Phuntsho et al. 2022 Bhutanese Journal of Agriculture 5(1), 109-119
https://doi.org/10.55925/btagr.22.5109

# Evaluation of Extension Device on Kubota Power Tiller for its Operational Maneuverability on Steep Terrain in Bhutan

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## ABSTRACT

*Bhutanese agriculture has been at the subsistence level and the adoption of mechanization started only in late 1986 with the establishment of the Agriculture Machinery Centre. One of the most popular farm machines is the power tiller, the use of which is fast replacing the old tradition of land preparation using oxen. However, the adoption of farm machinery for land preparation is limited to the narrow plain areas along the border with India. Most of the country is mountainous where the use of power tillers has become unsafe and less efficient due to high gradients. Further, farmers have been stretching the use of the power tillers for ploughing on the mountain slopes even though it is less labour-efficient and involves risk-taking. In many cases, power tillers are used on land with gradients exceeding 15 degrees with additional labour to prevent the machine from toppling. The experiment was carried out to determine the critical safe angle of the sideways tilt while ploughing, and also to determine the critical angle that is practically possible to increase by using an extension device that was designed and fabricated to increase the wheel tread. This research compares the three treatments, i.e., rubber wheel with normal axle, rubber wheel with the extension device, and paddy wheel for required machine stability. It was observed that the rubber wheel with the normal axle was only feasible up to 9.93 degrees slope, the paddy wheel and rubber wheel with extension device were feasible up to 20 degrees slope. There was a significant (P<0.05) difference between the rubber wheel with normal axle and the rubber wheel with the extension device in terms of stability and no significant difference was observed between the extension device and the paddy wheel. This was achieved by decreasing the centre of gravity in a high slope gradient land and this could help farmers bring more agricultural land with high gradient into meaningful cultivation, thereby, enhancing food production.*

**Keywords:** *Gradient; Toppling; Critical angle; Extension Device; Machine stability*

## 1. Introduction

Bhutan is a landlocked country in the eastern Himalayas between China and India. Geographically, it lies between 26°40’ and 28°15’N and 88°45’ and 92°10’E with an area of 38,393 km$^2$ (Dendup, 2018) Agriculture is the main occupation of Bhutanese people. Generally, traditional subsistence or semi-subsistence farming practice and 57% of the

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Bhutanese population is dependent on agriculture for their livelihood (Chhogyel & Kumar, 2018). However, there has been rapid adoption of mechanization, mainly for land preparation and post-harvest processing. Among the farm machinery, power tillers in land preparation are the most popular. The use of power tillers has substantially reduced farm drudgery besides reducing farm labour requirements (JICA, 2016). Farm mechanization has provided some solace in the face of decreasing farm labour in rural areas, particularly fueled by rural-urban migration.

However, the use of a power tiller for land preparation is severely limited by the gradient of the agricultural land (Kinga & Chetem, 2019; Norbu, 2017). With the decreasing animal draught power, the use of power tillers has been put to their extremes with the machine being used even in fields with slopes that are much beyond what is considered technically safe to operate. Further, 49.5% of Bhutan's geographical area has slopes greater than 50 degrees (Dendup, 2018). According to the Monitoring and Evaluation Report on Government Hiring Service, 26% of the respondents reported power tiller accidents from rolling over caused by inadequate measures to stabilize the machines (AMC, 2019). The existing method employed by the farmers to maintain the balance in the power tillers on extreme slopes is manual, involving one or two extra farm labourers supporting the machine to prevent it from rolling over the slope. This manual process continues throughout ploughing on extreme slopes and often requires one or two farm labours to exert constant force in pulling the machine upwards throughout the operation. Thus, the risk of accident is not only high but also the efficiency is drastically reduced. In the world, more than 50% of accident that involves death occurs due to lateral overturning and backward rollover of agricultural machines (Hwang, Jang, & Nam, 2021). Even though the demand for power tiller is high but due to the lack of its manoeuvrability on the slope, the usage is reduced (AMC, 2019). Therefore, there is a need to determine the way around utilizing power tillers safely and effectively on the slope of agricultural land.

Thus, this paper attempts to determine the maximum slope on which a power tiller can safely operate. There were three experimental treatments: a normal rubber wheel, a rubber wheel with an extension device, and paddy wheel attached to the power tiller. According to agriculture statistics, farm labour shortage is a major constraint in agriculture (DoA, 2016), with this research we plan to mitigate the labour shortage by improving the safe maneuverability of power tillers to operate at the higher gradient. The field experiment was conducted in three regions to ensure the validity of the findings across the regions.

## 2. Materials and Method

### 2.1 Test area

The common and the most popular power tiller in Bhutan, the Kubota model RT125 (Japanese made) was used to test the safe manoeuvrability of the power tiller at the maximum slope. The experiment was conducted in three regional districts of Pemagatshel, Paro and Trashigang. Pemagatshel is located in the southeastern part of Bhutan and is characterized by highly dissected mountain ranges, steep slopes, and narrow valleys with little flat land. Paro is situated in the north-western part of the country and is characterized by more gentle slopes and flat land as compared with Pemagatshel. Paro is located at an altitude of 2,250 m above sea level. Trashigang is located in the eastern part of Bhutan and has a topography similar to Pemagatshel. Trashigang is at an elevation of about 1174 m above sea level.

### 2.2 Tools and equipment

Kubota model RT125 (Japanese made) is used in the experiment as it is the commonly used power tiller and would represent power tiller used for land preparation in Bhutan. The detailed specification on physical make, engine and tyre as presented in Table 1 is based on a test report prepared by the AMC (AMC, 2015).

Table 1. Machine specification was used in the experiment (AMC, 2015)

| Serial No | Particular | Specification |
|---|---|---|
| 1 | Power tiller | |
| | a) Model: | RT125 |
| | b) Make: | Kubota |
| | c) Overall dimensions (mm) | |
| | • Length: | 2145 mm |
| | • Width: | 866 mm |
| | • Height: | 1210 mm |
| 2 | Engine | |
| | a) Type: | Diesel, horizontal |
| | b) Number of cylinders: | 1 |
| | c) Type of combustion: | Internal |
| | d) Make: | Kubota |
| | e) Model: | RT125 |
| | h) Rated engine power: | 12.5HP/2400 rpm |
| 3 | Tyre size (inch): | 6-12 inches |

Three treatments were used: a normal rubber wheel with normal axle, rubber wheel with extension device, and paddy wheel attached to the power tiller model as provided above (Table 2). The wheel-tread distance of the experimental treatments ranged from 700 to 970 mm.

Table 2. Three experiment treatments with different wheel tread distances.

| Serial No. | Treatments | Wheel tread distance |
|---|---|---|
| 1 | Rubber wheel with normal axle | 700 mm |
| 2 | Rubber wheel with an extension device | 970 mm |
| 3 | Paddy wheel | 950 mm |

The extensions used for the experiment were designed and fabricated at the AMC research workshop using mild steel plates. The fabricated parts were hexagonal sockets into which the hexagonal wheel axle could be inserted. Using the extensions, the wheel tread could be increased in steps of 40 mm from 970 mm to a maximum wheel tread of 1050 mm. The fabricated parts are shown in Fig.1 with their specification in Table 3.

Table 3. Specification of extension devices

| Model | Extension device |
|---|---|
| Length | 296 mm |
| Outer diameter | 130 mm |
| Inner across the corner | 55 mm |
| Inner across the flat | 47.5 |
| Machine weight | 3.5 kg |
| Cost | Nu.2500 |

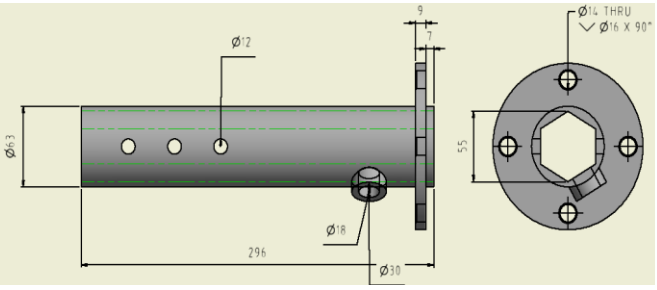

Figure 1. Extension device

### 2.3 Measurement procedures

The main objective of the experiment was to observe the stability of the power tiller operating on different gradients by using rubber wheels, rubber wheels with an extension of the axle, and the paddy wheels as different treatments during ploughing operation. The tests were conducted to determine the angles of tilts up to which the power tiller under different wheel treads successfully operates without toppling over. The experiment was conducted following a completely randomized design (CRD). In each of the three locations, the three treatments were replicated three times to increase the accuracy of the experiment.

In each location, a suitable experiment field with slopes ranging from 8 to 25° was selected using a Japanese-made inclinometer. Then the fields were ploughed using the three sets of treatments. The first set of data was collected using the rubber wheels with the normal axle, followed by the rubber wheel with the extension, and finally with the paddy wheel. The slope of the portion of the test plot was noted. The distance between the start and the end for one run was marked. The time taken for each run and the critical angle of tilt was recorded.

The experiment recorded two types of inclination, i.e., land gradient which is the initial inclination of the land before ploughing, and machine gradient which is measured when one part of the wheel falls on the furrow during the ploughing operation. The tests were repeated for varying slopes until the machine tended to topple. The data on the type of soil, depth and width of the furrow, speed of ploughing, and slope of the land were collected.

## 2.4 Laboratory test

For the stability analysis of the power tiller, the factor used is the sideways overturning angle (Kang et al., 2019). The experiment was conducted in the laboratory by making an inclined plane on which the power tiller is placed. The angle of inclination of the inclined plane is variable and was increased until the power tiller tended to topple. This meant that the centre of gravity is more than the power tiller's base stability, and the side rollovers depend upon the centre of gravity and centrifugal force of the power tiller.

## 2.5 Theoretical calculation of the centre of gravity of power tiller

The centre of gravity of the power tiller could be determined using similar formulae which are used to determine the centre of gravity of the tractor. The point where all the parts of a physical object balance one another is referred to as the centre of gravity (Prabhat, Ashish, & Kunal, 2014).

The terminologies used in the calculation of the centre of gravity and the tilting angle are:

Wheelbase (L),
Front tread (T1),
Rear tread (T2),
Left front load (Wl1),
Right front load (Wr1),
Left rear-load (Wl2),
Right rear-load (Wr2),
Total load (W),
Height in an inclined position (h),
Right rear load in an inclined position (W'r2),
Left rear load in an inclined position (W'l2) and

Effective radius (R)

### 2.5.1 Calculation of longitudinal length from a stand (Macmillan, 2002)

The location of the centre of gravity in a longitudinal direction could be found by measuring the weight on the front and rear wheel as:

$Lo = (W2*L)/W$………………………. (1)

Where Lo= longitudinal distance of support from the stand; W2= Wr2+Wl2

### 2.5.2 Calculation of lateral distance from centre to right as:

Lateral distance from centre to right (M) = $\frac{(Wr1-Wl1)T1+(Wr2-Wl2)T2}{2W}$…………… (2)

### 2.5.3 Calculation of vertical height (Macmillan, 2002)

This method could be calculated by lifting the front or rear wheel of the power tiller and measuring the weight in raised conditions.

$V = R + \frac{F*L}{W*Tan\Phi}$………………………….. (3)

where V= Vertical height; Φ= Tilting angle and F= difference between the weight of the front wheel

### 2.5.4 Calculation of tilting angle (Ciuffoli, 2019)

The maximum tilting slope could be obtained using the equation:

Tilting angle= $\tan^{-1}(T2/2)/V$………………(4)

where T2= Rear tread and V= Vertical height

### 2.6 Data analysis

The research data was compiled in Microsoft Excel and were analyzed using Excel ToolPak. Data generated using the completely randomized experimental design were subjected to the one-way analysis of variance (ANOVA) followed by post-hoc analysis with Bonferroni correction at $P < 0.05$ level of significance for multiple comparisons of the treatment means.

## 3. Results and Discussion

### 3.1 Laboratory result

During the sideways overturning test, it was found that the point of no return (critical angle) using the rubber wheel was 30 degrees. As it can be seen, the power tiller would not topple as long as the moment by the centre of gravity is less than the counter moment acting upwards by the reactions through the wheels. This will remain so if the line of action of the centre of gravity is within the wheel tread. Therefore, the stability can be increased by the extension of the axle length to contain the action of the centre of gravity within the wheel tread.

Based on the theoretical calculation, the tilting angle of Kubota RT 120 was 28.5 degrees. It was found that with the increase in the wheel tread, the tilting angle also increased. This explains why the stability of the power tiller with the extension device and paddy wheel is higher than that of the rubber wheel. The tilting angle with the rubber wheel calculated in the laboratory and that calculated theoretically were almost the same, i.e., 30 and 28.5 degrees, respectively.

In summary, the maximum tilting angle can be obtained with the maximum rear tread and minimum vertical height of the centre of gravity. Any condition that modifies these two factors will change the tilting angle and thus, the stability of the tractor changes, which is also similar to the findings described by (Guzzomi, Rondelli, Guarnieri, Molari, & Molari, 2009).

## 3.2 Field result

The laboratory experiments were followed by the field experiments. The soil texture was analysed at the end of the rainy season and was found to be friable. The soil structure in Paro (Pangbesa) was sandy loam, while that in Pemagatshel (Chimong) and Trashigang (Kanglung) were observed to be clay loam.

During the field experimentation, the average speed of the plough was maintained at 1.32km/hr with a furrow depth of 150 mm. Table 4 shows the results of an experiment conducted on a rubber wheel, extension device, and paddy wheel. Based on the data, it was found that the feasible angle of inclination of land (land gradient) for the rubber wheel was 9.93 degrees. At this degree (9.93) the machines were found to be stable and completed the ploughing operation without any difficulty and once we increased the gradient, the machines tended to topple. The feasible angle of inclination of land (land gradient) for the paddy wheel and the rubber wheel with extension device was ≥20 degrees. A similar observation was made during the ploughing operation on the rubber wheel with extension and paddy wheel, i.e., the machines ran in a stable condition but would face some difficulty while turning around, as we increased the gradient the machine was stable but not able to plough due to the downward sliding moment.

Table 4. Critical land gradient observed among the three treatments

| Regions | Rubber Wheel | Extension Device | Paddy Wheel |
|---|---|---|---|
| Pemagatshel | 10.2 ±0.26 | 20.50 ±0.62 | 20.5 ±0.40 |
| Paro | 10 ±0.2 | 20.00 ±0.43 | 20 ±0.20 |
| Trashigang | 9.6 ±0.17 | 20.00 ±0.20 | 19.5 ±0.36 |
| Mean | 9.93 ±0.31$^{a}$ | 20.17 ±0.29$^{b}$ | 20.00 ±0.5$^{b}$ |

Values are mean ± standard deviations of the means. Mean values within the rows with different superscripts are significantly different amongst the treatments at $P<0.05$ by Bonferroni correction.

Similarly, it was found that the feasible mean angle of inclination of the machine (machine gradient) was 23.33, 30.71, and 29.18 degrees for the rubber wheel, extension device, and paddy wheel, respectively (Table 5).

Table 5. Critical machine gradient observed among the three treatments

| Regions | Rubber Wheel | Extension Device | Paddy Wheel |
|---|---|---|---|
| Pemagatshel | 22.33 ±2.52 | 29.67 ±2.31 | 29.67 ±0.58 |
| Paro | 24.67 ±1.53 | 32.33 ±1.15 | 28.67 ±1.53 |
| Trashigang | 23.00±3.46 | 30.12 ±1.26 | 29.2 ±0.58 |
| Mean | 23.33 ±1.21$^{a}$ | 30.71 ±1.42$^{b}$ | 29.18 ±0.50$^{b}$ |

Values are mean ± standard deviations of the means. Mean values within the rows with different superscripts are significantly different (amongst the three treatments) at $P<0.05$ by Bonferroni correction.

During the analysis (by one-way ANOVA), it was found that there is a significant difference among the three treatments. Further segregation of means of the treatment was done using post-hoc analysis by Bonferroni correction. There was a significant ($P<0.05$) difference between the use of the rubber wheel with normal axle and rubber wheel with the extension device on the stability and no significant difference between the rubber wheel with extension device and the paddy wheel. However, there was no significant difference among the treatments in a particular location. Figure 2 shows the feasible gradient in the three different districts.

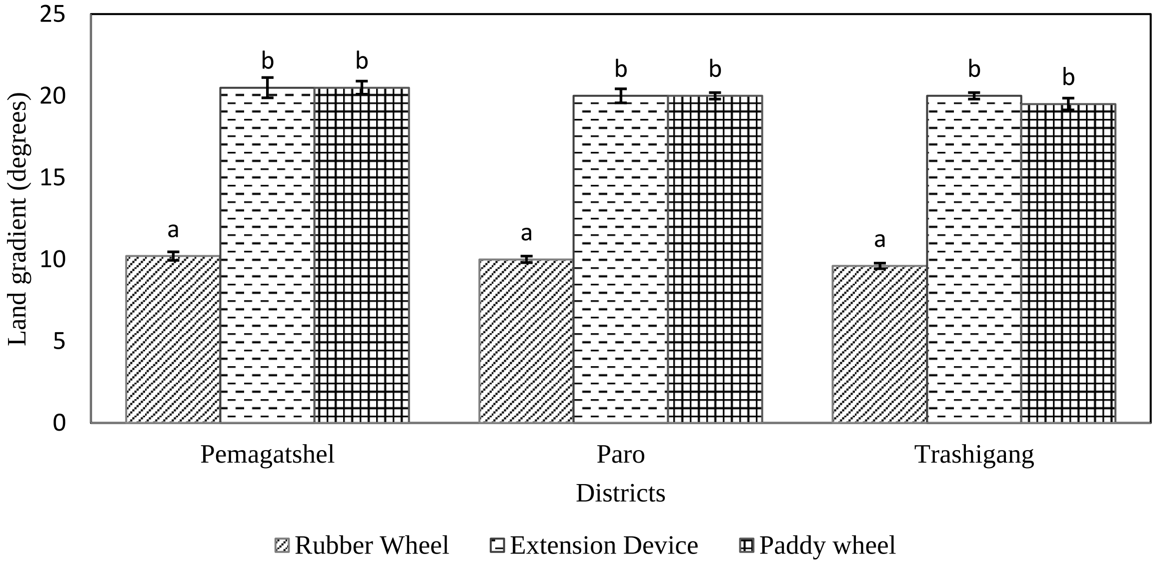

Figure 2. Feasible land gradient in three districts with the three treatments.

Values are mean ± standard deviations of the means. Mean values within a district with different letters indicate a significant difference at $P<0.05$.

Slope manoeuvrability is a very difficult test as the data collected varies from place to place due to geographical diversity. Therefore, we conducted the test in three different districts so that the data collected was generally valid on a gentle to a somewhat steep slope. The usage of extension and paddy wheel decreases the centre of gravity eliminating the risk of toppling and compared to the normal rubber wheel they can go up to 20 degrees. However, if we go beyond 22 degrees, even though the machine remained stable, the power tiller was not able to plough the field due to the downward sliding motion.

The government is encouraging farm mechanization as it makes farming easier by reducing farm drudgery and making farming more productive. Implementation of mechanized farming will create job opportunities and enhance national food self-sufficiency. Since a large percentage of the agricultural land is on slopes beyond the critical angle, the development and consolidation of the lands with slopes greater than the critical slopes will greatly enhance labour efficiency and safety.

### 3.3 Limitation

Although the experiment was conducted efficiently and data collected successfully, certain limitations should be considered before using/interpreting these findings. The key limitations are: (1) the result is applicable for the most common model of the power tiller, Kubota RK125/K120. For other power tillers, the centre of gravity may differ and therefore, the stability might vary. However, the experiment and the procedures to test other machines will remain the same, (2) the precision of the critical angle of the slope determined is limited and may vary with soil structures, moisture content, the skill of the operator, and the ploughing speed, and (3) in stony fields the safety limit of the slope will tend to be lower and will depend on the skill of the operator in stabilizing the machine.

## 4. Conclusion

Farm mechanization starts with land preparation using the power tiller, a machine that is key to preparation. However, due to the rough topography, most agricultural lands in the country are left fallow. The finding of this research indicates that the stability of the power tiller across varying slopes is improved by increasing the wheel tread (using the extension device and paddy wheel). This was achieved by decreasing the centre of gravity in a high slope gradient land, and this could help farmers bring more agricultural land with higher gradients into meaningful cultivation, which ultimately can enhance food production.

The use of power tiller is limited by the topography of our country. Initially, the farmers could not plough above 9 degrees due to machine toppling and the risk associated. Henceforth, Bhutanese farmers can plough land up to a 20-degree gradient easily using the extension device or paddy wheel. This study found that the normal rubber will plough only up to 9 degrees and by using the extension device or the paddy wheel, the power tiller could plough up to 20 degrees. The finding can serve as a way forward for the modification of different types of power tillers to make them suitable for mechanizing land with higher gradients.

## Acknowledgement

The research work was financially supported by the Agriculture Machinery Centre, Paro. The support and cooperation provided by all the farmers during the field experiment are duly acknowledged. We also thank Mr Chetem Wangchen, Farm Machinery Specialist, Paro, and Mr Kinga Norbu, Program Director, AMC, for their invaluable advice and guidance in accomplishing this research.

## References

AMC. (2015). *Power tiller (Kubota-RT125) -Test Report*. Retrieved from Paro, Bhutan

AMC. (2019). *Monitoring and evaluation report on government hiring service*. Paro, Bhutan: Agriculture Machinery Centre, Department of Agriculture, Ministry of Agriculture and Forests

Chhogyel, N., & Kumar, L. (2018). Climate change and potential impacts on agriculture in Bhutan: a discussion of pertinent issues. *Agriculture & Food Security, 7*(1), 1-13. doi:10.1186/s40066-018-0229-6

Ciuffoli, A. (2019). *Stability assessment of agricultural tractors and self-propelled sprayers.* (PhD Thesis), Università di Bologna Bologna, Italy.

Dendup, T. (2018). Agricultural transformation in Bhutan: From peasants to entrepreneurial farmers. *Asian Journal of Agricultural Extension, Economics & Sociology, 23*(3), 1-8.

DoA. (2016). *Agriculture Statistics 2016*. Thimphu: Department of Agriculture (DoA), Ministry of Agriculture and Forests, Royal Government of Bhutan

Guzzomi, A. L., Rondelli, V., Guarnieri, A., Molari, G., & Molari, P. G. (2009). Available energy during the rollover of narrow-track wheeled agricultural tractors. *Biosystems Engineering, 104*(3), 318-323. doi:10.1016/j.biosystemseng.2009.07.005

Hwang, S.-J., Jang, M.-K., & Nam, J.-S. (2021). Application of Lateral Overturning and Backward Rollover Analysis in a Multi-Purpose Agricultural Machine Developed in South Korea. *Agronomy, 11*(2), 297. doi:10.3390/agronomy11020297

JICA. (2016). *The preparatory survey report on the project for improvement of farm machinery for hiring services in kingdom of Bhutan*. Thimphu, Bhutan: JICA - Bhutan.

Kang, N. R., Choi, I. S., Lee, W. J., Woo, J. K., Kim, Y. K., Choi, Y., . . . Yoo, S. N. (2019). Sideways Overturning and Overturning Angle Test for a Three-Wheel Riding-Type

Cultivator. *Journal of Biosystems Engineering, 44*(1), 12-17. doi:10.1007/s42853-019-00008-y

Kinga, N., & Chetem, W. (2019). An economic analysis of government custom hiring services for different farm machineries in Bhutan. *SAARC Journal of Agriculture, 17*(2), 93-101. doi:10.3329/sja.v17i2.45297

Macmillan, R. H. (2002). *The mechanics of tractor-implement performance: theory and worked examples: a textbook for students and engineers*. Melbourne: RH Macmillan.

Norbu, K. (2017). Present situation and future prospect for farm mechanization in Bhutan. *AMA-Agricultural Mechanization in Asia, Africa and latin America, 48*(2), 40-43.

Prabhat, G., Ashish, D., & Kunal, S. (2014). To increase the stability of a tractor by lowering down the centre of gravity. *International Journal of Analytical, Experimental and Finite Element Analysis, 1*(3), 164–168.