317	0.008	0.226	0.178
	[0.26]	[0.45]	[0.39]	[-1.01]	[0.03]	[1.24]	[0.88]
Decision maker is > 70	-0.087	0.433	0.702	0.295	-0.121	0.177	0.421
	[-0.35]	[1.52]	[1.82]*	[1.03]	[-0.41]	[0.84]	[1.83]*
Altitude	2.1E-05	4.2E-05	-7.4E-04	-1.0E-04	1.4E-04	4.7E-06	-1.9E-04
	[0.15]	[0.26]	[-2.10]**	[-0.45]	[0.81]	[0.04]	[-1.47]
Actual no. of family member working on farm	-0.036	-0.012	0.097	-0.105	-0.038	0.057	-0.025
	[-0.80]	[-0.23]	[1.87]*	[-1.75]*	[-0.69]	[1.49]	[-0.59]
	0.144	-0.359	-0.248	-0.026	-0.399	-0.039	0.389

No. of season road is unusable	[1.04]	[-1.85]*	[-1.02]	[-0.12]	[-1.87]*	[-0.33]	[3.11]***
Wage rate (BTN/day)	0.0011	0.0000	0.0013	0.0012	-0.0001	0.0001	-0.0010
	[2.14]**	[0.08]	[1.62]	[1.51]	[-0.18]	[0.34]	[-2.09]**
Decision maker is head of family	0.002	-0.738	-0.548	-0.567	0.161	-0.622	-0.369
	[0.01]	[-2.32]**	[-1.34]	[-1.47]	[0.47]	[-2.63]***	[-1.43]
Decision maker is male	-0.226	0.197	-0.007	0.585	-0.253	-0.157	-0.049
	[-1.66]*	[1.12]	[-0.03]	[2.17]**	[-1.41]	[-1.33]	[-0.37]
Observations	1122	1122	1037	1122	1122	1122	1122

Significant results are shown in bold. z-statistics computed from robust standard errors in brackets. *** p<0.01, ** p<0.05, * p<0.1. The model includes the constant and Dzongkhags dummies.

3.3. Adoption rate of power tiller, mini-tiller and tractors technologies among the districts

The trend analysis shows that power tillers and mini tillers have seen substantial growth in adoption over the years, with power tillers peaking between 2016 and 2020 before declining slightly (Figure 3). Tractors, after a steady increase, have recently seen a significant drop in adoption, while mini tillers are currently on an upward trajectory.

From 1990 to 1995, the adoption of all three types of machinery was just one or non-existent. In the subsequent period from 1996 to 2000, there was a slight increase. A significant surge occurred between 2011 and 2015, where power tiller adoption jumped to 38, tractors remained stable at 22, and mini tillers saw a minimal increase to 2. This upward trend continued into 2016-2020, with power tillers reaching a peak of 105 adopters in five districts. Tractor adoption also increased to 57, while mini tillers saw a considerable rise to 15. These findings are in line with the registration data maintained by BCTA under Ministry of Infrastructure and Transport. These increase in the adoption rate can be attributed to several reasons such as introduction of government policies and subsidies and project incentives to encourage farm mechanisation in the country. The details analysis on the factors revealed by the adopter will be discussed in later in this section.

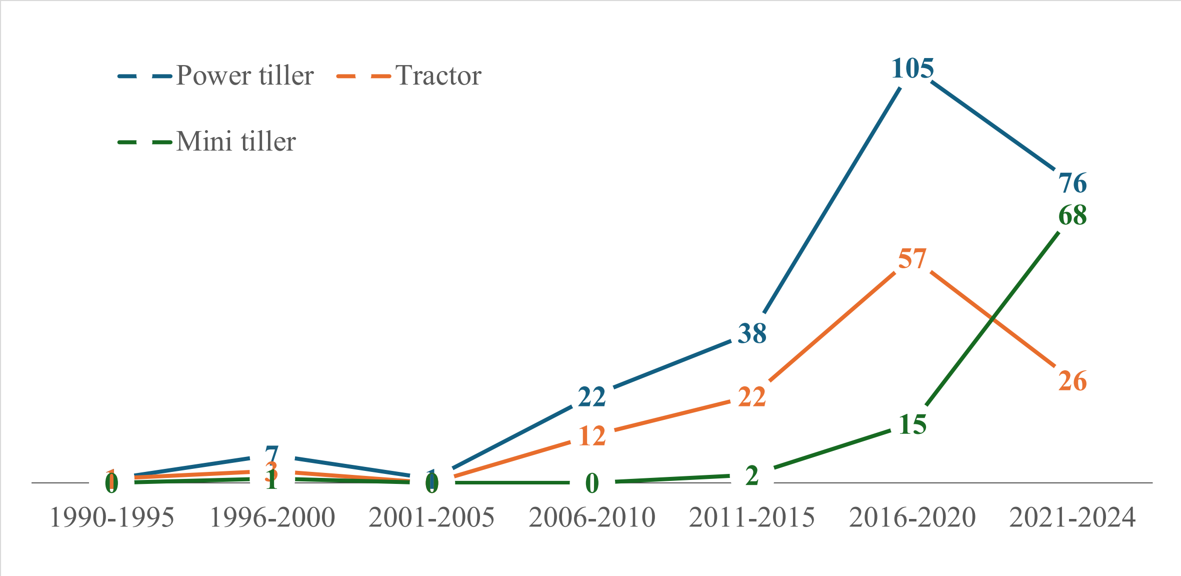


Figure 3. Trend of power tiller, tractor and mini tiller adoption rate over the 34 years

The survey data on adoption across five Dzongkhags - Samdrup Jongkhar, Samtse, Sarpang, Trongsa, and Zhemgang reveals variations in adoption rates. Overall, about 33% of the farmers in these districts reported using power tillers, which is the highest compared to tractors (10%) and mini tiller technologies (8%) (Table 6). In terms of the proportion of power tiller adoption, Trongsa district has the highest users (76.5%) compared to the lowest, Samtse district.

The interesting things is that Trongsa farmers do not use tractors at all, and this could be true since the data shows that majority of the farmers use power tillers and mini tillers as the landscape in Trongsa area may not favors utilization of tractor. As per the records Trongsa is located from 1203 to 2642m asl and the agriculture land are mostly sloppy making tractor less feasible in the areas. Interestingly, Sarpang farmers, among all the districts, use all three machines, with the maximum being tractors (28.5%), followed by power tillers (20.85%) and mini tillers (15.3%).

On the contrary, the Samtse district, which has a similar landscape to Sarpang, has the lowest usage of the three machines. The main reason that farmers mentioned was that the machines are expensive, and they could not afford to buy them. Additionally, respondents mentioned that most of the agricultural land is stony, and draught animals are still preferred by the people.

In general, the usage of power tillers is the highest because it might be determined by the land feasibility and the size of the land that the majority of Bhutanese own. The factors for adoption will be discussed in the latter part of the section below. However, the point here is that most of the farm size owned by farmers is about 23 acres per household, and power tiller machines best fit, except for a few large plain agricultural areas and sloped areas too.

Table 6. Adoption rate of power tiller, mini tiller and tractor by household in 5 districts (n = 1142)

Dzongkhag	Observation (nos.)	Adoption rate Power tiller (%)	Mini tiller (%)	Tractor (%)
Samdrup Jongkhar	252	23.4	3.57	13.9
Samtse	418	6.5	3.83	1.0
Sarpang	274	20.8	15.33	28.5
Trongsa	85	76.5	9.41	0.0
Zhemgang	113	37.2	9.73	3.5
Average		33%	8%	10%

3.4. Source of Power Tillers, Mini Tillers, and Tractors: Self-Owned or Hired

The farmers who use the above three farm machines were asked on the source of technologies, who either own the machinery themselves or hire it. The analysis shows that in Samdrup Jongkhar, 40% of respondents own power tillers while 67% hire them from a 59 HH users (Table 7). For mini tillers, 44% are self-owned and 56% are hired. Tractors are predominantly hired, with 94.3% hiring and only 5.7% owning them.

While the pattern is same in every district with majority hiring the services. When comparing the three types of machines, it is evident that power tillers and tractors are more commonly hired than self-owned across most districts. Mini tillers, however, show a higher rate of self-ownership in several districts, particularly in Samtse and Trongsa. The data reveals a general preference for hiring machinery rather than owning it. This signifies that the share of power tiller in the community has positive spillover effect on the adoption rates of the neighboring farmers.

Table 7. Source of farm machines for uses

Dzongkhag	Power tiller (%)		Mini tiller (%)		Tractor (%)	
	Self-own	Hiring	Self-own	Hiring	Self-own	Hiring
Samdrup Jongkhar	40	67	44	56	5.7	94.3
Samtse	26	74	63	38	75	25.0
Sarpang	23	77	52	48	1.3	98.7
Trongsa	17	83	63	38	0	0.0
Zhemgang	21	79	64	36	0	100

3.5. Determinant of the power tiller adoption revealed by adopters

Among the three machines, the power tiller is the most used in Bhutan and has the highest import records (2,985 nos.) by private individuals from 1970 to June 2, 2024 (BCTA, 2024). Furthermore, survey data shows its highest adoption rates (33%) in the five districts studied. A detailed analysis found that the main factor influencing the adoption rate is the reduction of drudgery, accounting for 65% of the responses, which is the highest frequency reported by participants (Table 8). A similar study by Basavaraju et al. (2019) found that mechanization has drastically reduced the load on various farming operations by 40 to 64.3%. This trend is consistent across all respondents in the five districts. The finding is relevant to the Bhutanese context. According to the Cost of Production (2023) report published by the Department of Agriculture is labor-intensive. For instance, paddy crop production requires about 78 person-days per acre, one of the highest labor requirements in the region. Therefore, labor-capital substitutions are crucial and could be the main reasons for adoption.

Affordability and income generation were also significant factors, influencing 14% and 13% of adopters, respectively. Both government incentives and peer influence were less influential, each accounting for 4% of the responses. This data indicates that government incentives and peer influence have a relatively minor impact on the adoption decision.

Table 8: Factors influencing adoption rate of power tiller.

Dzongkhag	No. of adopter	Government incentives	Peer Influence	Income generation	Affordable	Reduce drudgery
S/Jongkhar	59	4 (5%)	5 (6%)	12 (14%)	10 (12%)	55 (64%)
Samtse	27	0 (0%)	1 (3%)	6 (16%)	8 (22%)	22 (59%)
Sarpang	57	4 (5%)	4 (5%)	8 (10%)	9 (11%)	55 (69%)
Trongsa	65	5 (6%)	2 (2%)	7 (8%)	13 (14%)	63 (70%)
Zhemgang	42	2 (3%)	3 (5%)	11 (17%)	8 (12%)	41 (63%)
Total	250	15 (4%)	15 (4%)	44 (13%)	48 (14%)	236 (65%)

3.6. Factors that hinder the adoption rate of the power tiller

Regarding the non-adopters of the power tiller in the five districts, the main reason cited for not adopting power tillers was their cost, consistent across all districts. Accessibility and feasibility were also concerns, while awareness and perceived efficiency of the technology were more district-specific issues. The number of non-adopters varied, with Samtse having the highest and Zhemgang the lowest (Figure 4).

The factors influencing the adoption and non-adoption of mini tillers and tractors are like those for power tillers. A summary of the analysis is annexed at the end.

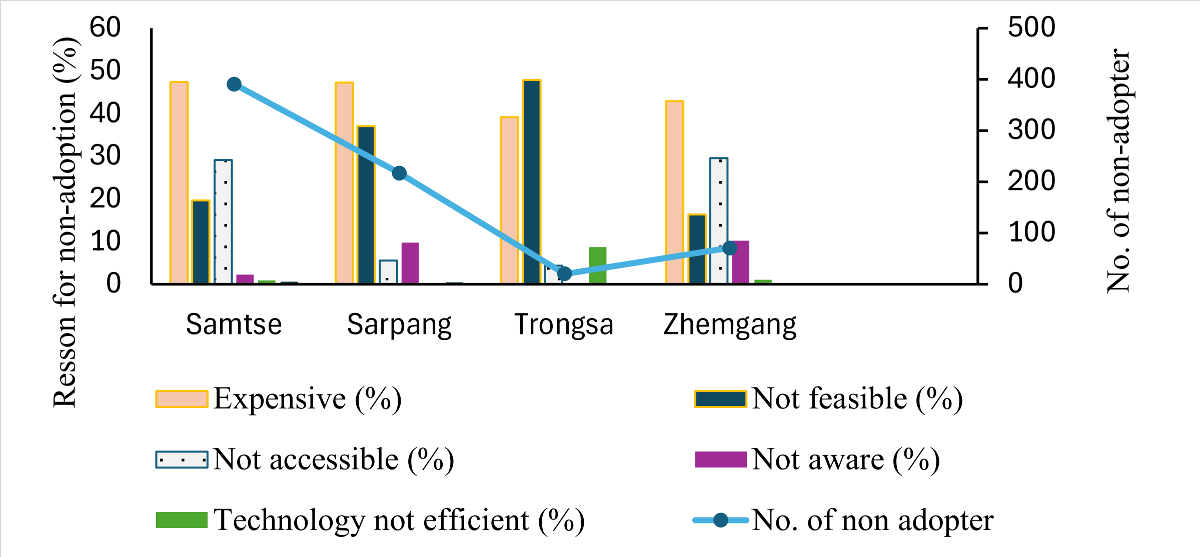


Figure 4: Reasons for not adopting power tiller (n = 892)

4. Conclusions and recommendations

The study aimed to understand the adoption patterns of labor-saving technologies among households in five districts of Bhutan, focusing on power tillers, mini tillers, and tractors. The survey covered 85% of the targeted sample size with negligible non-response. Most respondents were aged 19-64, with a balanced gender representation. Educational levels were generally low, with most respondents having no formal education. Adoption Rates and Trends: Power tillers had the highest adoption rate (33%) compared to mini tillers (8%) and tractors (10%). The adoption of power tillers and mini tillers has grown substantially over the years, while tractor adoption has recently declined. The probit model analysis revealed that larger farm size, higher education levels, and the influence of neighboring farmers significantly increase the likelihood of adopting labor-saving technologies. Knowledge, particularly higher literacy among family members, also played a crucial role. Reduction of drudgery was the primary revealed factor that influenced power tiller adoption, followed by affordability and income generation. Government incentives and peer influence were less significant. The main barriers to adopting power tillers were their cost and accessibility, particularly for smaller and less financially stable households.

Based on the findings, the following policy recommendations are proposed to enhance the adoption of labor-saving technologies in these five distircts, Samdrup Jongkhar, Samtse, Sarpang, Trongsa and Zhemang, Bhutan:

1. Subsidies and Financial Support: Introduce targeted subsidies and financial support programs to reduce the cost burden on small and medium-sized farmers. This could include low-interest loans or instalment payment plans for purchasing machinery.
2. Hiring Services and Cooperatives: Enhance and support establishment of machinery hiring services and cooperatives. This would allow farmers to access expensive machinery without the need for full ownership, spreading the costs and benefits across multiple users.
3. Training and Awareness Programs: Implement training and awareness programs to educate farmers about the benefits and usage of labor-saving technologies. Focus on improving literacy and technical knowledge to enhance the adoption rates.
4. Infrastructure Improvement: Improve rural infrastructure, such as roads and transportation networks, to facilitate easier access to machinery and spare parts, particularly in remote and hilly areas.
5. Peer Learning and Demonstration Projects: Leverage the influence of neighboring farmers by organizing demonstration projects and peer learning sessions. Seeing successful technology use in nearby farms can encourage more farmers to adopt similar practices.

The current study focused on the adoption rates of labor-saving technologies per household. However, to dive deeper into the efficiency of these machines, future studies may focus on the adoption rate per acre and understand the percentage of total agricultural land that is potential for mechanization. This will help in setting policy interventions for farm mechanization.

6. Annexures

Annexure 1: Type and Model of certified machines available in Bhutan

SN	Machine Type	Model
1	Yanmar Power Tiller	YZC-D
2	Vikyno Power Tiller	MK-120
3	Mitsubishi Mini-Tiller	MM658AS
4	Mubota Mini Tiller	M-80
5		KDT-610 CE
6		SHRACHI-6D3
7		SHRACHI-8D6
8		ARO PRO 55PC3
9		STIHL, MH710
10		PUBERT MAESTRO 55P
11		HUSQVARNA TF545D
12		HUSQVARNA TF230
13		Lilli 832TG
14		Alligator 9DP
15		BCS GRATIA- 100BH
16		BCS GRATIA- MC 730
17		G-105FQSD-A
18		AGROPOWER SHB 105-Z
19		AGROPOWER SHB 135-Z
20		MAESTRO PRO 70P
21	Mini Tiller	MAESTRO PRO 65LD
22		171FQ
23		135FC
24		RT65
25		FT550
26		FT750
27		XPW1150 D Plus GOLD
28		XPW750 PTO Gold
29		E)
30		FWMT250D
31		FWMT310D
32		FWMT210P
33		YKT140D
34		YKT110G
35		YKT110D
36		TX701TG- Direct shafting
37		TX701TG- Belt driven

38		YAP 120
39		BR120-T
40	Yanmar Power Reaper	VST 5PR
41	Portable Power Harvester	FR3900
42		P520BG
43		532RBS
44		542RBS
45	Brush Cutter	B-R436
46	Mini Oil Expeller	DK-119
47	Rice Mill	6N-40
48	Rice Mill	ZLN-4
49	Grain/Rice Mill	CM-1-1B
50	Flour Mill	FM 1.5
51	Grain/flour Mill	XP-CRMF
52	Single rice mill	XP-CRMF
53	Rice Mill	6N2018X
54	Rice Mill	SN-250R
55		6N2018-9FC21G
56		6N2020-9FC21A
57	Combine Rice Mill	6N90-F26
58		6NJ40-F26
59		XP-CRMF

Annexure 2: Survey Questionnaires

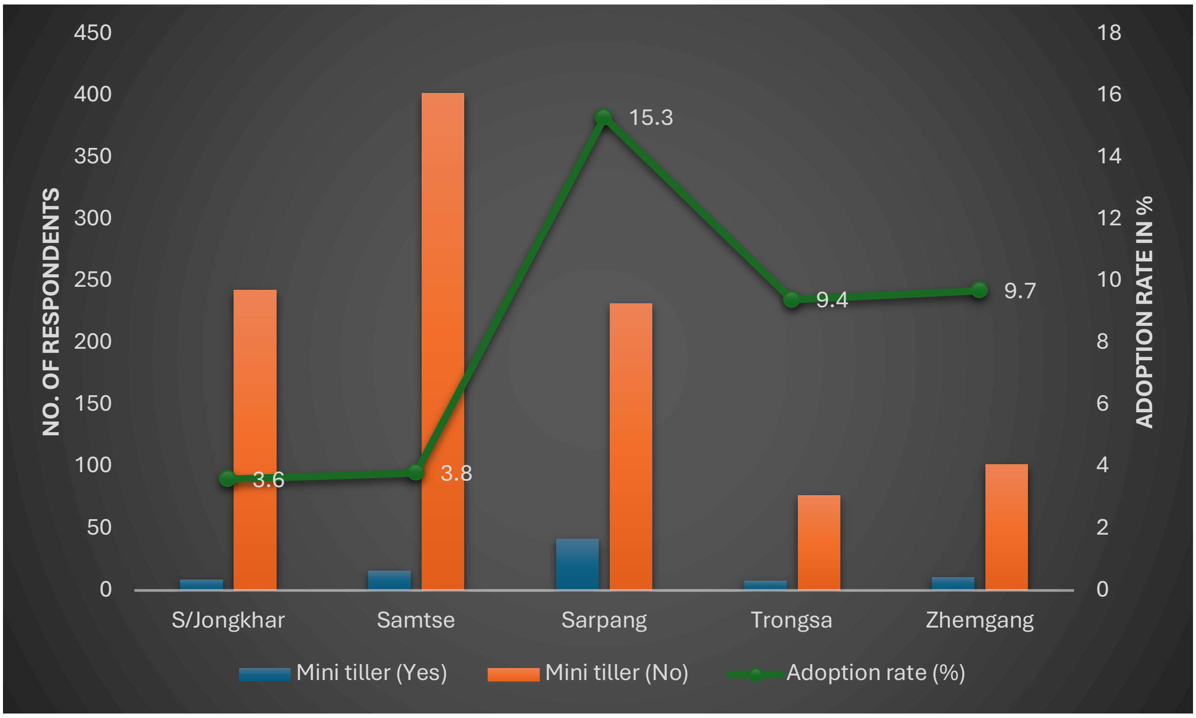
Annexure 3: Work Plan and Timeline

Activities	No. of days	Start date	End date	Actual Days
Development of questionnaires	30	01-03-2024	12-04-2024	42
1st Virtual meeting with ARDC team	1	01-04-2024	02-04-2024	1
Training of enumerators and technical discussion	2	08-04-2024	09-04-2024	2
Data collection	30	15-04-2024	27-05-2024	42
Data cleaning and validation	5	27-05-2024	03-06-2024	7
Write shop	7	03-06-2024	12-06-2024	9
Finalization of the write up (Proofing)	2	12-06-2024	14-06-2024	2
Publication	1	15-06-2024	17-06-2024	2

Annexure 4: Power tiller adoption rate in five districts (n = 1142)

Dzongkhag	Power Tiller (yes/no)		Adoption	Source (self-own/hiring)	
	Yes	No	%	self-own	hiring
Samdrup Jongkhar	59	193	23.4	19 (40%)	40 (67%)
Samtse	27	391	6.5	7 (26%)	20 (74%)
Sarpang	57	217	20.8	13 (23%)	44 (77%)
Trongsa	65	20	76.5	11 (17%)	54 (83%)
Zhemgang	42	71	37.2	9 (21%)	33 (79%)
Total	250	892	22%	59 (24%)	191 (76%)

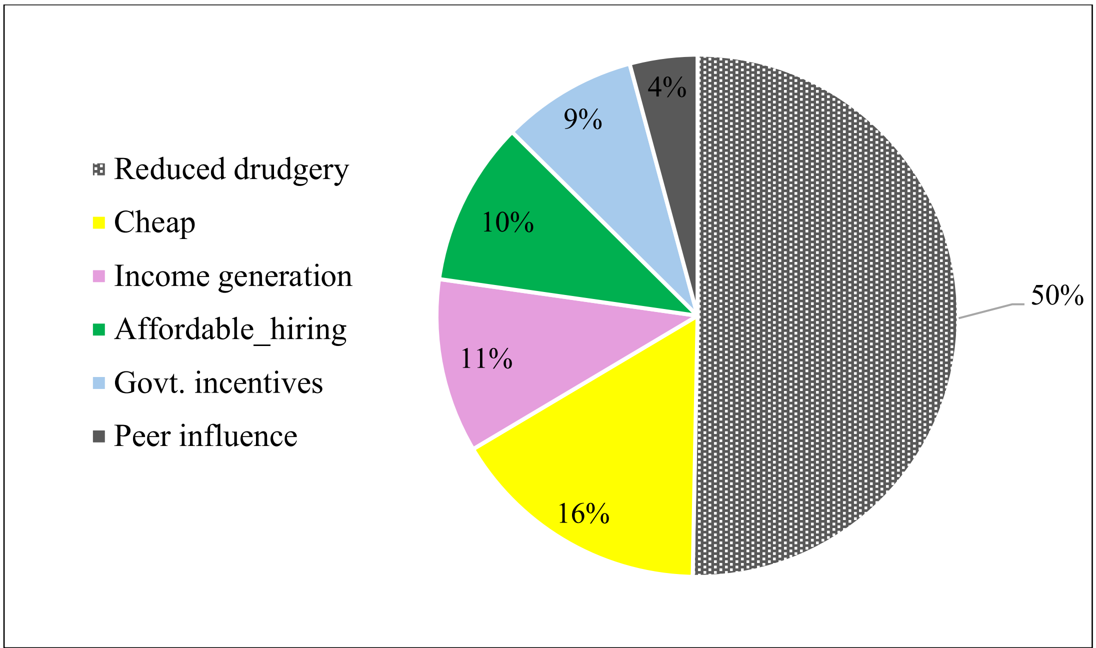
Annexure 5: Adoption rate of mini tiller in five districts



Annexure 6: Source of mini tiller for adopter

Dzongkhag	Source (self-own/hiring)		
	Yes	self-own	hiring
Samdrup Jongkhar	9	4 (44%)	5 (56%)
Samtse	16	10 (63%)	6 (38%)
Sarpang	42	22 (52%)	20 (48%)
Trongsa	8	5 (63%)	3 38%)
Zhemgang	11	7 (64%)	4 (36%)
Total	86	48 (57%)	38 (43%)

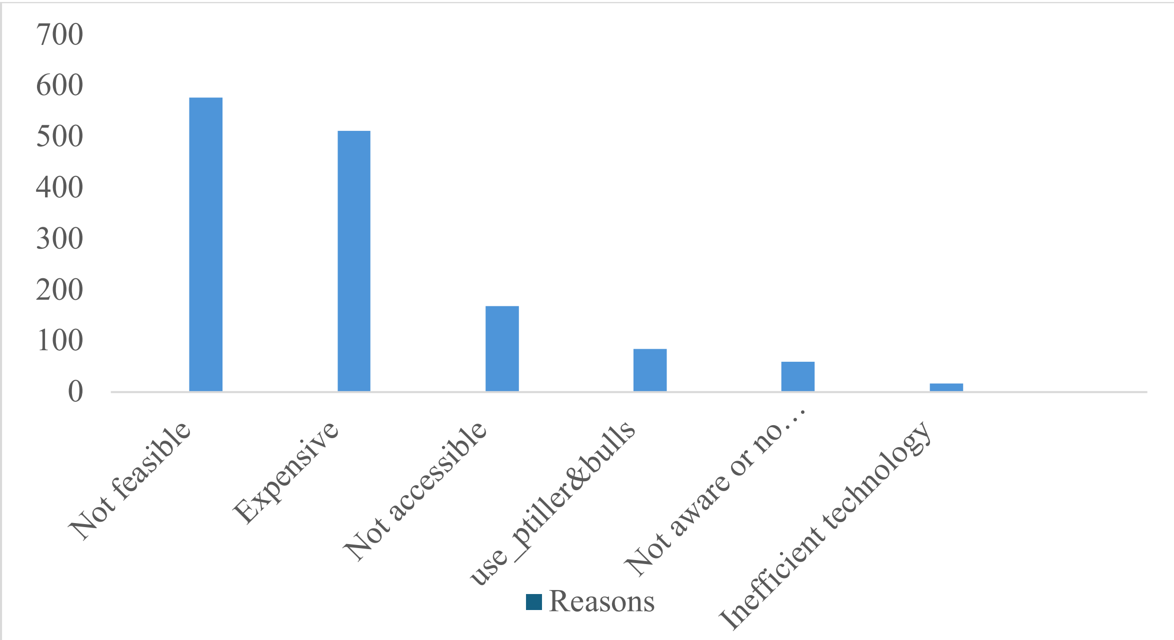
Annexure 6: Determinants of mini tiller adoption rate



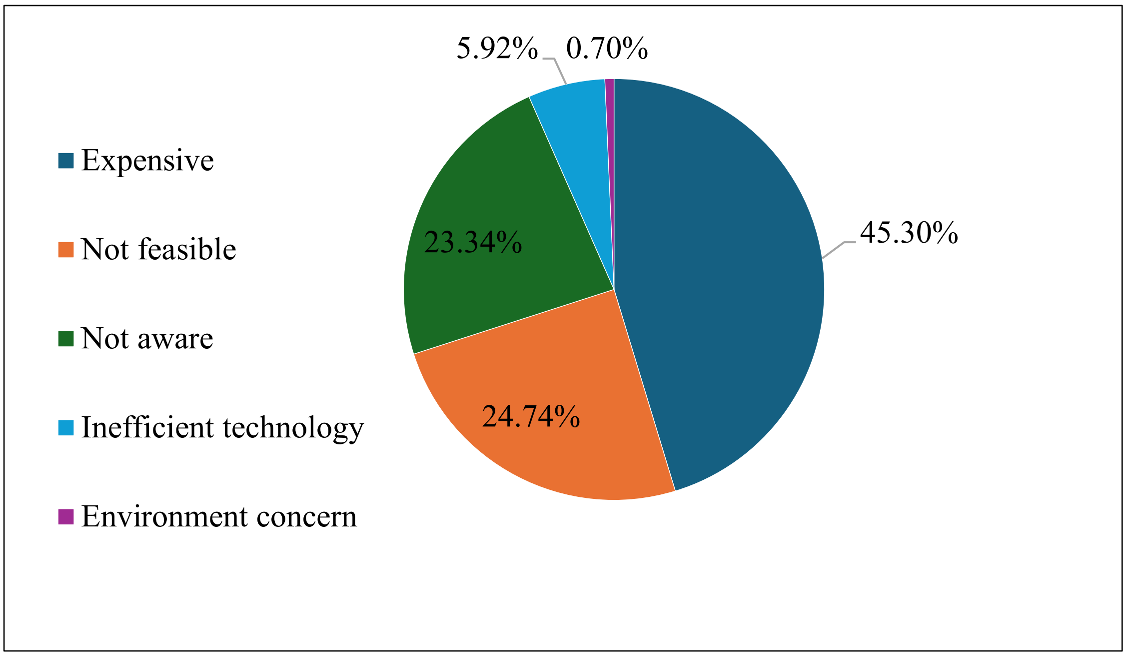
Annexure 7: Adoption rate of tractor

Dzongkhag	Adoption rate (%)	Hiring (%)	Self-own (%)
Samdrup Jongkhar	13.9	94.3	5.7
Samtse	1.0	25.0	75
Sarpang	28.5	98.7	1.3
Trongsa	0.0	0.0	0
Zhemgang	3.5	100.0	0

Annexure 8: Reasons for not using tractors



Annexure 9: Reasons for not adopting the mini tiller.



5. References

AMTC. (2024). Certified Farm Machinery Lists. In. Paro: Agriculture Machinery and Technology Centre.

BCTA. (2024). *Farm Machines Registration System*. Retrieved from: https://bcta.gov.bt/bctaweb/

Chang, S. C., & Tsai, C.-H. (2015). The adoption of new technology by the farmers in Taiwan. *Applied Economics, 47*(36), 3817-3824.

DoA. (2022). *Strategy on rice self-sufficiency and incentivization of rice production in Bhutan for its perpetuity*. Retrieved from Thimphu:

Edan, Y., Han, S., & Kondo, N. (2009). Automation in agriculture. *Springer handbook of automation*, 1095-1128.

Gallardo, R. K., & Sauer, J. (2018a). Adoption of labor-saving technologies in agriculture. *Annual Review of Resource Economics, 10*(1), 185-206.

Gallardo, R. K., & Sauer, J. (2018b). Adoption of labor-saving technologies in agriculture. *Annual Review of Resource Economics, 10*, 185-206.

Gylfason, T., & Zoega, G. (2006). The road from agriculture.

Heinicke, C., & Grove, W. (2001). Technological Unemployment in Agriculture: Cotton Harvest Mechanization in the U. S. In.

Herrendorf, B., Herrington, C., & Valentinyi, A. (2015). Sectoral technology and structural transformation. *American Economic Journal: Macroeconomics, 7*(4), 104-133.

Jones-Garcia, E., & Krishna, V. V. (2021). Farmer adoption of sustainable intensification technologies in the maize systems of the Global South. A review. *Agronomy for Sustainable Development, 41*(1), 8.

Manuelli, R. E., & Seshadri, A. (2014). Frictionless technology diffusion: The case of tractors. *American Economic Review, 104*(4), 1368-1391.

Meghna, U., Kharka, B. S., & Sangay, L. (2024). Degree of Mechanization in Paddy Cultivation: A Review of Available Data From 2018-2022. *Bhutanese Journal of Agriculture, 7*(1). doi:https://doi.org/10.55925/btagr.24.7103

NAS. (2023). *National Accounts Statistics* Retrieved from https://www.nsb.gov.bt/publications/national-account-report/

NSB. (2017). *Population and Housing Census* Retrieved from Thimphu: https://www.nsb.gov.bt/publications/census-report/

NSB. (2022). *Labour Force Survey*. Retrieved from Thimphu: https://www.nsb.gov.bt/publications/labour-force-survey-report/

Nyambo, D. G., Luhanga, E. T., Yonah, Z. O., Mujibi, F. D., & Clemen, T. (2022). Leveraging peer-to-peer farmer learning to facilitate better strategies in smallholder dairy husbandry. *Adaptive Behavior, 30*(1), 51-62.

Pingali, P. (2007). Agricultural mechanization: adoption patterns and economic impact. *Handbook of agricultural economics, 3*, 2779-2805.

Quayum, M. A., & Ali, A. M. (2012). Adoption and diffusion of power tillers in Bangladesh. *Bangladesh Journal of Agricultural Research, 37*(2), 307-325.

Ruzzante, S., Labarta, R., & Bilton, A. (2021). Adoption of agricultural technology in the developing world: A meta-analysis of the empirical literature. *World Development, 146*, 105599.

Thuijsman, E. S., den Braber, H. J., Andersson, J. A., Descheemaeker, K., Baudron, F., López-Ridaura, S., . . . Giller, K. E. (2022). Indifferent to difference? Understanding the unequal impacts of farming technologies among smallholders. A review. *Agronomy for Sustainable Development, 42*(3), 41.

Zhou, S., Herzfeld, T., Glauben, T., Zhang, Y., & Hu, B. (2008). Factors affecting Chinese farmers' decisions to adopt a water‐saving technology. *Canadian Journal of Agricultural Economics/Revue canadienne d'agroeconomie, 56*(1), 51-61.