Performance Evaluation Of A Hand Tractor To Climbing Sloping Land

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Abstract: Hand tractor is a popular agricultural vehicle in Asia, like Indonesia. Most of the hand tractors are used to soil tillage in paddy fields that are integrated with various types of implements such as plow, rotary, dishes, etc. The challenges a majority of the characteristics of paddy fields in Indonesia is sloping land (with a slope greater than 10°), small in size (5-10 m2 per plot paddy field) and irregular in dimensions between one paddy fields land and another. That requires the performance of hand tractors to be able to work moving between plot paddy fields so that it can achieve all plot paddy fields. Several studies have examined this issue for 4-wheel tractors; however, on the hand tractors have not been studied in depth to date. Therefore, the objective of this study is to analyze the performance of the hand tractor to climbing sloping terrain. The experiment of the field for trajectories of hand tractors is designed with a slope of 10°, 15°, and 30°. The performance of the hand tractor (torque, wheel rotational velocity, forward speed, sinkage, and slip) is measured when the hand tractor climb of the track. Traction efficiency is also calculated to show the level of effectiveness of the hand tractor when climbing of sloping land. The results show that the torque on the hand tractor increases with increasing land slope from 10° to 15°. But after that, the torque will decrease sharply in the condition of the land with a slope of 30°. Wheel rotational speed, forward speed, sinkage and slip of the hand tractor decrease by increasing the sloping angle of the land, respectively. The traction efficiency of the hand tractor also decreases along with increasing sloping terrain.

Index Terms: climbing, hand tractor, lug, paddy field , sloping land, soil tillage, wheel.

1 INTRODUCTION

Hills and mountains account for 28.5% of Indonesia's land area, which is an important part of arable land in Indonesia, as Fig. 1 [1]. Therefore approximately, half of the paddy field surface is not convenient for agricultural vehicles like hand tractors [2]. It is difficult for the hand tractor to be able to mobility in different ridge width, the height of different crops and different slope in hilly, undulating and slope terrain; because of the hand tractor not designed to do that.

Fig. 1 *The condition of rice fields on sloping land in Indonesia*

Unstructured road or soil profiles combined with driving speeds and operating environments create the biggest challenge for agriculture vehicles. Due to this reason there is a growing interest in developing systems that allow the mobility of hand tractors in rugged terrain. Traditionally, the methods by which it has been an improvement in traction and overcoming obstacles have been to increase the diameter and the profile of the wheels or by replacing these with metal tracks. However, hand tractors have serious limitations. The land where they operate must describe a continuous surface and they are not suitable to address obstacles larger then the wheel's radius. Tracked vehicles have the disadvantage of a high impact on the ground, mainly when changing vehicle orientation, which is excessive in some of the applications of these vehicles. Hence, the development of the hand tractors has received increasing interest and has been widely pursued by researchers [3]. On the one hand, several studies on the nature of the tractor in climbing sloping land have been carried out since the last few years as was done by Spencer and Owen [4] in the analysis of four-wheel tractors in crossing sloping land. They designed the device to be able to determine the slope of the trajectory that would be passed by the tractor. It is intended to be able to increase safety in using the tractor in crossing the sloping land. This experiment was carried out on the slope of the test track 20°. Other studies such as those conducted by Febo and Dwyer [5] reported the theory of four-wheel tractors in climbing of sloping land. They found that the coefficient of friction between wheels and ground was an important factor for four-wheel tractors in crossing sloping land. For the condition of the existing tractor, it is only recommended for maximum crossing on the slope of the land not greater than 60°. On the other hand, this research is mostly taken for four-wheel tractors. It causes the current four-wheeled tractors to have better performance compared to two-wheeled tractors. However, four-wheeled tractors are still very infrequently used for agriculture in Indonesia. It is caused by several reasons, such as the initial costs and expensive maintenance costs, and not according to the characteristics of rice fields in Indonesia. The nature of paddy fields in Indonesia incline on the sloping land (with a slope greater than 10°), small in size (5-10 m^2 per plot paddy field) and irregular dimensions between one paddy plot fields to land and another. However, the level of hand tractor needs for farmers in Indonesia is quite large. As done by Sitorus et al. [6] use hand tractors as a driving source for planting equipment. Hermawan [7] reported using a hand tractor by designing a moveable lug wheel for paddy fields in Karawang, Indonesia. However, the current performance of the hand tractors they use has not studied when hand tractors through sloping land/track when moving from one land plot to another. It is thought that it will cause a decline in the performance of hand tractors that have not been fully being discovered on the hand tractors performance. Therefore, to be able to improve its performance

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is an exceptional challenge for researchers farm machinery in Indonesia. Research that can improve the performance of hand tractors is few reported to date. As done by Hermawan et al. [8], were studied the single moveable cage wheels on soil bin. In line with that, Fajardo et al. [9] also carried out the design by varying the lug angle to improve the hand tractor's performance. However, the research study was only carried out in a laboratory using a soil bin and flat plane. Studies in the field to observe the performance of hand tractors using the cage wheel currently available have not been carried out. Additions, the study of hand tractors in climbing sloping land has also not been studied in depth. Therefore, this paper presents the results of analyzing the performance of hand tractor to climbing sloping terrain in the field.

2 Material and Methods

The Yanmar Bromo DX brand hand tractor (popular tractors in Indonesia) is 8.5, 2200 rpm and standard rigid fin iron wheels are used for testing (Fig. 2). The performance parameters measured in this test are wheel rotational speed, forward speed, torque on the wheel shaft, sinkage, slip, and efficiency tractions. The rotational speed of the wheel and the forward speed of the tractor are measured using a rotary encoder sensor and a rotary potentiometer connected to an ATMega3128 microcontroller. The torque on the tractor wheel is measured using a strain gauge sensor that is connected to a personal computer. Sinkage of tractor wheels is measured using an ultrasonic sensor.

Fig. 2. The hand tractors famous in Indonesian farmers

2.1 The testing tracks

The testing track is designed on sloping dry land and is located in the Siswadhi Supardjo LeuwiKopo field laboratory, Bogor, Indonesia. The width and length of the test track are 150 cm 300 cm respectively. The slope variations of the test track are 15°, 30° and 45°. The shape of the testing track is presented in Figure 3.

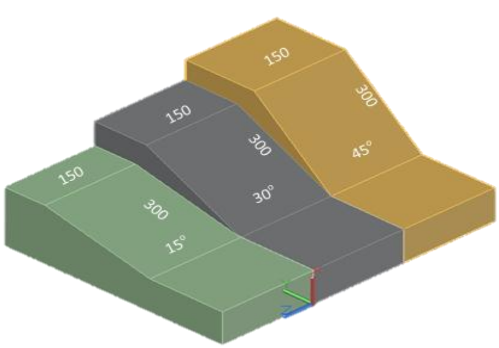

Fig. 3 Test tracks in the field

2.2 Measuring method of torque

Measurement of tractor wheel torque was measured using a strain gauge sensor. The recorded data signals then were converted to digital signals by an A/D converter in a personal computer. The sampling frequency per channel could be varied by a program and was set to 100 Hz. These converted digital signals were processed by a computer program, using their calibration lines, and the results such as figures of lug forces (pull and lift forces) were shown personal computer.

2.3 Measuring method for wheel rotational velocity and forward speed

The wheel rotational speed measurement unit uses a rotary encoder sensor that is connected to an ATMega3128 microcontroller and data logger. The rotary encoder is mounted on the engine pulleys in the gearbox using an additional shaft. Engine rotate speed will be recorded in a real-time sensor which is then stored on the memory card. In order to get the relationship of the wheel rotational speed with the sensor signal, the calibration is performed using a tachometer. The forward speed of hand tractor when climbing the sloping land is measured using a rotary potentiometer sensor that is connected to the ATMega3128 microcontroller. A line is attached to the front of the tractor, and the other end is rolled on a pulley equipped with a rotate spring so that when the tractor advances the pulley will roll the line. The rotation of pulley will be measured by a rotary potentiometer mounted on one end of the pulley shaft. The signal received by the rotary potentiometer sensor will be forwarded to the ATMega3128 microcontroller to be processed and stored on the memory card. In order to get the forward speed connection with the sensor signal, the calibration is performed first using the gage meter and stopwatch.

2.4 Measuring method of sinkage

Sinkage measurement uses an SRF04 ultrasonic sensor that is connected to an ATMega3128 microcontroller. The ultrasonic sensor is mounted on an additional arm attached to the wheel shaft, and the sensors surface side is mounted the ground parallel with the gearbox. The sensor will record the distance from the wheel shaft to the ground. Sinkage can be determined using Equation 1. In order to get a distance relationship with the sensor signal, the calibration is done using the calipers.

$$S_k = \frac{D_R}{2} - U_M \quad (1)$$

2.5 Analysis of hand tractor performance

In order to calculate the performance of the hand tractor, drawbar parameters, power input, and tractive efficiency will be measured and calculated. The drawbar power (P_o) and power input (P_i) in Watt units are calculated using Equation 2 and 3. The tractive efficiency value (η) in units % is calculated using Equation 4. Drawbar pull in this experiment is the mass of the hand tractor parallel to the slope of the test. The pulling load measurement scheme can be seen in Figure 4. The Pulling load can be calculated using Equation 5. Besides, the wheel slip factor due to the interaction of the wheel with the ground is calculated using Equation 2.

$$P_o = p \times v \quad (2)$$

$$P_i = T \times \omega \quad (3)$$

$$\eta = \frac{P_o}{P_i} \quad (4)$$

$$P = W_t \times Sin\ (\alpha) + R_r \quad (5)$$

$$S = \left[\frac{Lt - La}{Lt} \right] \times 100\ \% \quad (6)$$

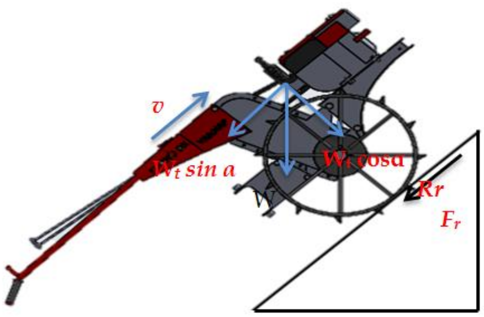

Fig. 4 The scheme of hand tractor weights on the sloping land

3 Results and Discussion

3.1 Soil condition

The characteristics of the soil of the test track are presented in Table 1. The highest water content and porosity are found on the track with a sloping land angle of 15°. The highest dry bulk density is located on a test track with a sloping land of 45°. Deviations from the all test track conditions for parameters of water content, dry bulk density, porosity are 7.51%, 0.026 g·cm^{-3}, and 6.72%, respectively. The average soil consistency in the liquid boundary trajectory is 64.29% with an average plastic limit of 42.22%, and the average plasticity index is 22.06%.

Table 1 Properties of the soil conditions used in the experiments

Sloping land angle (°)	Water content (%,wb)	Dry bulk density (g·cm^{-3})	Porosity (%)	Consistency limits		
				Liquid limit (%)	Plastic limit (%)	Plasticity index (%)
15	54.76	0.98	53.74	66.31	43.33	22.97
30	42.74	0,99	42.56	63.10	41.11	21.99
45	40.95	1.02	41.68	63.46	42.22	21.23

3.2 Driving torque

The torque that occurs on the wheel shaft of hand tractors is the reaction of the ground to the wheel to produce traction and overcome rolling resistance when the wheel moves across the slope. The results of tractor wheel torque measurements are shown in Figure 5. The torque of the hand tractor increases sharply to 561.28 Nm as the sloping angle increases to 30° and then decreases to 448.11 Nm at an angle of 45°. It is because of an increase in the sloping angle which increases the horizontal load on the wheel so the torque will also increase. However, when the sloping angle 45°, slips from hand tractors up to 100%. It indicates that the tractor is incapable of climbing the sloping land so that the recorded torque decreases. This phenomenon shows that hand tractors with existing conditions are only able to climb on the slope angle does not reach 45°.

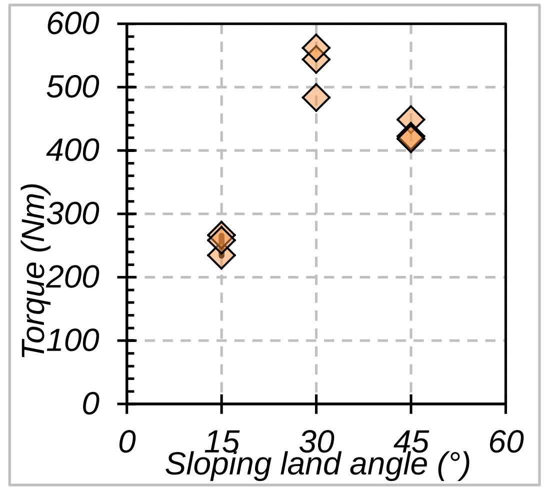

Fig. 5 The relationship of angle of sloping land to torque

3.3 Wheel rotational velocity characteristics of the hand tractors

The results measurements of rotational velocity when the climbing track is shown in Figure 6. The rotational velocity range from 12.34 rpm until 21.67 rpm. The rotational velocity of the wheels decreases dramatically from the slope angle of 15° to 30°. Then the rotational velocity decreases moderately from the slope angle of 30° to 45°. This phenomenon is in line with the results of research by Nguyen and Inaba [10] and Singh and Singh [11] that measure the rotational speed of four-wheel tractor in climbing sloping land. It is caused by an increase in the angle of the slope, which will cause the load received by the tractor to be even more significant so that the forward speed of turning the wheel will decrease.

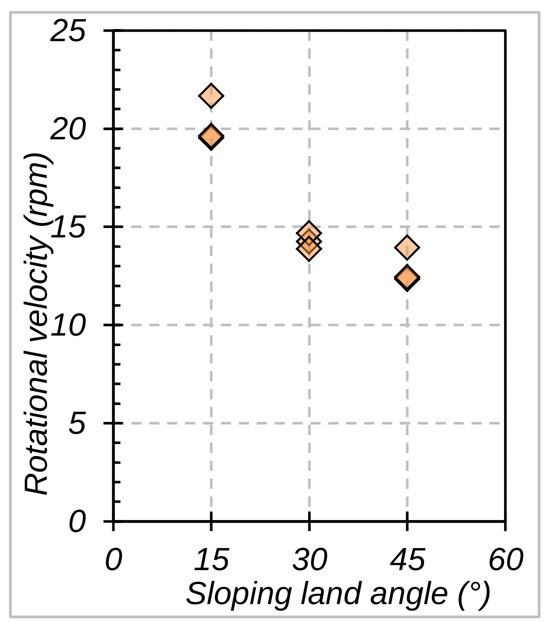

Fig. 6 The relationship of angle of sloping land to rotational velocity

3.4 Forward speed characteristics of hand tractors

The results of measuring the forward speed of a hand tractor when climbing a sloping land are shown in Figure 7. The maximum speed of a hand tractor when climbing a track is 1.12 $m \cdot s^{-1}$. The forward speed of the tractor decreases moderately with increasing slope angles from 15° to 30°. Furthermore, from the slope angle of 15° to 30°, there is a drastic decrease in the linear speed of the tractor. This phenomenon is caused by the increasing horizontal force or attraction experienced by the hand tractor when crossing the slope will reduce the forward speed of the hand tractor.

3.5 Sinkage characteristics of the lug wheels

Sinkage will influences wheel traction. The increase in sinkage causes an increase in wheel traction, which will then be inversely proportional to the slip. The results of tractor sinkage measurements are shown in Figure 8. The results show that sinkage has the trend of a decrease as the slope angle increases. It is caused by the angle formed between the angle of the slope with the angle of the fin of the 45 increases so that the lug difficult to penetrate the soil and cause a decrease in the sinking of the wheel.

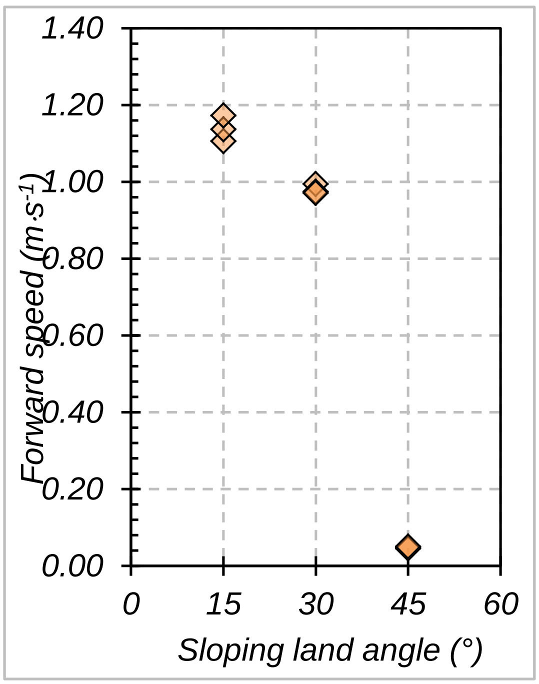

Fig. 7 The relationship of angle of sloping land to forward speed

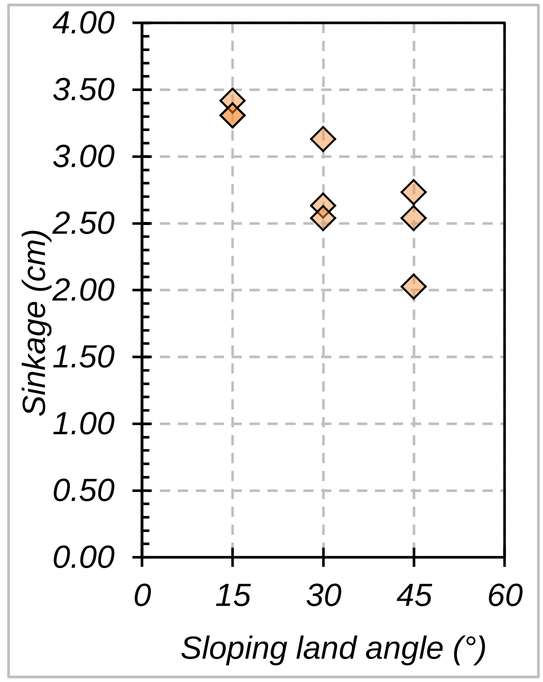

Fig. 8 The relationship of angle of sloping land to sinkage

3.6 Performance of existing hand tractors

The slip and traction efficiency of the testing of the existing hand tractor on the sloping track are presented in Table 2. The results show that the performance of hand tractors using conventional cage wheels has the smallest slip value of 31.97% on a sloping angle of 15 °. Slip on the tractor will continue to increase as the slope angle increases up to 100% at a 45 ° angle. This phenomenon is in line with the results of Alipour et al. [12], Shafaei et al. [13] and Singh and Singh [11] which states that slip is influenced by soil conditions, water content, dimensions of tensile devices, soil pressure distribution and cage wheel design. The highest traction efficiency is 57.11% at a slope of 15 ° and continues to decrease as the slope angle increases to approximately 4.28%. It shows that the amount of traction that can be used by existing hand tractors is still meager for climbing of sloping land. The results research of Żebrowski [14] report that traction efficiency in four-wheeled tractors that have been modified of the traction tool can reach 80%, which previously was smaller than 30%. It shows that the value of traction efficiency allows it to be also increased for two-wheeled tractors through the study of traction tools from the hand tractor.

Table 2 The performance of hand tractors to slip and traction eficiency

Sloping land angle (°)	Slip (%)	Traction eficiency (%)
15	31.97 ± 11.02	57.11 ± 1.94
30	47.02 ± 3.08	46.04 ± 2.72
45	100.00 ± 0.00	4.29 ± 0.24

4 Conclusion

An analysis of the performance of the existing hand tractor in climbing sloping land has been carried out. The maximum torque of the hand tractor is at a slope angle of 30° that is equal to 561.28 Nm. The tractor wheel rotational velocity, forward speed, and sinkage decrease with increasing slope angle. The traction efficiency of the tractor also decreases with increasing slope angle. Meanwhile, the tractor wheel slip will increase by increasing the slope angle. Therefore, existing hand tractors present can only climb sloping land with a sloping land does not reach 45°. The future works from this research are increasing the traction efficiency of hand tractors so that it can climb more than a sloping angle of 45° through the development of traction devices from the hand tractor.

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