Design Analysis Of Narrow Lug Wheel For Wet Paddy Field

Muhammad Idkham, Tineke Mandang, Wawan Hermawan, Gatot Pramuhadi

Abstract: The use of tractor in paddy plant nursering and maintenance is having difficulties because it is not suitable between the wheel width of the tractor and the spacing of paddy which have the effect of damaging paddy.One idea is to develop a narrow lug wheels that can operate between rows of paddy plants. The objective of this research is to finda proper shape and size of the narrow lug wheel components that will be attachedto hand tractor. Data on soiland paddy plant characteristics such as mud depth, row spacing, plant height, panicle shear ability were usedto modify hand tractor wheels.The result of analysis show that a narrow lug wheel for hand tractors operated in lowland rice fields has been designed based on the characteristics of the soil, rice plants and tractor. The construction of the lug wheel is composed of one rim which is reinforced with 4 spokes attached to a flange.The lug plate measuring 14 cm x 21 cm, made of 4 mm thick steel plate , wheel diameter 100 cm , rimdiameter 63 cm, The flange is 20 cm in diameter and made of steel plate 10 mm in thickness, number of lugs (8, 10 and 12) and angle of lugs (30^0 and 45^0).The best type of material selected for steel plate is BJPS and solid round steel is KS 1020 type. The row spacing of paddy plant was 25x25 cm, so the Operating the luged narrow wheels is done by placing three rows of paddy plants between the two wheels with a wheelbase of 61 cm and the operator straddling one row of paddy plants.

Keywords:Narrow lug wheel, wet paddy field, paddy plant, design analysis.

1. INTRODUCTION

THE use of hand tractor inpaddy cultivation isstill limited to land preparation. post-planting activities such as fertilization, pest and weed control are conducted by manual. (human power). This causes the use of hand tractors to be very short, limited, technically and functionally not optimal and inefficient. Mechanization in agriculture is considered as a solution to the problem of lack of labor and high wages as well[6].This happens because the condition of the existing cage wheel does not match with row spacing of paddy on fields, the width of the lug wheel is greater than the paddy row spacing, so the activity of the lug wheel can damage and even destroy the paddy plants.. In addition, paddy field in Indonesia is generally not consolidated or does not have hardpan or the hardpan is too deep [5].Agricultural mechanization innovations is needed to solve these problems, and one of which is by determining the appropriate type of hand tractor wheels such as narrow lug wheel that can operate between the row spacing of plants without affecting the growth of paddy on the fields, and able to produce good traction performance, as well as reduce slip and sinkage.Measurement and analysis of tractors and paddy fields condition is necessary as the basis for the design of narrow lug wheels, include tractor data (dimensions) and paddy fields data (dimensions, row spacing, height and diameter of paddy plants in one clump, resistance of paddy panicles). The purpose of this study is to find the appropriate shape and size of the narrow lug wheel components that will be attachedto hand tractor.

- *Muhammad IdkhamisPostgraduate Student of Bogor Agricultural University (IPB) and lecturer of Syiah Kuala University, Indonesia, PH+628111151979. E-mail: idham_desky2002@yahoo.com*
- *TinekeMandang, WawanHermawan, GatotPramuhadi are Lecturers of Bogor Agricultural University (IPB), Indonesia.*

2 PROCEDURE

2.1 Experimental methods and Equipment

The research was carried out in the following stages: 1. Collecting information about the characteristics of paddy plants, condition of paddy fields, and dimensions of hand tractor, 2. Analysis of paddy parameters, wheel and tractor, 3. Analysis to determine the shape and size of narrow lug wheel, 4. determinethe model of narrow lug wheel for paddy field. The diagram of research activities of developing a narrow lug wheel for paddy fields is presented in Figure 1. The research was carried out in the Field Laboratory "SiswadhiSoepardjo", Department of Mechanical Engineering and Biosystems, Faculty of Agricultural Technology, Bogor Agricultural University.

2.2 Measurement of Paddy Plants and Paddy Fields

Measuring the dimensions of paddy plants in the form of spacing, the size of the clump diameter, height of stems and panicles of plants. The spacing is observed both sideways (left and right) and facing directions (front and back). Data dimensions of paddy plants are very important in designing the building of narrow lug wheels as a functional approach. Wheel Base (WB) is very much determined by the spacing, Ground Clearence (GC) is largely determined by the wheel diameter, the wheel diameter can be determined by the height of the paddy plant, the dimensions of the lug are very much determined by soil conditions and spacing as well. Map the observed land located in Cikarawang village, Dramaga sub-district, Bogor Regency.Plant height was determined by measuring the stem height of paddy clumps and panicles, the height of paddy plants was categorized as 3 levels: 1. Big (highest), 2. Medium and 3.Small (shortest). The level of ability of panicles of paddy friction of objects passing above the surface is also done, to find out how the resistance level of panicles of paddy plants without damage, so that growth, development of paddy plants after being crossed by hand tractors in plant maintenance activities in paddy fields.

Fig.1.*Measuring the dimensions of paddy plants on paddy fields*

2.3 Dimensions of Hand Tractor

The dimensions of the tractor are measured as the basis of the design to determine the shape and size of the the wheels of narrow lug wheels. The dimensions measured are wheel base, ground clearance, and conventional wheel diameter (existing). There are four hand tractor units to be observed, namely: YanmarBromo DX, Yanmar TF. 85ML-in, Kubota RD85 in, Te550. Observations and measurements were carried out in the SiswadhiSoepardjo Field laboratory, Department of Mechanical Engineering and Biosystems, Faculty of Agricultural Technology, Bogor Agricultural Institute. Measuring the dimensions of the hand tractor to determine the diameter of the functional lug wheel model and the smallest volume, so that the parameters of the rim diameter and distance of the radius have sufficient dimensions to cross the paddy field and still have the smallest volume.Related to the design parameters, to increase the traction of narrow lug, the following parameters neded to be considered, the lug angle, lug spacing, lug size, lug shape, lug mechanism and circumferential angle.

2.4 Analysis of Narrow Lug Wheel Design Parameters

Wheel diameter is determined based on the dimensions of the hand tractor, the height of the maximum paddy panicle that is able to withstand friction. Parameter analysis is done to determine the dimensions of the wheel model components that are functional in the field and the lightest. Fig. 2 presents a scheme for determining the diameter of a narrow lug wheel.

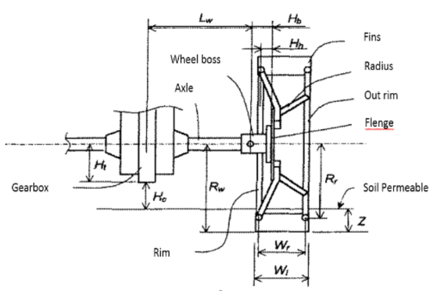

Fig.2.*The scheme for determining the wheel size (Hermawanet al. 2001)*

Based on the schematic image, the minimum size of the outer radius of the wheel can be determined using the equation (1).

$$R_w = H_t + G_c + Z \quad (1)$$

In this case Rw is the outer radius of the wheel, Ht is the gearbox radius, GC is ground clearance and dan is sinkage. In the study of luged lean wheels Ground clearances can be expressed as the vertical distance between the ground surface and the bottom surface of the lower hand tractor (gearbox and axle shaft), GC is determined based on the difference between the maximum height of paddy plants 14 days after planting (HST) with the maximum limit of the friction of the tractor body with paddy panicles. Sinkage is obtained through measuring the depth of the foot that enters the ground.Radius of the rim (Rr) is determined based on the outer radius of the wheel, the height of the lug and its position on the rim. The rim diameter can be determined by the following Equation (2).

$$Rr = Dw - Gt \quad (2)$$

Dw is the outer diameter of the wheel (cm), Gt is the distance of the tip of the lug with the rim [1]. According to [4], cage wheels used in paddy fields have lugs that are wider and fewer in number than cage wheels for dry land. Because the lugs are wider, or the lug pitch is longer, and the number of lugs is less, it is very effective to prevent the earth lumps from sticking or trapping between lugs. The number of minimum lugs from cage wheels for paddy fields can be determined by the following Equation (3).

$$N_l \geq \frac{2\pi}{\cos^{-1}(1-S)} \quad (3)$$

Nl is the number of minimum lugs and S is the expected slip (Sakai et al. 1998). According to the number of simulated lugs, namely 8, 10 and 12. The soil reaction force on lugs can be influenced by the distance (space) between lugs. The closer the lug is, the less ground will be supported. The distance between lugs can be determined using the following Equation (4).

$$S_{as} = 2R_w \sin\left[\frac{180°}{J_s}\right] \quad (4)$$

In this case Sas is the distance between lugs and Js is the number of lugs. Horizontal distance between lugs can be calculated by the following Equation (5).

$$S_{hs} = \frac{(1-S)\pi D_w}{J_s} \quad (5)$$

In this case Shs is the horizontal distance of the lug, S is the wheel slip (Hermawan 2001). The lug angle to be assessed is determined to be 30° and 45° as a comparison of the stress value of the lug. Active lugs are deluged as lugs that enter the ground when the cage wheel is operating.The selection of materials consider on 5 criteria for prospective ingredients, namely: 1. Selected according to the function of the narrow wheel, 2. Selected based on the minimum strength of the material from the strength analysis of the material, 3. Light density material, 4. The material is easily welding and easy to shape, 5 Prices of material, to minimize the cost. In addition, the selection of materials is determined based on the type and shape of the material, according on the type of material selected for low carbon materials and according to the shape of the material selected for the flat and round shaped material. Material selection evaluation method is carried out by weighting index by determining the basics of assessment, namely the strength of the material, density, corrosive resistance, non-stickiness, manufacturing capability, price and market availability.The angle of compression of the lug to the ground (α) <0° or (α)> 90°, the soil reaction force produced can be seen through Fig.3.

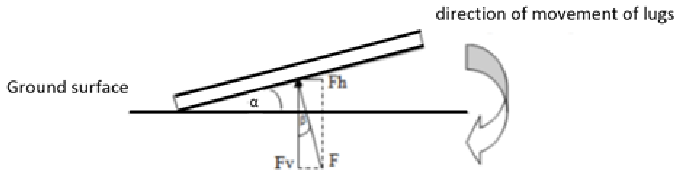

Fig.3*.Sketch the lug angle to the ground with (α) <0° [1]*

Fig.3 shows that the lugs move downward towards the ground. When the lug touches the surface of the ground, the angles are formed by the lug against the surface of the ground (α). The direction Fh is negative with respect to F so that the resultant force of the lug is close to zero ($Fh \approx 0$).

3 RESULTS AND DISCUSSION

The two types of basic data that important for design the narrow lug wheels were the data regarding the paddy plant characteristic in the paddy plots and the data regarding the hand tractor is dimensions. The problem faced by the conventional wheel is that the size of the wheel is not suitable with the dimensions of the paddy field paddy plants. Due to this issue, the field analysis was conducted to obtain preliminary data as the dimension range to design a good narrow lug wheel. Paddy field plots are the size of the land used for wetland paddy cultivation. The plots used in this study were plots in Cikarawang Village, Bogor Regency. The measurements were conducted on paddy plants aged 14 and 28 days post-planting. Paddy cultivation in this village uses the surface irrigation system which did not submerge the field, instead the water condition is that the soil is left to dry until cracks appear as applied in the SRI method (System of Paddy Intensification), with a planting space of 25 x 25 cm and 3-5 seedlings per paddy cluster.

TABLE 1 *THE PADDY DIMENSION CHARACTERISTICS IN THE PADDY FIELD PLOTS DATA*

HST	Spacing (cm)		Height (cm)			dr	H
	X	Y	b	m	s	(cm)	(cm)
14	20	25	46	37	29	3	25
	22	23	46	38	26	3	25
	22	25	33	28	18	3	25
28	23	27	52	41	29	4	30
	20	24	57	41	31	5	30
	23	25	55	39	29	5	25

The selection of materials based on type and shape, the selected material has yield strength characteristics above the determined stress, has good corrosion resistance and manufacturing capability and available on the market according to the dimensions required. The selected material is material produced by Krakatau Steel in Indonesia. The type of plate material chosen consists of BJPS, Galvanized and SS400, and the type of solid round material selected SWRM8, Galvanized and KS 1020. The best type of material selected for steel plate is BJPS and solid round steel is KS 1020 type..The paddy dimension characteristics in the paddy field plots data can be seen in Table 1.The measurements taken were the planting space (S); with the assumption that it is perpendicular to the operator's direction (X) and parallel to the operator (Y), the paddy plant height (H) including the panicle. The panicle is the uppermost part of the paddy plant that is elastic to friction against hard objects. The elasticity of the tip of the plant was defined as the panicle ability limit (BM), plant height was measured as follows: the tallest/largest panicle (b), medium/intermediate height panicle (m), and the shortest/smallest panicle (s) in the paddy plant cluster. Each paddy plant cluster had its seedlings measured, namely the paddy plant cluster diameter (dr).The paddy plants were aged 14 and 28 days post-planting when measured. When measured, the tallest paddy plant was 46 cm; the panicle ability limit was 25 cm. The calculation of the minimum radius for the luged narrow wheel design with an assumption that sinkage was 20 cm was:

$Rw = Ht + Gc + Z$

Rw= 9+ (46−25) + 20

Rw= 50 cm

The rim radius could be determined by calculating the difference between the outermost radius of the wheel Rw and Gt, the distance between the tip of the lug to the rim. The rim radius was determined through the following calculation:

Rr=(50)−(21cos45)

Rr=50−14.85

Rr≤35.15 cm

TABLE 2 *THE DATA OF MEASUREMENTS OF TWO OPERATORS AND WALKING IN THE PADDY FIELD PLOT*

No	Condition	V (m/min)	
		Op 1	Op 2
1	Straddling one row	35.84	34.72
		33.33	35.67
		34.36	37.50
	Average	34.51	35.96
2	Walking interrow	33.86	26.57
		33.67	27.00
		29.50	30.18
	Average	32.34	27.92

The size and shape of the flen is adjusted to the existing wheel condition, it is determined that the flange diameter is 20 cm with a thickness of 1 cm plate material. The paddy planting space in the paddy field plots was used as the basic data to adjust the distance between 2 luged narrow wheels (the wheelbase) used in the hand tractor. The operator's leg position and movement system were also used a basic consideration in determining the wheelbase value. There were two alternatives observed in the field: 1. both legs moved in one row between paddy plants (in the interrow), 2. Both legs moved by stepping in different rows, and when a step was taken, the left and right legs were separated by one row of plants parallel to the operator's movements (the operator straddling one row of paddy plants). The measurements of two people (operators) walking in the paddy field plot can be seen in Table 2.

3.1. TheAngle Adjustment Mechanism, Number of Lugs, and Lock With The Rim

The angle adjustment mechanism was meant to change the position of the wheel lugs at a determined slope. The mechanism was conducted through an analysis of the outer rim diameter, lug height, and angle size parameters. Lugs sized 14 x 21cm were joined with additional plates Fig. 4a and also joined with angle-adjusting pins Fig.4b. Then they were linked with two pins, the upper pin and lower pin on the rim; the lower pin connected to the lug angle-adjusting pin which had two holes to change the angle of the lug toward the soil. The upper pin was connected using an additional lug plate to fix the lug to the rim. The angle adjustment mechanism is presented in more detail in Fig. 4c.

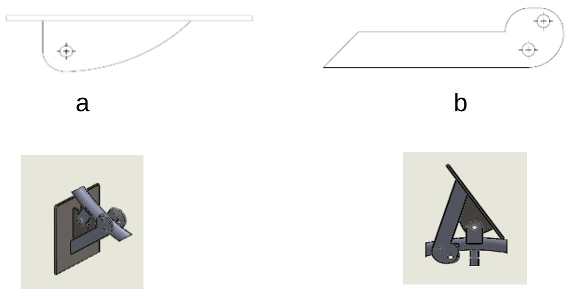

Fig.4. *Lugs with additional plates (a) and the angle adjustment lugs (b), The angle adjustment mechanism (c) and number of lugs mechanism (d).*

The lug number adjustment mechanism was created by analyzing the rim diameter and number of lugs, namely 8, 10, and 12. And then, a corresponding number of pins were made and placed according to the predetermined distance between lugs. The pin had two holes and was locked to the rim by welding it to the center of the rim. The lug number adjustment mechanism can be seen in Fig. 4d.The engineering drawing was made using the 2015 SolidWorks application. The dimensions and form were designed to move in a paddy field with 2-week-old paddy plants. Each component was made individually then assembled on SolidWorks. The engineering drawing of the narrow wheel can be seen in Fig.5.

Fig.5. *The narrow lug wheel model with 12 luged and 45° angle*

3.2.The Hand Tractor Dimension Data

There were four units of hand tractors that were observed: YanmarBromo DX, Yanmar TF, 85MLY-di, Kubota RD85Di, and Te550. The dimensions measured were the wheelbase, ground clearance, conventional (existing) wheel diameter, and tractor weight. The observation data collected from the four units of tractors can be seen in Table 3.

TABLE 3 *THE OBSERVATION DATA COLLECTED FROM THE FOUR UNITS OF HAND TRACTORS*

Tractor	Wheel-base (cm)	GC (cm)	Wheel Diameter (cm)	Weight (Kg)
Bromo DX	60	33	84	250
Te550	40	19	40	61
Yanmar TF. 85MLY-di	70	20	60	196
Kubota RD85Di	50	35	90	320

From Table 3 above, it can be seen that the GC value had a linear correlation to DR and tractor weight, but it was not linear to WB. The WB value ranged between 40 and 70 cm.

3.3. Wheel Parameter Analysis

The lug size was determined at 21 x 14 cm, with a width of 14cm and length of 21 cm. The width of 14 cm was determined based on the distance between the outermost diameter of the paddy plat cluster which was 20 cm and the 2 cm root extension, resulting in a lug width of 14 cm with a 1 cm tolerance, the distance between the lug sides and paddy plat roots. The basis for this decision was to maximize the contact area with the soil and to make the wheel design suitable to its function to traverse paddy fields. The lug length used was 21 cm which was to maximize the lug sinkage with a sinkage of 20 cm and a 2:3 ratio between width and length, resulting in a length of 21 cm. The dimension data was to determine the wheel's minimum number of lugs. The resulting number was 8 lugs with F_{rv} = 1386.789 N and F_{rh} = 1386.78 N. The maximum number of lugs was determined based on the circumference of the wheel. The number of lugs was determined to discover the most suitable number of lugs for its role and to lugd the least number of lugs to reduce the weight of the wheel model.The rim radius was the difference between Rw and the lug height ant a 30° lug angle. The 30° angle was used because it had the greatest multiplication value among the other angles that were to be tested. The rim radius was the difference between R_w and the height of the 30° angle lug. The 30° angle was used as it had the greatest multiplication value among the other angles that were to be tested.

Jr = Rw−(21cos30)
= 50 – 18.18
= 31.72 cm

Selected 31.75 cm so that the rim diameter is 63.5 cm
circumference of the wheel = 2×π×Rw
circumference of the wheel = 2×3,14×50
circumference of the wheel = 314 cm

The maximum number is the circumference of the wheel divided by the length of the lug
Maximum number of lug = 314/21 cm
Maximum number of lug = 14.95 cm

The numbers 8, 10, and 12 were chosen because, in a paddy field, the more lugs there were, the more likely soil clumps would adhere to the wheel and the number of lugs desired was the least one to reduce the weight of the wheel model.

The analysis of data regarding forces working on the lug can be seen in Table 4.

TABLE 4 *THE NUMBER OF ACTIVE LUGS USED AND THE FORCE PRODUCED*

Lugs number	Lugs anggle	Active lugs	Active lugs	Fr(N)	Fh (N)	Fv (N)
8	30°	2.36	3	139.72	69.86	121.00
	45°			69.69	49.28	49.28
10	30°	2.95	3	133.17	66.58	115.33
	45°			76.86	54.35	54.35
12	30°	3.54	3	139.72	69.86	121.00
	45°			114.08	80.67	80.67

The force produced by active lugs was the greatest in 12 lugs at a 30° angle and active angle number 3, resulting in a total lifting force of 139.72 Newtons in active lugs. This value was to be used as a comparison between the theoretical value and simulation value, to determine whether it was true that the greatest reaction value was the result of 12 lugs at a 30° angle. The data from these results were also used to analyze the forces on the wheel due to the soil reaction force.

3.4. LipidThe Wheel Engineering Drawing

The engineering drawing was made by adjusting the dimensions that had been analyzed previously. The engineering drawing was created based on the analysis of dimension parameters and with consideration of the wheel functions and the aim of reducing the weight of the wheel model. A greater number of lugs and a greater radius in the wheel would influence the wheel's weight. The engineering drawing of the luged narrow wheels is presented in Fig.6.

Fig. 6. *Model engineering drawing of the narrow lug wheel*

The trend of the comparison between the number of lugs and the maximal stress value of the wheel at 2 lug angles can be seen in Fig.7.

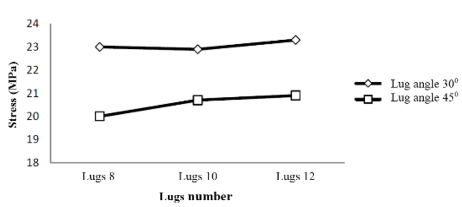

Fig.7.*The maximum stress value of the wheel*

The graph shows the influence trendof the number of lugs on the stress value of the wheel. Thistrend showed that the stress value at a 30° angle decreased at lug 10 and increased at lug 12, because the rim position at 10 lugs was not at the center of the rim. At a 45° angle, there was increased stress in 10 lugs was found compared to 12 lugs because 10 lugs caused the lugs to be positioned not in the center of the rim, but the 45° angle made the lug in that position to receive greater force. From the results above, the optimum wheel model based on the simulation was the wheel model with 8 lugs and 4 spokes because it had the least weight and a 30° angle because it had a higher stress value which is expected to improve traction.

3.5. Illustration Of Implementations The Narrow Wheel

The measurements in Table 1 and Table 2 above show the average walking speed of operator 1 and operator 2 by straddling 1 row were 34.51 m/min and 35.96 m/min, respectively, while the speed when both legs were in one row was 32.34 m/min and 27.92 m/min, respectively. The records demonstrated that the speed on the operator using the first system where the operator straddled one row of paddy plants was better than that of the second system where both of the operator's legs were placed in one row (interrow). This is illustrated visually in Fig.8.

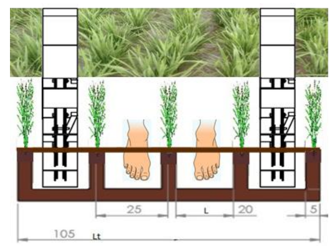

Figure. 8.*Implementations of narrow lug wheel and operators in rows of paddy plants on paddy fields*

The results of the tractor dimensions with conventional wheels and dimensions of the paddy plant characteristic in a paddy field plot can then analyzed using a comparative method, resulting in a luged narrow wheel prototype which could be developed based on the data collected so that narrow lug wheels that can be operated in planted paddy fields for plant maintenance activities such as fertilizer application, spraying, and weeding can be made.

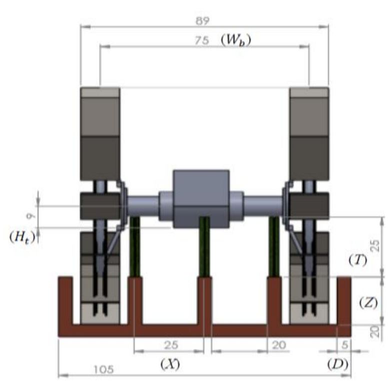

Fig.9. *The dimensions of the narrow lug wheel model on paddy fields*

Based on the planting distance in 14-day-old post-planting plants, the diameter of the paddy plant cluster and operator's walking speed in paddy field plots where paddy plants are growing, the tractor wheelbase using luged narrow wheels was determined to be 61 cm under the conditions of placing three rows of paddy plants between the tractor wheels (three rows of paddy under the tractor's belly) as seen in Figure 18. More details on the functional dimensions of the narrow lug wheel on hand tractor are presented in the Fig.9.Based on

Table 3 above, it is shown that the tractor suitable for the wheelbase value from the analysis of paddy plant characteristics in a paddy field plot was the Yanmar DX Bromo tractor. Therefore, this two-wheel tractor type was chosen for further design and performance tests of the narrow lug wheels.

4 CONCLUSION

A narrow lug wheel for hand tractors operated in lowland rice fields has been designed based on the characteristics of the soil, rice plants and tractor. The construction of the lug wheel is composed of one rim which is reinforced with 4 spokes attached to a flange, and 12 lug plates mounted on the rim. The lug plate measuring 14 cm x 21 cm, made of 4 mm thick steel plate. The lug angle is 30 degrees. The rim is 63 cm in diameter, and made of solid steel cylinder 30 mm in diameter. The spokes are made of solid steel cylinder 15 cm in diameter. The flange is 20 cm in diameter, and made of steel plate 10 mm in thickness. Operating the luged narrow wheels is done by placing three rows of paddy plants between the two wheels with a wheelbase of 61 cm and the operator straddling one row of paddy plants.

REFERENCES

[1] ISCebro. 2006.Computerized Design System for Hand Tractor cage Wheels.[Thesis]. Bogor (ID): Bogor Agricultural University.

[2] Hermawan W. 2001. The Development of Moveable Lug Wheel for a Walking Type Tractor. Final Report. The Young Academics Program Batch IV. Bogor Agricultural University.

[3] Kementan. 2017. BalaiBesarPenelitianTanamanPadi. BALITBANGTAN (BB PADI). http://bbpadi.litbang.pertanian.go.id/index.php/tahukah-anda/358-tiga-fase-pertumbuhan-padi. Jakarta.

[4] Sakai J, Sitompul RG, Sembiring EN, Setiawan RPA, Suastawa IN, Mandang T. 1998. Hand Tractor. Bogor (ID): TEP IPB.

[5] Setiawan, R.P.A., I.W. Astika, D.M. Subrata, A. Azis. 2013. Design of iron wheel of a light tractor for crop maintenance in unconsolidated paddy field. The International Symposium on Agricultural and Biosystem Engineering (ISABE).

[6] Triratanasirichai K, Oida A, Honda M. 1990. The performance of cage wheels for small power tiller. Journal of Terramechanics. 27(3):193-205.