Lham et al. (2024). *Bhutanese Journal of Agriculture*, *7*(1), 14-29.

https://doi.org/10.55925/btagr.24.7102

Evaluation of Locally Fabricated Ridger Attached to Power Tiller and Mini Tiller for Bed Making and its Breakeven Analysis

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ABSTRACT

Growing vegetables in raised beds offers several advantages, including proper drainage, weed control, and higher yields, among others. However, Bhutanese farmers construct these beds manually due to the lack of appropriate equipment's, which is labor-intensive and tedious. To address this issue, ridgers attached to power tillers and mini tillers were designed and evaluated. Power tiller attached ridger was tested at three forward speeds 1.1, 1.4 and 2.4km/h and mini tiller attached ridger was tested for the interaction of the same speeds and two different depths to determine the bed height, furrow width and field capacity of the machines. The result shown that power tiller ridgers showed increased capacity of 4.51 acre/day at higher speed of 2.4km/h, while mini tiller ridgers maintained a relatively constant capacity ranging from 3.44 acre/day to 3.46 acre/day at forward speed ranging from 1.1km/h to 2.4km/h. The result indicated that forward speed had a minimal effect on bed height formation. Deeper tillage resulted in higher bed heights within recommended range of 20-30cm. Furrow width slightly increased with higher speeds. Power tiller and mini tiller bed making is 55 and 38 times more efficient than manual labor, and the investment in these implements can be recovered after using them for 1.03 and 0.55 acres, respectively, indicating their economic viability. Incorporating ridgers into vegetable cultivation practices has the potential to improve productivity and alleviate the burden on farmers in Bhutan.

Keywords*:* *Raised bed; Machine capacity; Break even use; Forward speed*

1 Introduction

Agriculture holds significant importance in Bhutan, contributing significantly to employment and the country's economy. However, scaling up commercial agriculture poses a challenge due

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to rugged topography, issues with land fragmentation, and the prevalence of small landholders engaged in subsistence farming. Despite its modest size, Bhutan has diverse agro-ecology stemming from considerable variations in altitude (Katwal, 2013), indicating the nation's potential to enhance production through the adoption of improved farming practices.

Today vegetable production is picking up in the country, where the self-sufficiency in vegetables stands at 84%, contributing to an overall food self-sufficiency rate of 68.30% (Tshering, 2022). Additionally, vegetables continue to play a remarkable role in human nutrition and health due to their nutrient's contents such as dietary fiber, phytochemicals, vitamins, and minerals (da Silva Dias & Imai, 2017). There has been a noticeable increase trend in the consumption of vegetables in recent times in Bhutan and the import figures has also increased despite the increase in domestic vegetable production (Guidebook on vegetable cultivation, 2020). The demand for vegetable consumption will continue to increase with increase in population, income, and change in healthy dietary habits.

In Bhutan majority of the farmers continue to adopt traditional practices of land preparation for vegetable cultivation which are highly labour intensive and tedious. The vegetable cultivation processes include land preparations and making beds of suitable heights to prevent water logging and improved aeration (Lham, Norbu, Phuntsho & Zangmo, 2022). Studies found that crop cultivation on raised beds is a good technique in farming systems. On-farm research found that growing crops on raised system saved 20-34% irrigation water, 16-69% planting cost, and ensured higher crop yield compared to conventional system (Hossain, Islam, Hossain, Meisner, & Rahman, 2010). Raised bed method helps in reducing irrigation requirements of crops and increase crop production even in soils having low permeability, seasonal water logging, salinity, and shortage of water supply (Qureshi, McCornick, Qadir, & Aslam, 2008). Various studies have reported on the performance of different crops under raised beds farming. Rajput et al., (2009) observed about 55 % increases in crop yield in raised bed system as compared with the flatbed system due to improved soil drainage, effective weed control, enhanced water retention, and optimal nutrient distribution. Many crops, such as peanut, cotton, sweet potato and other vegetables are planted on raised beds with furrow irrigation, a method which not only has the potential to save water but is also convenient for water management (Bouaziz, A., & Chekli, H. (2000). Hence, cultivating vegetables using raised beds has demonstrated a substantial increase in overall yield.

Making raised beds manually is a labor-intensive and tedious task, resulting in higher production cost and disrupting the timely cultivation process due to the unavailability of farm labour, consequently impacting crop yields. To meet growing demands for vegetables while addressing labor shortages and reducing labor-intensive tasks, it is imperative to adopt innovative, science-based agricultural technologies aimed at enhancing vegetable production. Carrying out timely operation and reducing cost of production are prerequisite for enhancing the production and productivity of vegetables as well as to make vegetable cultivation commercially viable and profitable for the farmers. Kumari, N., Singh, P. K., & Singh, P., (2020) found out that the ridge making activity done through mini tiller took 95% less time in compared to human and 50% in compared to pair of bullocks. The total cost saving in ridge making activity by mini tiller is 93.59% in compared to human and 56.38% in compared to bullock pair.

To overcome the challenges associated with manual bed-making and to enhance mechanization efficiency, there is a need for the development of innovative agricultural machinery implements, specifically a ridger designed for making beds. This implement would be attached to power tillers or mini tillers, which are widely used in Bhutanese farming communities. The popularity of these smaller farm power tools stems from their adaptability to the steep terrains found in Bhutan's agricultural areas. Moreover, individual ownership of these machines is more viable for farmers due to their cost-effectiveness and practicality. According to (JICA, 2016) among the farm machineries, power tillers in land preparation are the most popular, the use of power tillers has substantially reduced farm drudgery besides reducing farm labour requirements. It is recommended that marginal farmers with small land holdings consider utilizing compact farm power tools such as a 7 HP mini tiller and a lightweight power tiller for their agricultural operations (Kumari, N., Singh, P. K., & Singh, P., 2020). This suggestion closely aligns with the prevailing trend in Bhutan that the average land holding in Bhutan is about 3.7 acres per household (Renewable Natural Resources Census of Bhutan, 2019).

During the operation, the speed of the bed-making machine can impact the size of beds formed. It is considered that the forward speed of the machine is one of the important and direct factors that affect the machine’s quantity and quality, through which the productivity of agricultural machinery is determined (Kakahy, A. N. N., Alshamary, W. F. A., & Kakei, A. A. 2021). Abdul Karim, T.T and Mumtaz, I.H, (2011) pointed that the increase in the speed of the tractor led to the increase in the traction force, the efficiency of conduction capacity, the volume of the disturbed soil, and the practical productivity reached the lowest. Therefore, adjusting and optimizing the speed of bed-making machinery is crucial in achieving consistent and desirable bed sizes for effective vegetable cultivation.

The power tiller and mini tiller attached ridger for bed making is designed within the country and it is important to do a breakeven analysis to determine the economic advantages of these machines. This analysis is essential for effective resource allocation and hence justifying investments by end users especially Bhutanese farmers. According to Haquel, M. A., Alaml, M., & Sarker, T. R., (2014) break even analysis gives an insight to the minimum annual use of a particular machine that would justify the economic operation of that machine over the other options available.

This study aimed to design and evaluated a ridger for bed-making compatible with both power tillers and mini tillers. Its primary objective was to explore how the forward speed of the machine affects the dimensions of the formed bed and its field capacity, particularly concerning the ridger attached to power tillers. Furthermore, the study aimed to examine the interaction between implement depths and forward speeds on bed dimensions and field capacity, specifically for the ridger attached to mini tillers.

2 Materials and Method

2.1 Design of the implements

Two types of ridgers were developed for power tillers and mini tillers. The sizes vary due to the distinct power sources; however, the design and operational principles are the same. The ridgers for bed making were specifically designed to create raised beds of height 20 to 30 centimeters. These implements can make a bed while moving forward and accurately adjusting to any desired bed widths on its return based on the specific requirements for different crop types. This approach allows for making raised beds of any desired width, catering to individual preferences and crop requirements.

The ridger attached to the mini tiller can be adjusted to two different depths D1 (47.5cm measured from the base of the implement to the center of the hole of the shaft) and D2 (43cm measured from the base of the implement to the center of the hole of the shaft) respectively allowing for making of beds at varying heights.

The frame and other working parts were made of Mild Steel sheet of thickness 3mm and the parts were assembled with nuts and bolts. The process basically involved making the parts by cutting, grinding, and welding followed by fitting and assembling. The prototype was tested in the field.

Figure 1. Ridger for power tiller Figure 2. Ridger for mini tiller

2.2 Field experiment

The experiment was conducted in Rukubji where vegetables were dominantly cultivated. Rukubji is located in Wangduephodrang district at 27.5141° N, 90.2748° E. The experiment was conducted in the month of May 2021. The soil composition at the site was predominantly loam with moisture content of 20% at the time of experiment conducted. A separate experiment was conducted for power tiller and mini tiller attached ridger for bed making. The experiment followed a completely randomized design for testing power tiller attached ridger treated under three different forward speeds and the experiment involving mini tiller attached ridger was conducted adopting factorial design incorporating two factors, implement depth tested at two levels D1 and D2 and forward speed tested at three levels with each factor being replicated three times. This factorial design facilitated the examination of the main effects of implement depth and speed, as well as potential interactions between these two factors.

A total of nine plots were selected as the experimental units for applying the three treatments for power tiller, and 18 plots were selected for applying interaction of two different factors (speed and depth) for mini tiller. As per the recommendation outline in the guidebook on vegetable cultivation, 2018) bed width of 0.7m was maintained for both the machines: Forward speeds i) 1.1km/h operated at gear position 1 ii) 1.4km/h operated at gear position 2 and iii) forward speed of 2.4km/h operated at gear position 3 were determined for both the machines by recording the time taken to cover a distance of 10 meter using the formula;

$$V = \frac{Sx3.6}{t} \qquad (1)$$

Where;

V= forward speed (km/h), S= travelled distance (m), t= time of the experiment (sec)

1m/sec= 3.6km/h

2.3 Experiment with making bed manually

An experiment on bed making manually was conducted adopting completely randomized design by a man with three replications to determine the time taken to make a bed of length 10m, 0.7m wide and 20-30cm height in the well ploughed field which is compatible with the bed dimensions made by the machines. The capacity of the man in making the desired dimension raised bed was calculated using the formula:

$$\mathrm{MC} = \frac{\mathrm{A}}{\mathrm{T}} \mathrm{x} 7 \qquad (2)$$

Where,

MC=Man capacity, A=total area covered (acre), T=Total time taken to cover that total area (h), 7= working hours in a day.

2.4 Data collection

The data collected during the experiment were bed height, machine capacity and furrow width. Representative values for bed height and furrow width were taken by randomly selecting points along a 10-meter-long bed formed during the experiment. The width of the furrow is measured from the edge of one bed to the opposite edge of the adjacent bed. The time taken to make raised bed manually was recorded inclusive of the rest taken by the man and other miscellaneous time lost. Soil sample from certain depths were collected using soil corer to assess the moisture content of the soil using the formula:

$$\mathrm{MC} = \frac{\mathrm{W}i - \mathrm{W}d}{\mathrm{W}d} \mathrm{x} 100 \qquad (3)$$

Where,

MC = Moisture content (%), Wi = Initial weight (g), Wd = Dry weight (g)

2.5 Statistical Analysis

All the data collected were subjected to an analysis for variance (ANOVA) using excel software. Differences among treatment means were examined using the "Turkey Post hoc Test" at 5% significance level.

2.6 Cost analysis

Breakeven point was calculated to compare the operating costs of bed making using a ridges and the costs associated with manually making a bed for vegetable cultivation.

2.6.1 Fixed cost

These costs depend on how long a machine is owned rather than how much it is used. The fixed costs for farm machinery include depreciation, interest on investment, insurance, and taxes/registration.

Table 1. Field capacity of farm machineries used for the study (Directory of certified farm machinery, 2022)

Name of machine	Capacity for plowing (acre/day)	Capacity for rotary (acre/day)	Capacity for bed making (acre/day)
Vikyno Power tiller (MK-120)	1.56	2.94	4.51
Mini tiller (KDT-610CE)	0.54	2.36	3.46

Depreciation cost

This cost reflects the reduction in value of a machine with the use (wear) and time (obsolescence). According to Kepner et al (2005), the annual depreciation was calculated using straight line method as follows.

$$\mathrm{D} = \frac{\mathrm{P-S}}{\mathrm{LH}} \qquad (4)$$

Where,

P= Purchase price of the machine, S=Salvage value (10% of P), L=Useful life of machine (years), H=Annual use of machine (hours)

Interest on investment

As per Bank of Bhutan (assessed on 27^{th} September 2023) the fixed interest rate on agriculture term is 10.85%. It is calculated using the formula;

$$\mathrm{I} = \frac{\mathrm{P+S}}{2} \,\mathrm{x}\, \frac{\mathrm{i}}{\mathrm{H}} \qquad (5)$$

Where,

i = prevailing interest rate

As per the Road Safety and Transport Authority Regulation 2021, farm machinery was exempted from the registration and renewal fees.

Insurance and taxes

Insurance and taxes for agricultural use is 2% per annum (Norbu, 2018)

$$In = \frac{2\% \text{ of } P}{H} \qquad (6)$$

Where,

In=Insurance and taxes per hour

2.6.2 Operating cost (variable cost)

It varies in proportion to the amount of machines used. Operating costs include repair and maintenance cost, fuel cost, oil cost and labour cost.

Repair and maintenance cost

Repair and maintenance expenditures are necessary to keep a machine operable due to wear, part failure, replacement of tyres and tubes and accidents. The accumulated repair and maintenance costs (TAR) at any point in a machine's life can be estimated from the following formula (Singh & Mehta, 2015);

For two-wheel drive tractor (power tiller and mini tiller);

$$TAR = 0.120X^{1.5} \qquad (7)$$

For plough, planter, harrow, ridger and cultivator:

$$TAR = 0.301X^{1.3} \qquad (8)$$

$$X = \frac{H}{H \text{ x } L} \text{x}100 \qquad (9)$$

Fuel cost

The price of fuel (Diesel) was taken by observing the market price, State Trading Corporation of Bhutan Limited, Bhutan Petroleum (16 August-31 August 2023) recorded at Nu.80.19/liter for Thimphu. Average fuel consumption was estimated by the following formula (Singh & Mehta, 2015);

$$Ad = 0.15 \text{ x B} \qquad (10)$$

Ad= Average diesel consumption (both power tiller and mini tiller are diesel operated engine),

B= Rated power (KW)

**for the machines used in our experiment (power tiller: 9kw and mini tiller: 4kw)*

Oil cost

Oil consumption should be taken as 2.5 to 3% of the fuel consumption (Sarker, Alam, Haque, & Zaman).

2.6.3 Total operating cost

It is the sum of fixed cost and operating cost

2.6.4 Overhead cost

It should be assumed as 20 % of the sum of fixed and variable costs (Singh & Mehtha, 2015)

2.6.5 Manual operating cost

The manual operating cost was calculated, taking into account the local wage rate of Rukubji of Nu. 800 per day, with the understanding that one individual is needed to make a raised bed.

2.6.6 Breakeven use

Determining the use of farm equipment is the most important decision in farm management, in this regard computing break-even-use of a farm machine is a must. The break-even-use is the amount of use where the cost of using a machine owned would be the same as the cost of doing the same operation manually (bed making for our experiment). Owning a machine would be financially viable when used beyond the break-even point.

Break-even-use can be determined by the following formula:

$$\mathrm{BEU} = \frac{\text{Total Fixed cost}}{\text{manual operating cost} - \text{total operating cost}} \qquad (11)$$

If manual operating cost is more than total operating cost, it is profitable to do the activity by machine than manually.

3 Results and Discussion

3.1 Effect of forward speed and depth of implement on the heights of bed formed

Figure 3 shows the bed heights formed by ridger attached to power tiller and mini tiller at three different forward speeds: 1.1 km/h, 1.2 km/h, and 2.4 km/h. A very small variation in bed height across different forward speeds was observed for power tiller attached ridger which suggests that forward speed may have a limited effect on bed height formation in our experimental setup. This may be attributed to the design of the ridger's hitching system which was fixed at one point and was engineered to maintain consistent heights across different speeds. Further statistical analysis also suggested that there was no significant difference among the bed heights formed.

On the other hand the impact of interaction of forward speed and depth of the implement on bed height formed using mini tiller-attached ridger showed that at the lower forward speeds, both D1 and D2 depths tend to yield slightly higher bed heights and there was a slight reduction in bed heights with increase in forward speeds to which Ismail and Ismail, (2013) suggested was due to increase in the collapsed soil, and consequently more quantity of soil falling on the profile sides as forward speed of the machine increases. Overall D1 depth consistently resulted in taller bed heights because of its deeper depth maintained compared to depth D2. The interaction effect between depth and speed on bed height formed was not statistically significant and forward speed did not yield a significant difference in bed heights formed. However, we observed a significant difference in bed heights between depths D1 and D2, specifically, deeper tillage (D1) resulted in taller beds compared to shallower tillage (D2).

Nonetheless, as per Nueces County AgriLife Extension. (2020), and Iowa State University Extension and Outreach. (n.d.) 20 to 30cm of bed height is usually adequate to be effective for vegetable cultivation, which is comparable for the heights formed at all the speeds and depths for both power tiller and mini tiller.

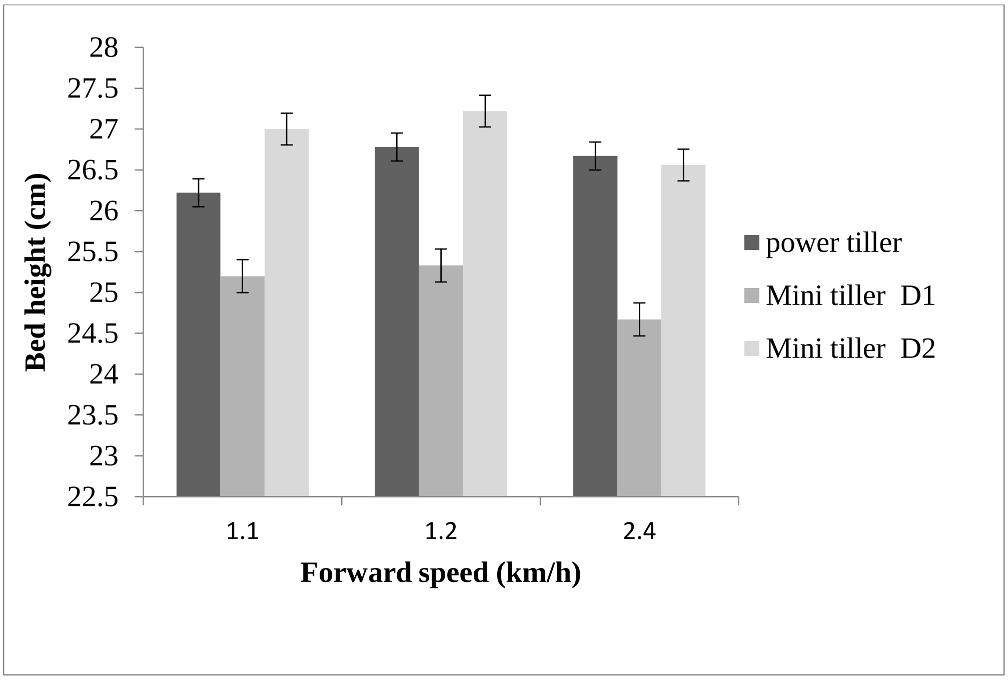

Figure 3. Effect of forward speed and depth on the bed height. Error bars represent standard error of mean.

3.2 Effect of forward speed and depth of implement on the furrow width.

Table 2 shows the impact of forward speed on the furrow width of the bed formed. It is evident that with the increase in forward speed the furrow width consistently increased for both power tiller and mini tiller attached ridger for making raised bed. Furrow width made by power tiller attached ridger at forward speed of 1.1km/h was significantly narrower than at higher speeds. Regarding the mini tiller attached ridger, no significant differences in furrow widths were observed at both the depths. However, the forward speeds of 2.4km/h played a significant role in the furrow width formed with the widest width of 56.89 and 56.55 cm for depths D1 and D2, respectively. As per the guidebook on vegetable cultivation 2016-2021, it is recommended to maintain the width of the furrow within the range of 50-60cm to facilitate easy weeding and other cultural practices. Our experimental results align with this recommendation except the furrow width formed at the forward speed of 1.1km/h using power tiller attached ridger which recorded 47.67cm only.

Table 2. Furrow width formed at different speed and depth

SN	Forward speed	Power tiller	Mini tiller	
			D1	D2
1	1.1	47.67	54.47	53.33
2	1.2	52.12	54.52	56.89
3	1.4	54.89	55.11	56.55

3.3 Effect of forward speed and depth of the implement on the capacity of the machine

For power tiller attached ridger, its capacity increased significantly with increase in forward speeds. The highest capacity of 4.51acres/day was recorded at the highest speed of 2.4km/h (Figure 4) considering standard working hour of seven hours per day as per the directory of certified farm machinery, 2022. This can be attributed to enhanced efficiency, greater power output of the machine and reduced idle time with increased forward speed. Experiment carried out by Issa, Zhang, El-Kolaly, Yang, & Wang, (2020) also revealed that, the machine capacity increased rapidly by increasing the machine forward speeds and stated the machines forward speed greatly affecting the actual field capacity is the key factor to approach the machine optimum performance.

On the other hand, for mini tiller attached ridger, the machine capacity remained relatively constant across all the forward speeds and depths. This may be due to the cage wheel used for mini tiller which increased the slippage with increase in speed (Hensh, Chattopadhyay, & Das, 2022). The traction developed at the soil-tyre interaction surface provided the required force to overcome the speed and rolling resistance. At a higher speed, the traction of the soil-tyre interaction was not able to supply the required force, which caused an increase in the wheel slippage. The same behavior of the increasing wheel slippage with the increase in the speed was also reported by Narang & Varshney, (2006), Schreiber & Kutzbach, (2008) and Moitzi et al., (2014).

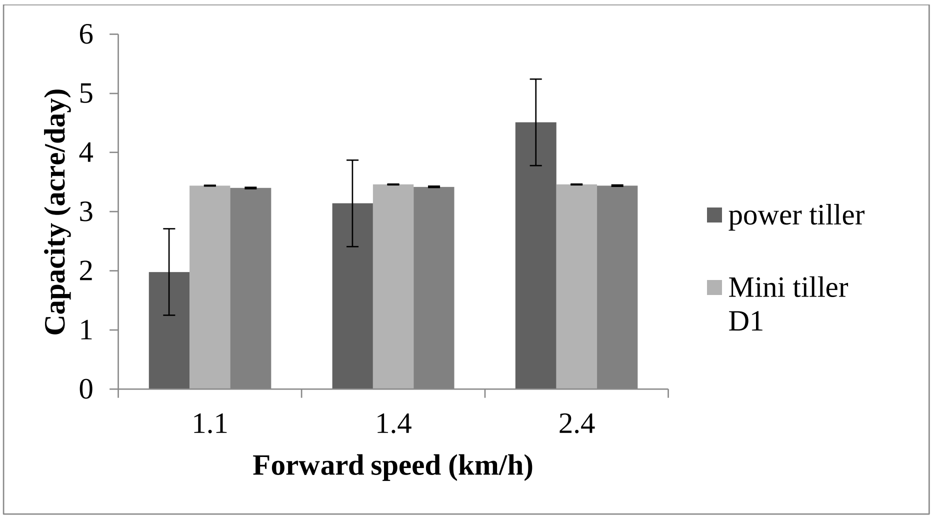

Figure 4. Effect of forward speeds and depths on capacity of the machine. Error bars represent standard error of mean.

3.4 Comparing Bed-Making Machine Productivity to Manual Bed-Making

On an average, a man took 9 minutes 6 seconds to make a raised bed of desired bed dimension which would cover an area of 0.083 acres/ day. While the field capacity of making bed of the same dimension using power tiller at forward speed of 2.4km/h was 4.51 acres/day and that of mini tiller at forward speed of 1.4km/h was 3.14 acres/day which is about 55 and 38 times more efficient than manual labor respectively.

3.5 Economic analysis of the machines

The break-even point for locally fabricated ridgers was noted at 1.03 acres for power tiller-operated bed making and 0.55 acres for mini tiller-attached bed making. As shown in Figure 5, when compared with the cost of manual operation, the break-even point indicated the minimum annual usage that rendered a machine economically viable for bed making at 1.03 and 0.55 acres for power tiller and mini tiller, respectively. This study aligns with the findings of Haquel, M. A., Alam, M., & Sarker, T. R. (2014), where the break-even point of the power tiller bed planter was recorded at 1.2 acres compared to manual operation. Manual operation costs became very expensive mainly due to its very low throughput capacity, as well as its rate of coverage (Table 3). In contrast, power tiller and mini tiller achieved a flat trend owing to their high throughput capacities. Therefore, the use of machines is economically justified compared to manually making raised beds.

Table 3. Useful life (IS 9164, 1979) and calculated operation cost of farm machines used for the study.

Name of machine	Price (Nu.)	Useful life(years)	Useful hour/year	Fixed cost (Nu./h)	Operating cost (Nu./h)	Total operating cost (Nu./h)	Total cost of bed making (Nu./h)
Power tiller	300,000	10	800	63.63	261.78	325.41	
Ridger	8200	8	125	7.99	2.90	10.89	**336.30**
Mini tiller	150,000	10	800	31.81	196.23	228.04	
Ridger	6600	8	125	6.43	2.33	8.76	**236.80**
Manually	500	5	100	4.89	114.28	119.26	**119.26**

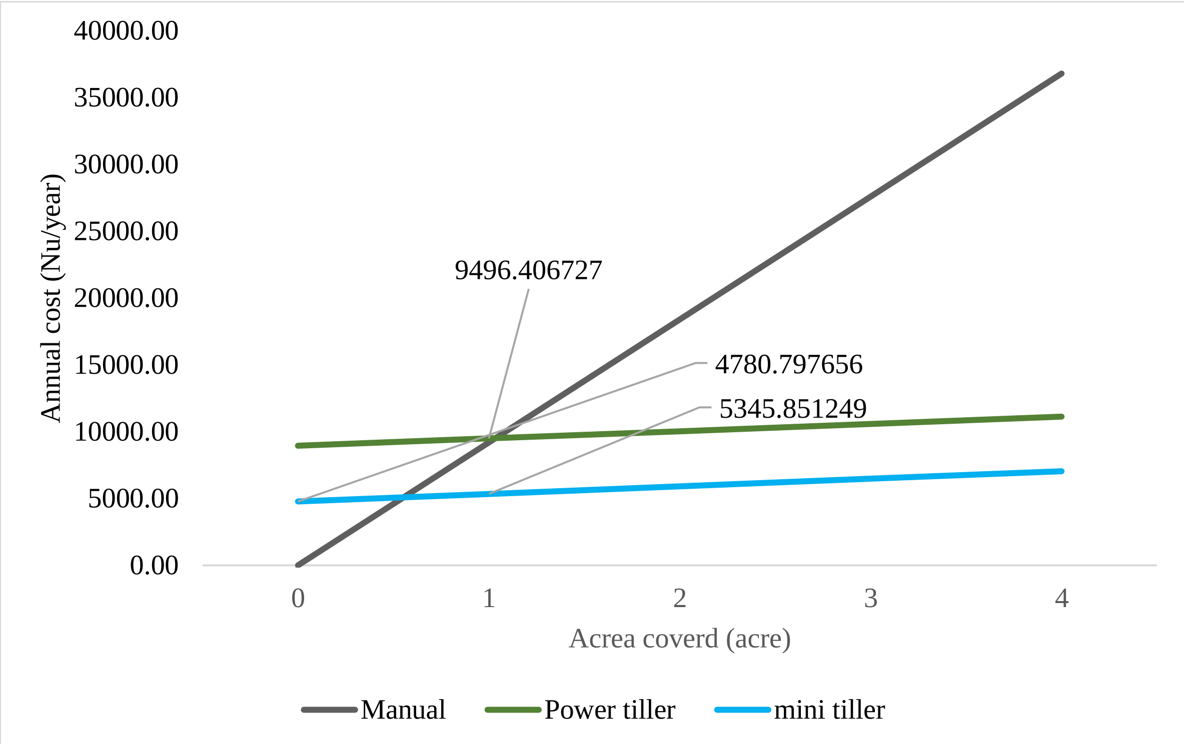

Figure 5. Break even analysis of bed making machines

4 Conclusion

The findings of this study indicates that forward speed had minimal impact on bed height formation for both power tiller and mini tiller attached bed making, with subtle variations observed across speeds. Deeper tillage resulted in higher bed height compared to shallower tillage, while furrow width slightly increased with higher speeds, maintaining a consistent range except at 1.1 km/h for the power tiller. This study recommends operating the mini tiller attached ridger at 1.1 km/h at any depths, while the power tiller attached ridger is recommended to operate at a speed of 2.4 km/h to achieve optimum bed dimensions and higher field capacities. These insights offer valuable guidance for optimizing the performance of both types of ridgers in bed making across various crops and soil conditions. Mechanized bed making with power tiller and mini tiller significantly outperforms manual labour. Moreover, the breakeven analysis also demonstrates the economic justification of using machines for bed making over the manual labor. This suggests that investing in these locally fabricated machines for bed making would be commercially viable after utilizing them for the specified acreages, indicating the advantages of mechanized bed making in vegetable production.

5 Acknowledgement

The authors express sincere gratitude to the management and staff of the Agriculture Machinery and Technology Centre, Paro, for their invaluable guidance and technical assistance throughout the execution of this study. Special appreciation is extended to the farmers of Rukubji village for graciously permitting us to conduct the field experiment in their field.

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