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Pitoyo, Joko

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Doctoral Dissertation

STUDY ON THE EFFICACY AND POWER EFFICIENCY OF WALKING-TYPE POWER WEEDER FOR PADDY FIELDS

(水田用歩行型動力除草機の除草率および
動力効率に関する研究)

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Graduate School of Agricultural Science, Kobe University

Joko Pitoyo

Preface

Weeding on paddy field is still important activity as part of entire activities on cultivating paddy field. Weeding by mechanical control not only eradicates weed between rows but also softens superficial soil and enhances aeration of soil.

Considering the appropriate farm machinery for weeding at paddy field in developing country, the walking type power weeder is one appropriate machine. It because simple in construction and quite light. This walking-type power weeder has rotor weeder as active tool, which it only work in are inter-row, therefore inter-row weeding. The total weight of this machine is less than 30 kg, therefore can be transport easily into paddy field even though in less farm road. The fuel consumption of machine is still big issue for developing country. It has competition to the on farm labor cost.

In order to evaluate the performance of weeder relatives to the power consumption the research was done. Since this machine has simple contruction therefore to do measurement of comsumption power by put a load cell or starin gage has many difficulties. The new power measurement system was proposed instead using conventional load system system. The engine reaction torque as power measurement has been developed. It was proved that the counter force of engine body had correlation to the transmitted torque at the engine shaft. Therefore this power measurement system was appropriate power measurement system instead conventional system which was difficult to be apply at this condition of this machine.

The slippage on the rotor is one important factor in correlation with the weeding efficacy. To make certain variation of slippage on rotor weeder, the modification has been done by adding an additional cage wheel. It was powered by sprocket and chain through rotor shaft. It was revealed that changing in slippage made positive effect on reducing power and energy required on rotor shaft. But, in the other hand, it gave negative effect on weeding efficacy as well as grain yield of paddy.

It has been found that the more the slippage the less power and energy required on rotor shaft of weeder. Reducing slippage of rotor weeder gave negative effect on final weed evaluation as well as grain yield. But the effect of variation of slippage only gave significant effect in 21-DAT plot not for 10-DAT plot.

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List of Symbol

N_r	: rotational speed of rotor (1/s)
V_f	: forward speed of weeder
Z	: number of blades attached to the circumference of rotor
L_p	: length of pitch tillage
V_r	: peripheral speed of rotor weede
R_r	: radius of rotor weeder
S_a	: actual slippage of rotor
ω_r	: rotational speed of rotor (rad/s)
t	: time
S_E	: root-mean-squared error
R_E	: root-mean-squared relative error
T_i	: measured of rotor shaft torque
$\hat{T}_i$	: estimated of rotor shaft torque
S_{th}	: theoretical slippage of rotor weeder
V_w	: peripheral speed of cage wheel
R_w	: radius of cage wheel
N_w	: rotational speed of cage wheel (1/s)
G_r	: rotation ratio between rotor of weeder and cage wheel
DAT	: day after transplanting

P_r	: required rotor shaft power
T_r	: required torque at rotor shaft
E_r	: required energy per length of operation at rotor shaft
W_η	: weeding efficacy
W_t	: number or weight of weed after weeding on treated area
W_{ut}	: number or weight of weed in the untreated area.
N_l	: number of lugs,
v	: expected travel speed of wheel (cm/s)
r_l	: outside radius of the wheel (cm) and
s	: expected travel reduction of cage wheel (in paddy field 0.10-0.20)

I. INTRODUCTION

1.1 Weeding in The Paddy Field.

Rice is one of the most important staple foods in the world. Over 50 percent of the world population depends on rice for about 80 percent of its food requirements. About 95 percent of the global output of rice is produced and consumed in developing countries. Important progress has already been made. With the slowdown in the growth of rice production since 1990, however, it has become increasingly important to renew efforts to sustain this crop in order to meet the increasing demand ⁴⁾. Weeding is one of the important activity on growing of rice.

Weed species that cause problems in rice vary with soil, temperature, latitude, altitude, rice culture, seeding method, water management, fertility level, and weed control technology. The current major weed species in paddy rice fields in Japan are annual species such as; barnyard grass, smallflower umbrella sedge (*Cyperus difformis*), monochoria (*Monochoria vaginalis*), toothcup (*Rotala indica*), false pimpernel (*Lindernia* spp.), ammannia (*Ammannia multiflora*) and others, while common perennial ones are knotgrass (*Paspalum distichum*), mizugayatsuri (*Cyperus serotinus*), spikerush (*Eleocharis acicularis*), bulrush (*Scirpus juncooides*), sagittaria (*Sagittaria pygmaea*) and others ⁸⁾.

The serious weeds in Japanese paddy fields have changed since the introduction of herbicides ⁶⁾. Before herbicides, a mixed weed community including barnyard grass, annual broad-leaved species such as monochoria and some perennial species was controlled by hand weeding and use of the rotary weeder. The important weed in Japanese paddy field are listed in Table I-1

Table I-1 Important weed in Japanese paddy fields ⁶⁾

Annual species	Perennial Species
Grasses	Grasses
<i>Echinochloa oryzicola</i>	<i>Leersia oryzoides</i>
<i>E. crus-galli</i> var <i>crus-galli</i>	<i>Paspalum distichum</i>
<i>Leptochloa chinensis</i>	Sedges
Sedges	<i>Cyperus serotinus</i>
<i>Cyperus difformis</i>	<i>Eleocharis acicularis</i> var. <i>longiseta</i>
<i>C. iria</i>	<i>E. kuroguwai</i>
Broadleaves	<i>Scirpus juncooides</i> var. <i>ohwianus</i>
<i>Ammannia multiflora</i>	<i>S. nipponicus</i>
<i>Biden frondosa</i>	<i>S. planiculmis</i>
<i>B. tripartite</i>	Broadleaves
<i>Eclipta prostate</i>	<i>Alisma canaliculatum</i>
<i>Ludwigia epilobiodes</i>	<i>Sagittaria pygmaea</i>
<i>Lindernia procumbens</i>	<i>S. trifolia</i>
<i>Monochoria korsakowii</i>	<i>Oenanthe javanica</i>
<i>M. vaginalis</i> var. <i>plantaginea</i>	Algae
<i>Persicaria hydropiper</i>	<i>Spirogyra arcla</i>
<i>Rotalia indica</i> var. <i>alignosa</i>	<i>Phitopora zelli</i>

(Shibayama 2001)

In Japan on the 1980s, ‘one-shot’ herbicides were introduced as compound herbicides which would control annuals and widely distributed perennials listed above by a single application. Since they have come into use with that competition removed, the perennial sedge kuroguwai (*Eleocharis kuroguwai*) and the perennial broadleaved weed arrowhead (*Sagittaria trifolia*), together with some other species, have become the new problem ⁶⁾.

Many ecological and crop production principles influence the presence and abundance of species or groups of weeds in rice fields. Important factors include seeding method and soil moisture regime, crop rotation, air and soil temperatures, land preparation, fertilization, rice cultivar, weed control technology, and the interactions of those factors.

In Japan, weeding of rice paddies required more than 500 labor hours/ha before herbicides became available. If 300 labor hours/ ha were needed for manual weeding, labor cost per hectare would be more than \$260 in South Korea, \$1,000 in Japan, and \$200 in Taiwan. If one application of a typical soil-applied herbicide gave similar control to hand weeding, chemical weeding would cost roughly less than \$40/ha (materials and labor) in Taiwan and South Korea. Japanese statistics indicated a cost of about \$120 for herbicide (applied twice yearly on the average) and \$222 for labor (herbicide application plus manual weeding), a total of \$342, to control weeds in 1 ha of rice in 1979. The labor requirement for weeding was 9.5% of total labor in 1979, whereas it was more than 20% in the early years of herbicide use. Such a reduction in the percentage of weeding labor implies that herbicides have contributed to labor saving to a greater extent than has mechanization ⁸⁾.

1.2 Walking-Type Power Weeder

1.2.1 Overview of Walking–Type Power Weeder

Rotary weeder, with or without an engine, is useful in weed control, and some Japanese farmers still like to use it. Rotary weeder is often used to control perennial weeds which emerge late from deep underground tubers after annual weeds have been controlled by herbicides. However, this method is suitable only for small-scale farmers, who do not suffer from a labor shortage, as it involves a great deal of heavy work⁷⁾. The mechanical weeding is one solution to solve it. Mechanical weeding, a classical control method, is one of the most viable techniques that can be adopted easily by balancing biological. Walking-type power

weeder is simple machine but useful for weeding in paddy field especially in developing country.

Despite some disadvantages, the use of rotary weeder and hand weeding may be the most effective methods for controlling annual and perennial weed in paddy field. One pass over the transplanted rice fields between 10 to 15 days after transplanting is desirable time⁶⁾. Two times of hand weeding at about 20 days and 40 days after transplanting will be sufficient to control weeds, save labor and increase rice yield ⁶⁾. The capacity and efficiency of this machine was higher than the manually push-pull weeder. Depend on the condition and weeding date, the efficiency could be reach until 90% ⁶⁾.

The working mechanism of walking-type power weeder is similar with rotary axle which mostly the efficacy depends on the slippage of rotary. The important component are rotor which mostly 36 cm in diameter and attached by 6 units of blade. The rotor are rotated around 200 rpm and by function of resistant bar the operator could handle and adjust the forward speed of this machine to be convenience for walk in paddy field around 1 – 1.6 km/h. By those condition, the number of slippage of walking type power weeder around 88 – 93 %. By those number will give effect on optimum efficacy of weeding. To keep the certain number of slippage on rotary axle, operator should control the handle of machine

Traveling speed for operating walking type two-wheel tractor in the field are vary depend to the type of farm work¹⁷⁾. The travel speed of two wheel tractor is shown in Table I-2.

Table I-2 Travel speeds of two-wheel tractors

	(cm/s)	(km/h)
Rotary tillage	26- 50	0.9-1.8
Miscellaneous filed wark*	50 – 70	1.8-2.5
Plowing	70 – 120	2.5 – 4.3
Transportation**		15 or 25 or 30

(Sakai 1999)

* Puddling, inter row cultivation, seeding, mowing, etc

** Normally traffic law may determine legal speed. actual max speeds may be set by local customs

The construction of walking-type power weeder is very simple. It has a light on weight, which purposed to be easy for operator during turning by lifting this machine. In order to get light weight machine, this machine has simple transmission. Mostly, two-stroke engine is installed which has a simple centrifugal clutch. From the engine shaft power is transmitted to rotor shaft through a worm gear within high reduction gear ratio. The operational of this machine also very simple, by increasing throttle of the engine, the power will be transmitted and to stop just decreasing the throttle of the engine.

For the walking-type power weeder, the value of slippage of rotor varies. It depends on soil condition and operator. The operator, when operating this machine is necessary to lift or push up the handle to make resistant on this machine through resistance bar devices. The level of slippage on walking type power weeder is very crucial as described in equation (I.1) and (I.2) and has consequences on its performance. Since the operator and soil condition are not constant and same, therefore the performance of this machine will also fluctuate. When the operator walks too slow or pressing on the handle too much, the rotor will produce more slippage. By that condition, the machine tendency to be over slippage and less field capacity.

Otherwise, when operator walks too fast and less pressing on the handle, the field capacity will high but possibility less in less in weeding efficacy. The outline view of walking-type power weeder is shown in Fig I-1

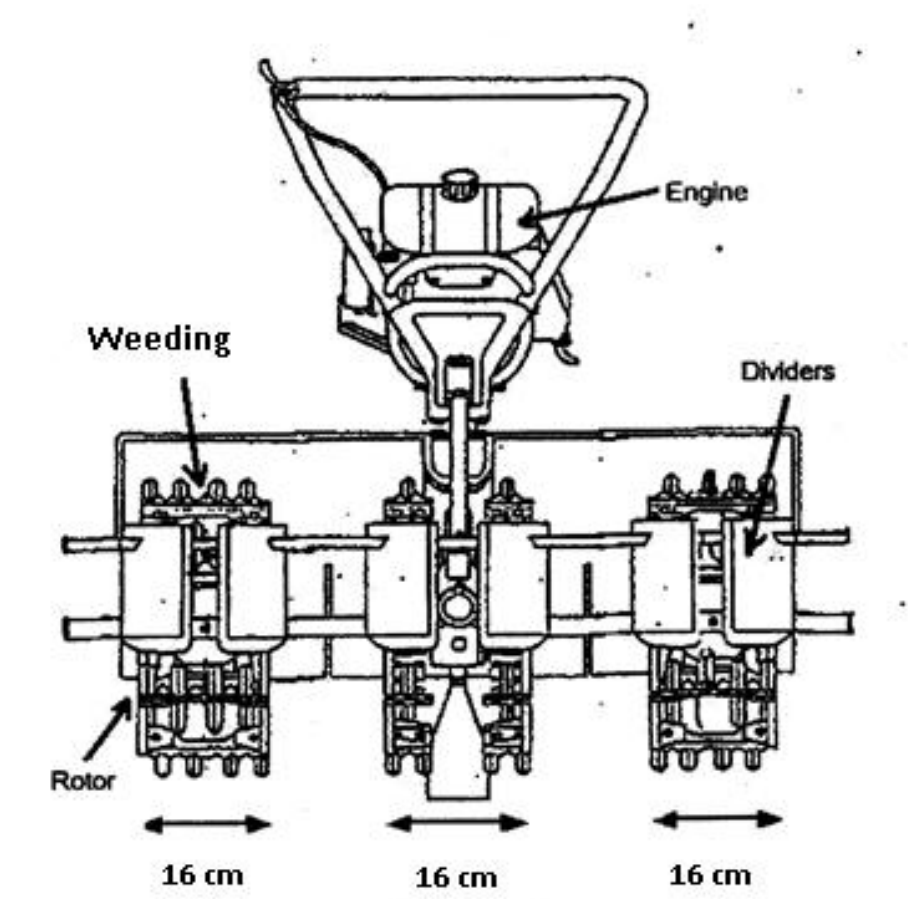


Fig. I-1 Outline view of walking type power weeder.

Walking-type power weeder has been developed in Indonesia by Yanmar Indonesia through cooperation research with ICAERD (Indonesia Center of Agricultural Engineering Research and Development) as Agency of Agricultural Research and Development Ministry of Agriculture of Indonesia in 2004 – 2009. The product has been introduced to the farmer through some pilot projects in several center of rice fields. The machine has 2 rows, diameter of rotor 48 cm which attached by 8 blades at circumference of it. The big diameter of rotor was designed to adapting the condition paddy field of which have deep hard pan. The

rotation of rotor is around 175 rpm and when operated at actual travel speed around 1 km/h resulted slippage number around 92 %¹⁹⁾

The field performance of this machine on some normal hardpan condition are quite good. Condition of paddy field in Indonesia are varies, on the extreme deep hardpan the slippage become high which effected to the field capacity and also fuel consumption. Therefore, the efforts to solve that problem is needed. The research on evaluation of walking type power weeder by evaluate the correlation of slippage of rotor weeder to the efficacy and power consumption is necessary. The photo of product Yanmar Indonesia walking type is shown in Fig. I-2

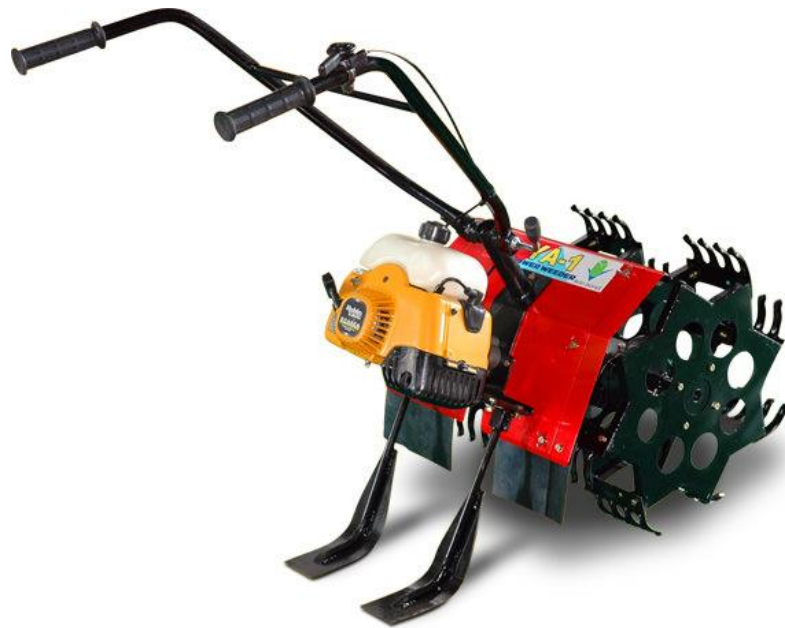


Fig. I-2 Yanmar Indonesia walking-type power weeder YA-1¹⁹⁾

1.2.2 Locus Simulation of Blade of Walking-Type Power Weeder

The working performance of rotating blades of power weeder is similar with the rotary tiller, which has a correlation to the size of cutting soil or pitch tillage. The different between rotary tiller and walking type power weeder are on the device to control forward speed. The forward speed of power weeder is depend on the interaction of rotation of the rotor and

resistance bar device which located on the rear of the machine. The correlation among of the parameters on rotor blade of weeder is drawn in equation (I-1);

$$N_r = \frac{1000V_f}{ZL_p} \quad (I-1)$$

Where N_r is rotational speed of rotor (1/s), V_f is forward speed of weeder (m/s), Z is number of blades attached to the circumference of rotor and L_p is the length of pitch tillage (mm). Here the important parameter is length of pitch tillage because it will effect on the performance of weeder. The smaller the length of pitch tillage the fine the muddy soil cut by the blade.

The forward speed of walking-type power weeder is depend to the capacity and comfort ability of operator. Since the size of pitch tillage is decided and number of blade also known, the rotational speed of rotor can be calculated. After the rotational speed of rotor is obtained, then the peripheral speed of rotor weeder can be calculated by equation (I-2), it will be assumed as theoretical forward speed as follow:

$$V_r = \frac{2\pi N_r R_r}{60} \quad (I-2)$$

where V_r is peripheral speed of rotor weeder (m/s) and R_r is radius of rotor weeder. Normally, V_r is faster than average of forward speed in the paddy field which suitable for operator. Since there is different between peripheral speed on the rotor and the actual forward speed, next, the slippage of rotor can be calculated by equation (I-3):

$$S_a = \frac{2\pi N_r R_r - V_f}{2\pi N_r R_r} \quad (I-3)$$

where S_a is actual slippage of rotor (%).

Theoretically, the locus of the tip of rotor blade of power weeder will dynamic and change anytime and can be described in Y and X as shown in equation (I.4) and (I-5) respectively:

$$Y = R_r \sin(\omega_r t) \quad (I-4)$$

$$x = V_f t + R_r \cos(\omega_r t) \quad (I-5)$$

Where ω_r is rotational speed of rotor (rad/s), t is time (s).

The simulation of locus of rotor weeder will show the mowing pattern of blade rotor weeder. It will cut the soil and will resulted in the variation of pitch tillage. It will vary depend on the changing of others parameter as mentioned from equation (I-1) until (I-5).

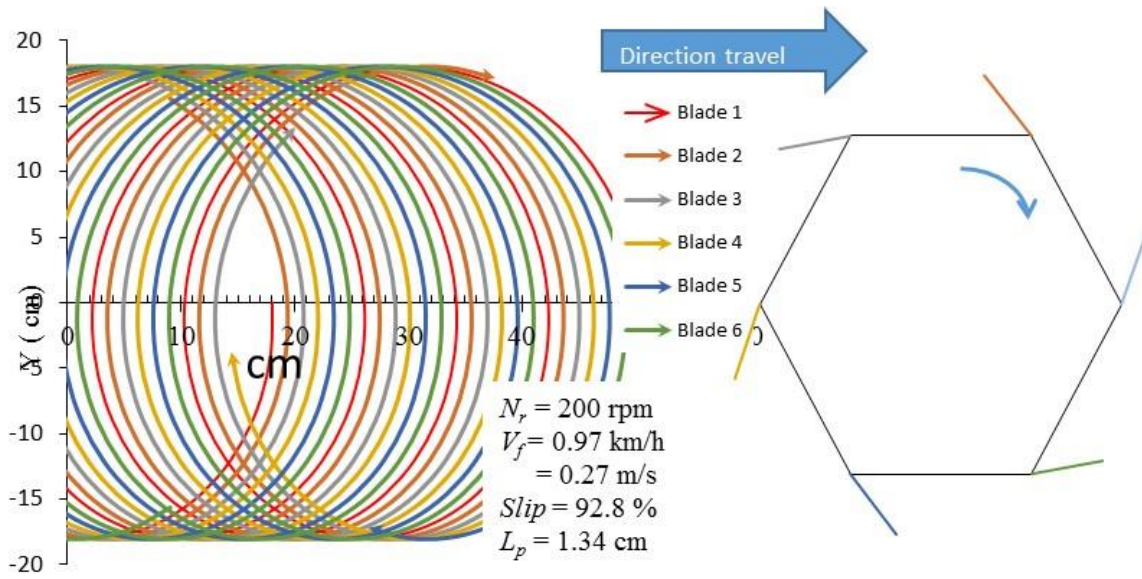


Fig. I-3 The locus simulation of rotor blade at $V_f = 0.27$ m/s , $Slipp = 92.8$ % , $N_r = 200$ rpm.

+

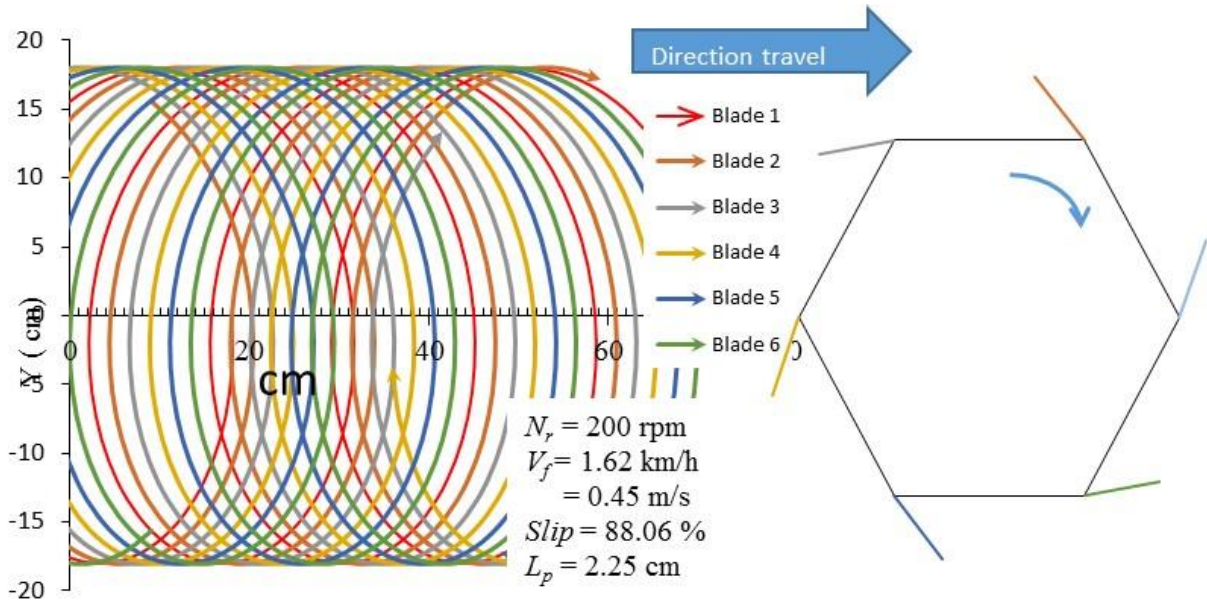


Fig. I-4 The locus simulation of rotor blade at $V_f = 0.45$ m/s , $Slipp = 88.06\%$, $N_r = 200$ rpm.

Fig. I-3 show the simulation of blade of rotor weeder, where the parameters are set: forward speed (V_f) 0.27 m/s or equal 0.97 km/h, rotational speed of rotor 200 rpm, slippage 92.8% , therefore the pitch tillage is 1.34 cm. While another simulation by set; the forward speed (V_f) 0.45 m/s or equal 1.62 km/h, rotational speed of rotor 200 rpm, slippage 88.06% , therefore , the pitch tillage is 2.25 cm as shown in Fig. I-4. Refer to equation (I.1), it can be concluded that theoretically when the rotational speed of rotor is constant, the size of pitch of tillage will increase proportionally to the forward speed.

1.3 Supporting wheel For Walking-Type Power Weeder

The recent prototype of walking type-power weeder are designed as light and simple machine, which consist of rotor of weeder as main component of weeding and a resistant bar as a tool to control the forward speed of rotor weeder which by adjusting pressure on it. Operator of walking-type power weeder are requested to adjust pressure on resistance bar by raising or lowering the handle. Those action should be done while work on the paddy field. Hand tractor with rotary plow is agricultural machinery, which have similarity with walking-

type power weeder in working mechanism. The difference, hand tractor has cage wheel for supporting and keeping the forward speed otherwise on walking-type power weeder. By the supporting cage wheel on hand tractor, operator become easier for operating the machine, just following the machine without raising or lowering the handle.

According Sakai (1999), hand tractor have a variety of names likes: single axle tractor, hand tractor, walking tractor, walking-behind tractor as shown on Fig. I-5 ¹⁷⁾

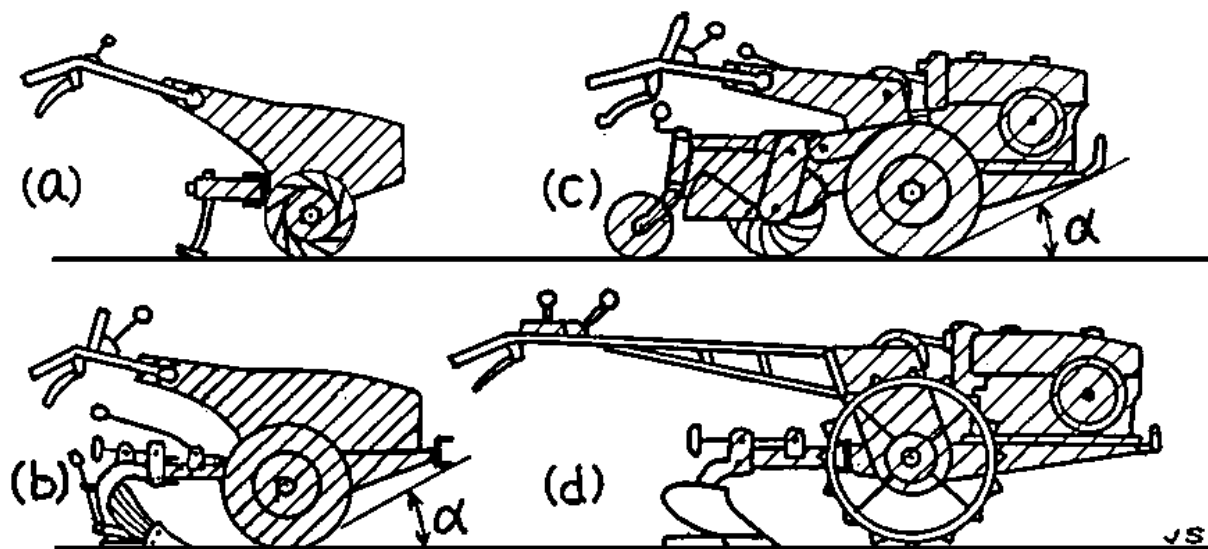


Fig. I-5 Type of two-wheel tractor (Sakai)

The tractor in Fig I-5 is classified as a mini-tiller type (1.5-2.2 kW). This machine can work by attached blades on rotor and for controlling the travel speed and effectiveness of work a drake-stake is installed at the rear hitch of the machine. This machine also called a motor tiller of wheel less cultivator, it usually used for only small hobbies gardening other than professional farming. While for Fig. I-5b is called traction type (2.9 – 4.4 kW), which used for plowing and towing a trailer, can used for rotary tillage. In some Asia countries, IRRI on 1970s had been developed such kind of tractor. For Fig. I-5c, it known a rotary power tiller and has weight around 300 – 400 kgf. When the rotary implement is coupled at behind the machine, process of tillage and harrowing can be done.

More ever, cage wheel are classified into two types i.e. upland and wet land cage wheel¹⁷⁾. The number of lugs attached on rim for upland has more than wetland. Fig. I-6. show the wetland cage wheel which normally used in paddy field, it has 6-12 lugs. By wider lug spacing and small number of lug has purpose for easy allow the adhesive soil falling dawn and to avoid stuck on the cage wheel.

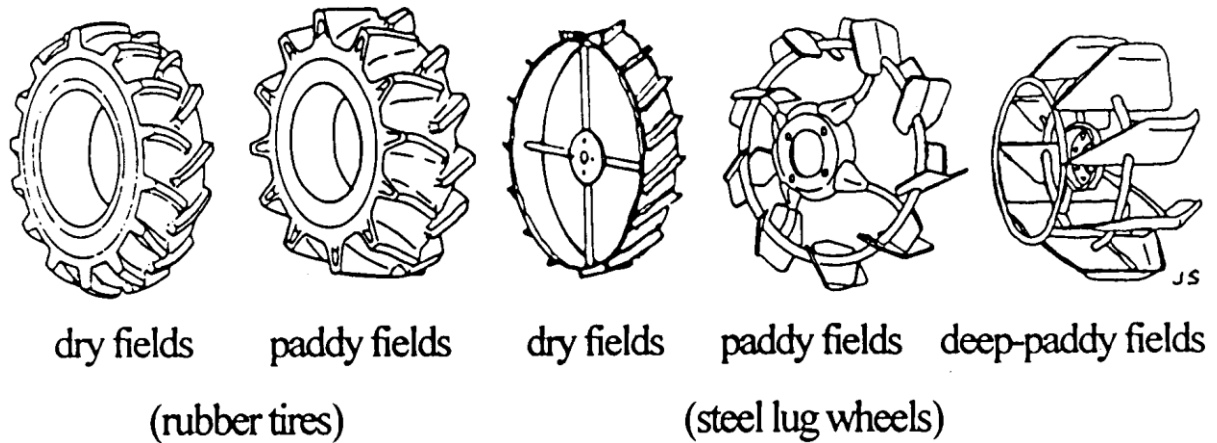


Fig. I-6 Rubber tired wheels and steel wheels (Sakai 1999)

Sakai (1990)¹⁷⁾ has developed the equation for determining number of lug (N_l) as below:

$$N_l \geq \frac{2\pi}{2 \cos^{-1}(30v / \pi r_1)} \quad (I-6)$$

$$N_l \geq \frac{2\pi}{\cos^{-1}(1-s)} \quad (I-7)$$

Those formula are determined by consideration that the lugs should be given a maximum lug spacing to move only downward and backward direction as illustration shown in Fig. I-7 .

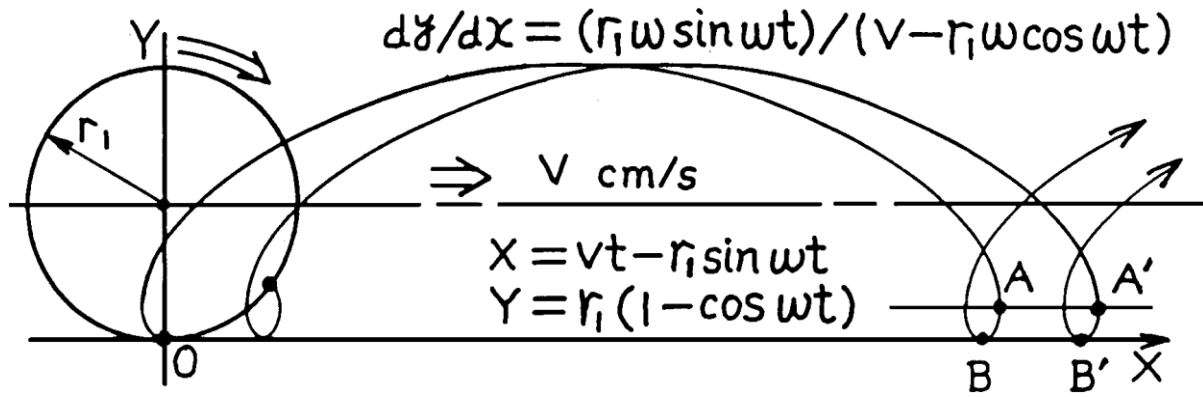


Fig. I-7 Minimum number of lugs (Sakai 1999).

Where N_l is number of lugs, v is expected travel speed of wheel (cm/s) and r_l is outside radius of the wheel (cm) and s is expected travel reduction of cage wheel which usually in practical value 0.10-0.20 in paddy field.

In power tiller machine, the traction power is important, it resulted from interaction of traction device and soil surface. In wet condition, farm machinery require special traction. When soil in wet, it become soft and has less bearing capacity. Furthermore, slip of wheel and sinkage is increased then tractive efficiency is decreased.

In the other case, cage wheel installed on rotary type implement, it has main function to support the machine from sinkage on the soft soil and to keep the machine for moving not too fast rather than to generate traction force. Generally, the tractive force will generated by rotation of rotary implement which will add the tractive force generate by cage wheel. Therefore, design of cage wheel on such kind rotary type implement machine is need to be consider for minimizing sliding or negative slippage and giving supporting force to avoid machine sinkage on the muddy soil, rather than focusing on generate traction force.

II. POWER MEASUREMENT ON WALKING-TYPE POWER WEEDER BY BODY ENGINE REACTION TORQUE

2.1 Background

Self-propelled small farm implements, originally developed in Japan, such as rotavators, weeders, or ridgers, which usually around 1 to 2-kW gasoline engine directly connected through a centrifugal clutch, are useful in developing countries. Considering their dissemination especially in resource-poor countries, fuel consumption is an important factor in evaluating their efficacy in soil pulverization, weeding rate, and crop growth, where additional research and development under different local condition is needed.

Instead conventional put load cell or strain gage on the shaft which wanted to be measure, the utilize anti torque mechanism is an simple solution. When the body of engine is freely rotate within the output shaft itself and produce torque the torque, the body of engine will generate the torque which to preventing act of the generated torque by opposite direction⁹⁾.

Instruments are needed for measuring both rotational speed and torque to determine power consumption in real time by the machine. The focus has been on torque sensing since it is more complicated than the rotational speed sensing. The most typical method is to adhere strain gauges to the rotating shaft and to acquire the signal through slip rings. The slip rings are, however, expensive and sensitive to water and dirt that are commonplace with such implements. The measurement of torque on shaft by detect the angle of shear stress, which was proportional to the torque, it done by installing two pulse generators on a loaded shaft at some distance to sense minute phase differences associated with torsion³⁾. Torque measurement using magneto resistance has been reported by Takenaka and Kawai, in which torsion angle of magnet coupling from two sensors are sensed and converted to the torque¹⁰⁾.

Tomita *et al.*, (2010) have devised a torque meter with strain gauges that transmits the signals wirelessly, and mounted it into the pulley of the engine in a combine harvester²⁾. A counter-torque sensor has been developed for measuring a small cutting torque through a piezo film sensor adhered between the carrier and the stopper on a milling machine ¹¹⁾.

In this study, a walking-type power weeder is focused to evaluate its efficacy in terms of its power requirement while operating in the field. To put the above-mentioned concepts into effect, however, considerable modification is requisite because of the limited space around the main rotor shaft and the transmission shaft. The objectives of this study are to develop a new method of sensing the torque for the power weeder and to calibrate and validate the sensing system.

2.2 Material and Methods

A commercially available three-row walking-type power weeder was used as the platform (Fig. II-1 and Table II-1).



Fig. II-1 Walking-type power weeder in the paddy field

Table II-1 Specifications of the power weeder

Manufacturer	Otake (Ama-gun, Aichi, Japan)
Type of machine	HK4-5CKS
Size	1350 (L) × 830 (W) × 840 (H) mm
Engine	2-stroke gasoline, 1.6 kW at 7000 rpm
Mass	22.5 kg
Number of rows	3
Row spacing	300-330 mm
Reduction ratio of worm gear	33 : 1
Diameter of rotor	360 mm

The rotor shaft was driven through the worm gear at a reduction ratio of 33 to 1; therefore a high rotational speed of the engine was reduced to around 200 rpm at the rotor shaft. Here, engine reaction torque was measured without slip rings, instead of torque on the rotor shaft. The housing of the centrifugal clutch, connected directly to the engine, had been inserted into the pipe frame of the weeder and tightened with two bolts. The modification was done to slightly increase the diameter of the housing from 27.0 mm into 27.3 mm to allow clearance between the pipe frame and the housing of the centrifugal clutch, so that the housing could rotate freely within the pipe frame as a sliding bearing when greased (Fig. II-2). Since the engine was not heavy, it was supported by this simple structure, and the sliding motion of the bearing was smooth. In order to minimized the friction between pipe frame and housing the grease is applied as necessary during operated.



Fig. II-2 Re-installation of the engine and its peripheral parts of power weeder

The housing was fitted with an extended arm, then connected through two ball joints and a J-hook to a 50-N cantilever load cell (TU-CR-5k, TEAC, Tokyo, Japan), whose other end was fixed to the pipe frame of the weeder (Fig. II-3). By multiplying the force of the cantilever load cell with the length of the extended arm that was measured from the center of the engine shaft to the point of application (180 mm), the measured force was converted to engine reaction torque. The J-hook and the ball joints were connected to the load cell at one end and to the extended arm at the other. The base of the ball joint on the right connected to the extended arm through a hole with double nuts supported only one direction of the rotation of the engine (one-side stopper). It allowed the operator to ascertain that the load cell was clearly disconnected when the centrifugal clutch was off at a low rotational speed, so that the zero-point of the engine reaction torque was properly recorded and defined at the beginning of each run.

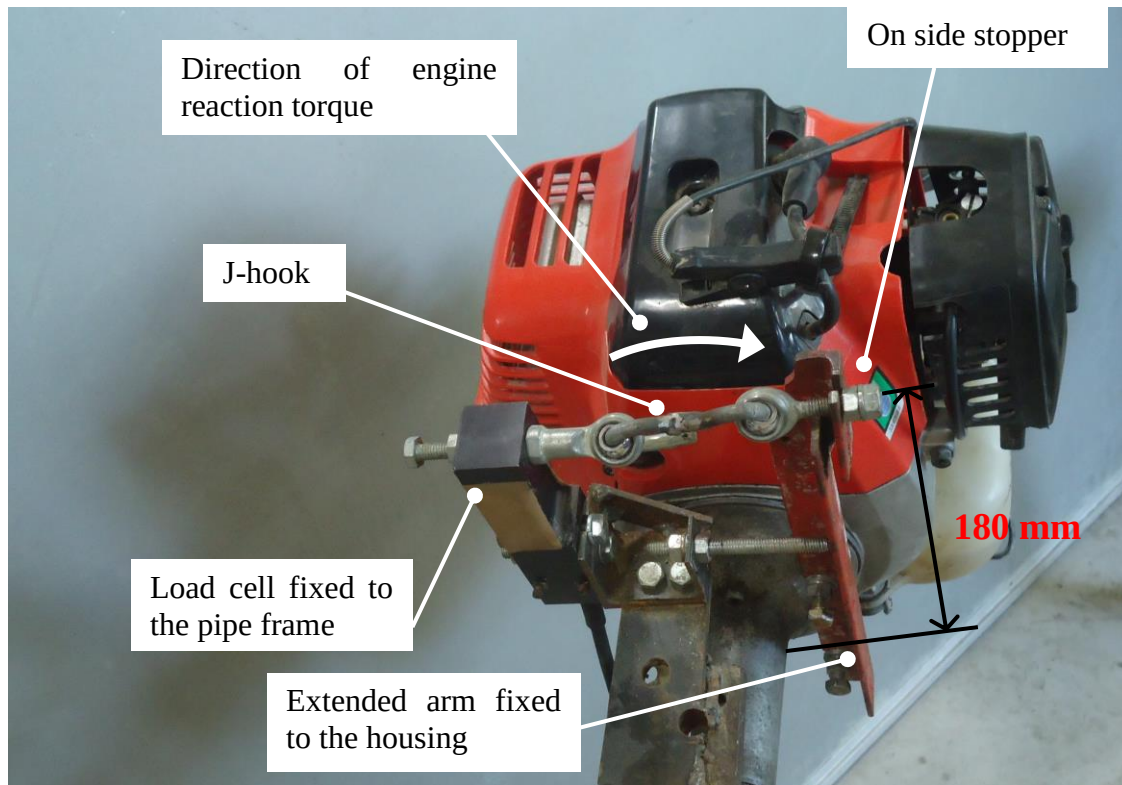


Fig. II-3 Installation of the load cell for measuring engine reaction torque.

To measure the rotational speed of the engine, an ignition pulse detector (IP-3000A, Ono Sokki, Yokohama, Japan) was affixed to the ignition cable of the engine. In the laboratory, the engine reaction torque was calibrated to the rotor shaft torque, and the experimental apparatus were arranged as illustrated in Fig. II-4 and Fig. II-5. An electromagnetic brake (111-12-13G, Miki Pulley, Zama, Kanagawa, Japan) was installed onto the rotor shaft as the load calibrator, which received an electric current regulated through a variable resistor\ to generate a range of loads. The base of the brake supported by bearings was fitted with an arm at the end of which touch to a 500-N load cell (TU-CR-500N, TEAC, Tokyo, Japan). The rotor shaft torque was then calculated by multiplying the force at the load cell by the length of the arm (300 mm) as in Fig. II-4. The output from all the transducers was processed and recorded (DR-CIMKII, TEAC, Tokyo, Japan). The sampling

rate was set at 50 Hz with the low-pass cut-off frequency at 20 Hz, which was aimed at canceling the vibration directly caused by the rotation of the engine.

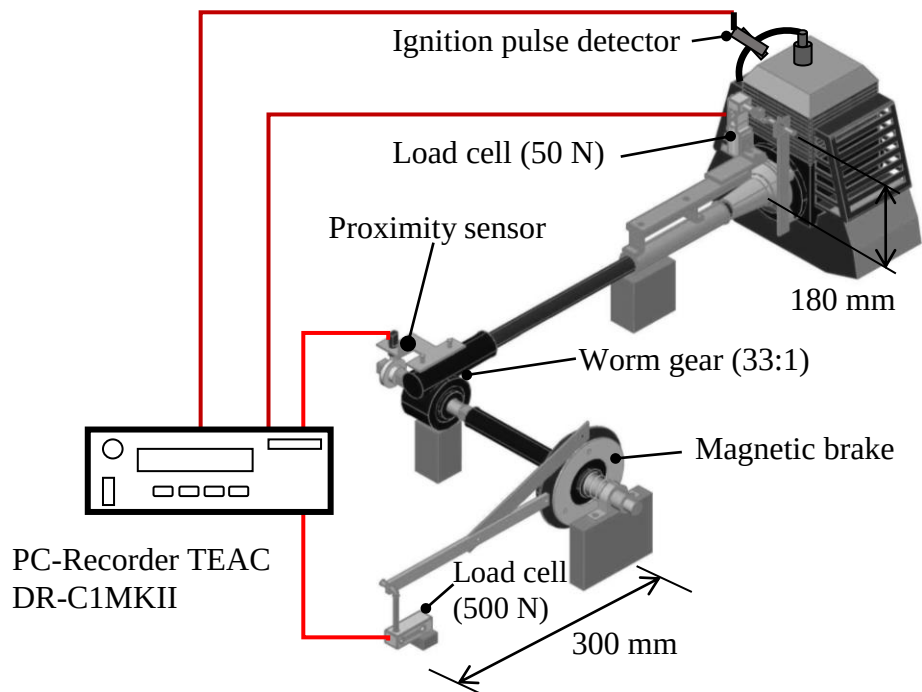


Fig. II-4 Layout of the experimental apparatus for calibration in the laboratory.



Fig. II-5 The view of experimental for calibration in the laboratory

At calibration, the rotational speed of the engine was initially set around 9000 rpm without the load, then electric current on electromagnetic brake was applied gradually to near the maximum capacity of the engine and until the centrifugal clutch remained securely connected without slipping. Every increment of the load was maintained until the rotational speed of the engine became stable. Additionally, the decrement of the load was also measured. An independent run was also carried out by continuously and randomly varying the load.

2.3 Results and Discussion

At calibration, the signals were recorded as shown in Fig. II-6. The engine reaction torque had a similar trend to the rotor shaft torque, regardless of the rotational speed of the engine that decreased with the load.

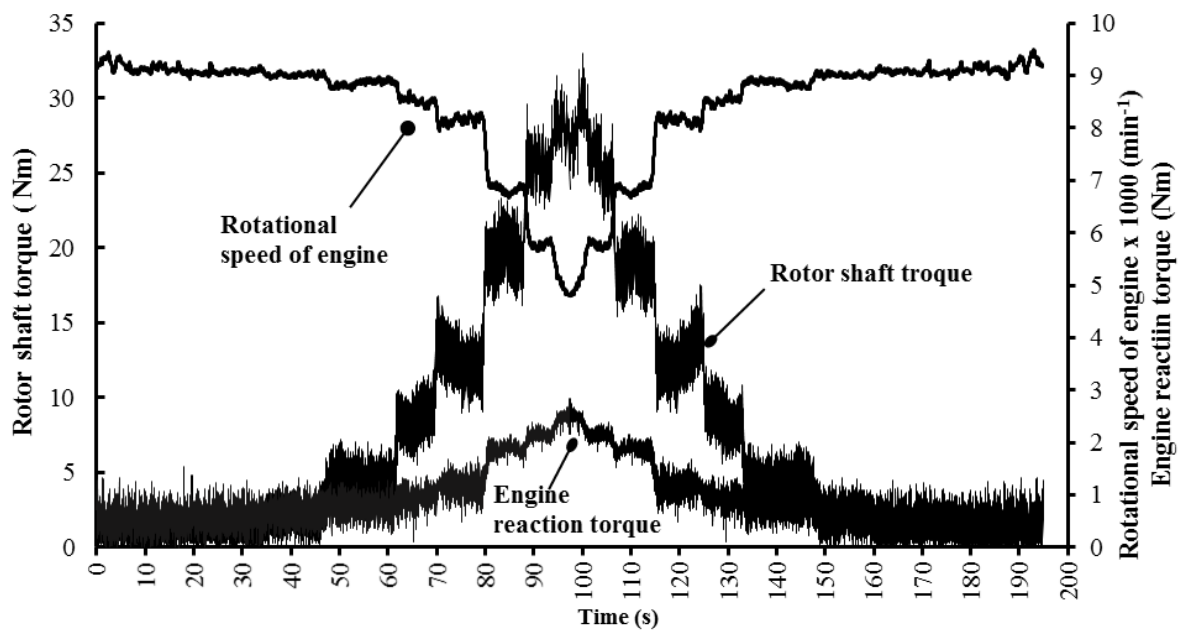


Fig. II-6 Continuous recording of engine reaction torque, rotor shaft torque and rotational speed of engine.

From the power spectrum analysis of data rotor shaft torque as shown in Fig. II-7, the first peak frequency appeared around 4.3 Hz and 2.6 Hz at zero and full loads, respectively, which can be attributed to the actual rotational speed of the rotor shaft. While for data engine

reaction torque, the spectrum analysis show that the peak frequency was not too big as shown in Fig. II-8.

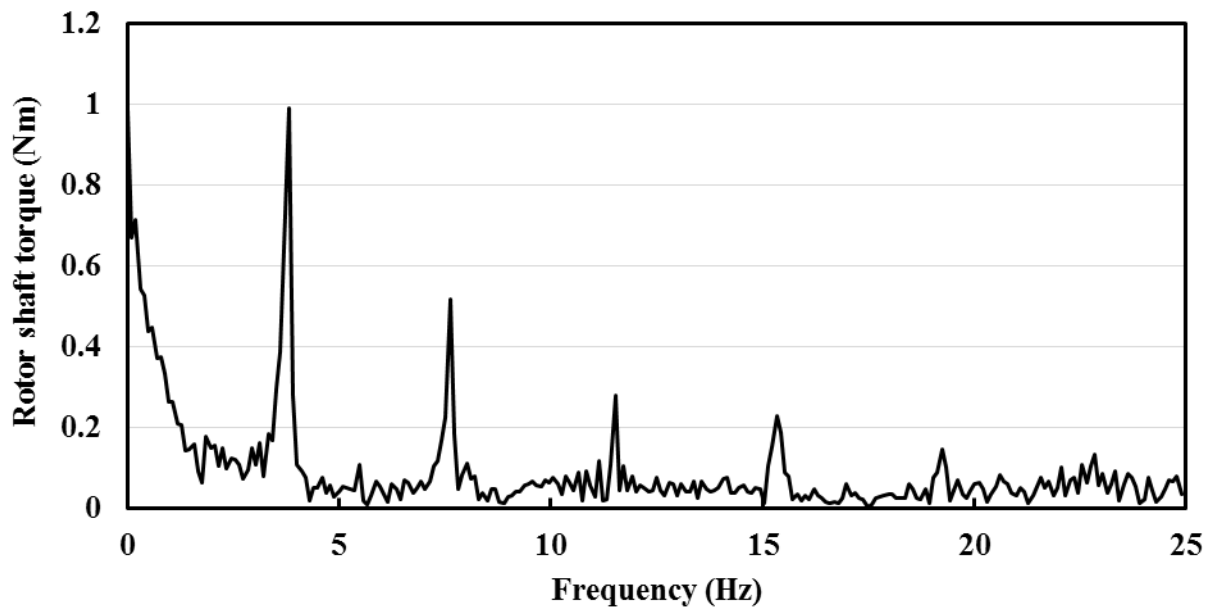


Fig. II-7 Spectrum analysis of data rotor shaft torque during continuous recording.

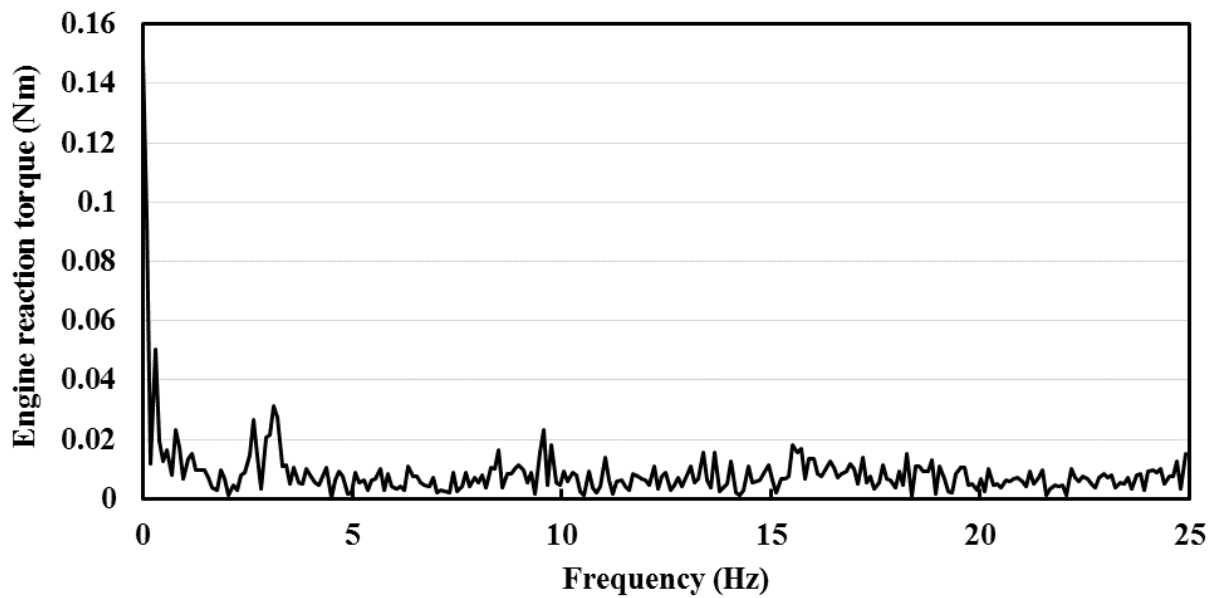


Fig. II-8 Spectrum analysis of data engine reaction torque during continuous recording.

The signals were then averaged for each level of load and plotted on the graph in order to estimate the rotor shaft torque from the engine reaction torque (Fig. II-9). A simple proportional regression showed a slope of 15.7: the rotor shaft torque in reference to the engine reaction torque. The calibration has standard error of 1.4 Nm within the range for a rotor shaft torque under 27 Nm, indicating that the sensing system can be used in research. Since this weeder has the worm gear with the reduction ratio of 33:1, the ideal slope without any transmission loss should be 33. The transmission efficiency of the worm gear was therefore 45.7%, which is within a typical range between 20% and 98% ¹⁾.

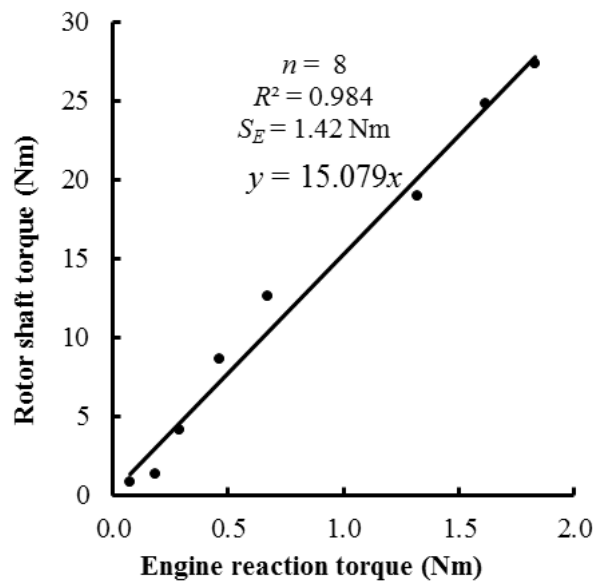


Fig. II-9 Relation between rotor shaft torque and engine reaction torque.

The estimated and measured rotor shaft torque at the random loading are shown in Fig. II-10. The calibrated slope was used for the estimation, and in order to cancel the fluctuation associated with the rotational speed of the rotor (3.3 Hz on the average), the moving average of one-second window was applied. The estimated rotor shaft torque was almost similar to the measured rotor shaft torque, with some difference in several points. Therefore, standard error S_E (root-mean-squared error) and relative error R_E (root-mean-squared relative error) were calculated for each load as follows:

$$S_E = \sqrt{\frac{\sum_{i=1}^n (T_i - \hat{T}_i)^2}{n}} \quad (\text{II-1})$$

$$R_E = \sqrt{\frac{\sum_{i=1}^n \left(\frac{T_i - \hat{T}_i}{T_i} \right)^2}{n}} \quad (\text{II-2})$$

where T_i is the measured and $\hat{T}_i$ the estimated rotor shaft torque, and n the number of the sampled data for each load. The relative error was between 2.3% and 6.5% with an average of 4.2%, whereas the standard error on the average was 0.45 Nm.

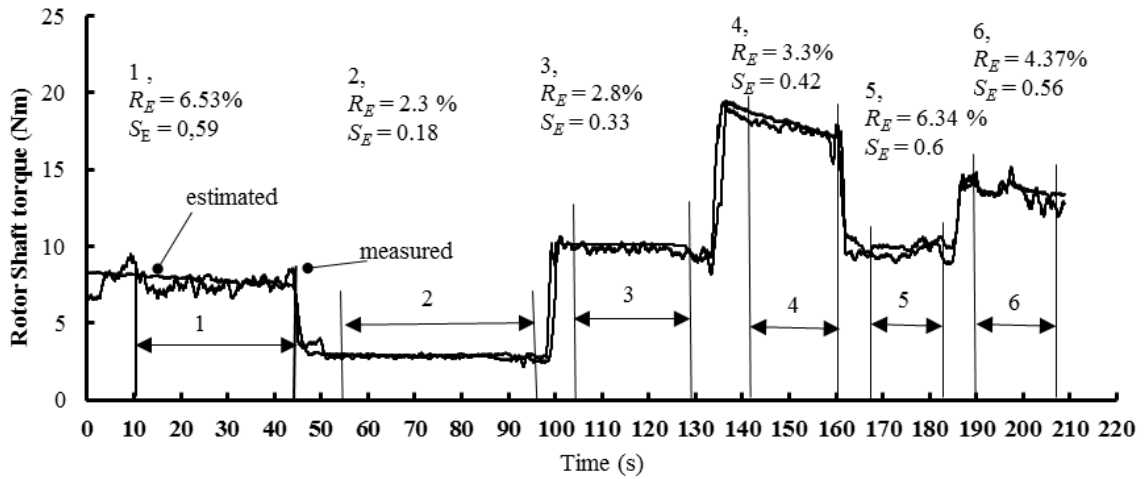


Fig. II-10 Comparison plots of measured and estimated rotor shaft torques.

These results are not necessarily as accurate as those reported by Tomita *et al.* (2010)²⁾, where the strains were directly sensed at the solid spoke of the pulley for conversion to the torque. Here, there are mechanical components that involve friction, such as ball bearings, the worm-gear, and the oil seals; nonetheless, the proposed instrumentation for the engine reaction torque has proved to be viable in practice with a simple structure.

The application of those measurement system in the experimental paddy field has been done. The trials of measurement were done at two different setting of slippage i.e. low (79%)

and high (93%) slippage. The data which recorded by PC-recorder were processed by excel software and presented to be graph. The graph was aimed to show the important data related to the power performance of walking-type power weeder such as engine and rotor shaft of rotational speed, rotor shaft power and engine reaction torque. Figure Fig. II-11 show the power requirement at low slippage (79%) was about half of that at high slippage (93%), indicating considerable energy saving with the increase in traveling speed. Yet, the efficacy of the weeder (weeding rate) will definitely be affected as the pitch of rotor blade weeders and the depth of operation may become shallower with a decrease in the slippage. Therefore, the balancing of such power requirement and the efficacy of the weeder will be discussed in the next step of the study.

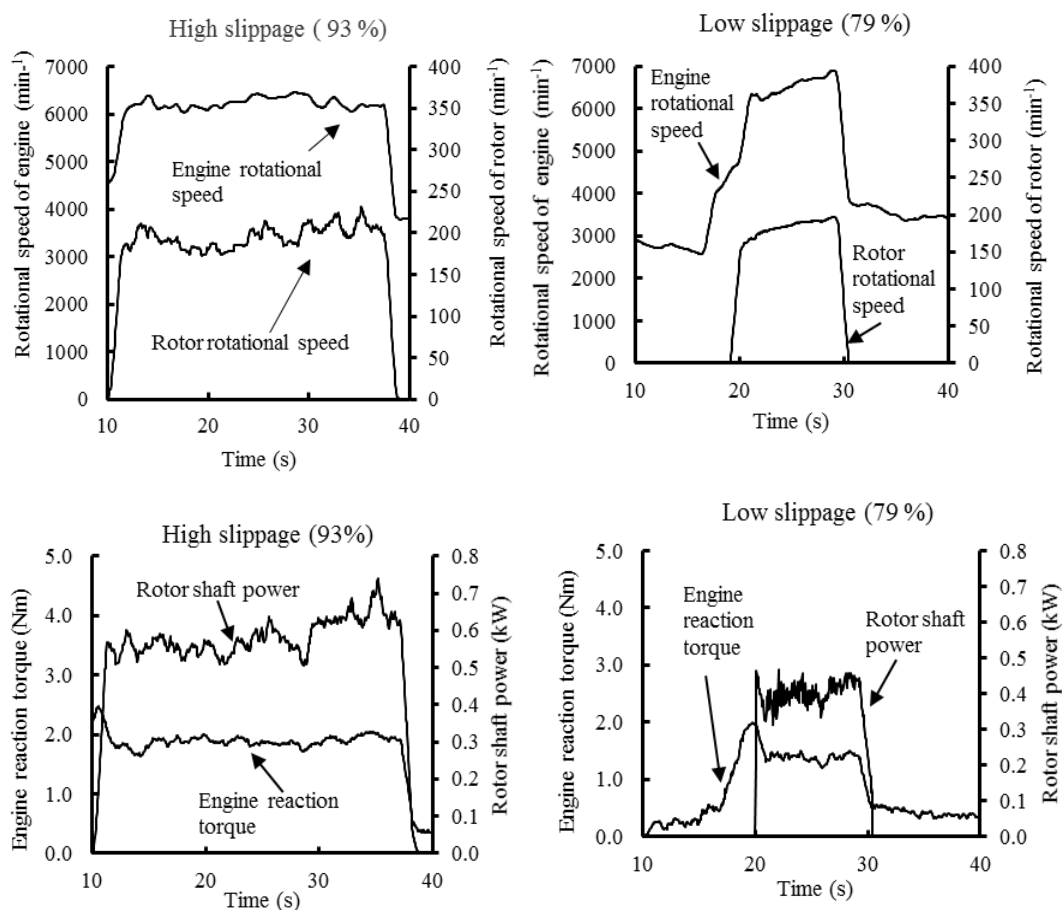


Fig. II-11 Examples of power measurement in paddy field of the weeder at slippage of 93% (left) and 79 % (right).

2.4 Conclusions

- 1) A simple method of measuring the power of a walking-type power weeder was demonstrated by sensing the engine reaction torque by using a load cell without slip rings.
- 2) The estimation of rotor shaft torque in the laboratory demonstrated that the relative error between the actual and the estimated rotor shaft torque was 4.2 % on the average.
- 3) The measurements were also feasible in the paddy field, and differences in power requirement were clearly observed at different slippages of the rotor.

III. POWER EFFICIENCY AND EFFICACY OF WALKING TYPE POWER WEEDER IN THE PADDY FIELD

3.1 Introduction

Lowland rice is traditionally grown throughout Asian countries, and where line planting (rather than random planting) is adopted, power weeders have been recently used to overcome labor shortage. Even in developed countries like Japan, rotary weeders with or without engine power are still used by some organic or low-chemical farmers (Shibayama, 2001). Among several varieties of the weeders, walking-type power weeders are handy to introduce and effective to suppress weeds. For example, Nakai and Toritsuka (2013) have proved that the combination treatment by near intra-row weeding using an inter-row walking-type power weeder after rice bran application is effective on the suppression of weed compare to the rice bran application or the powered weeding alone ¹³).

Walking-type power weeders are mostly powered by small gasoline engine of 1 – 2 kW and do not have a power wheel for traveling or even for controlling the forward speed during weeding. To avoid the weeder from moving forward too fast, a resistance bar is usually fixed just behind the rotor. It has a function as a brake of the weeder, and the operator can control the braking action by raising and lowering the handlebar of the weeder. This work is yet quite difficult to be handled, specially in a field of hard soil.

The performance of the weeder is affected by peripheral and forward speeds of the rotor, typically expressed as slippage. The slippage of the weeder in the paddy fields is usually over 90%, where the slower the forward speed, the finer the soil that can be tilled and the more the energy required per area of the operation. With a similar mechanism, on the other hand, Salokhe *et.al.* (1993) have revealed that increasing forward speed a rotavator from 1.0 to 2.0 km/h at the same rotational speed *i.e.* reducing the slippage of the rotor on wet clay soil in the repeated path does not give significant increase in the torque ¹⁴). Similarly, the soil condition

of a paddy field during weeding period is still soft in most cases, since the latest farm activity related to the soil is the puddling. Therefore, there is an opportunity here for trying to operate the walking-type power weeder at faster forward speed to save its torque *i.e.* power requirement.

The effect of the slippage of the rotor on power requirement and simultaneously on weeding efficacy of walking-type power weeder, however, has not been studied well as far as the authors' knowledge. Therefore, in this research, the effect of variation of slippage of the rotor within operatable range will be first studied related to the power requirement. Weeding efficacy and grain yield analysis will be followed to evaluate the potential drawback associated with the reduction in the slippage.

3.2 Material and Methods

3.2.1 Modification of Walking-Type Power Weeder by an Additional Driven Cage Wheel

The existing walking-type power weeder (Otake, HK4-5CKS) was used in this research. The machine had three rows of the rotor and powered by a 40 cc two-stroke engine of 1.6 kW at 7000 rpm. In order to get a variation of slippage on the rotor weeder of walking-type power weeder, the modification was needed. It was done by adding a driven cage wheel instead original resistance bar (Fig III.1). The function of cage wheel is for a traveling device like on a rotary tiller. Therefore it would keep the constant forward speed on the walking-type weeder machine. The specification of cage wheel is shown in Table III-1, and the over view of cage wheel is shown in Fig. III-2.

The cage wheel was designed by considering the available space at the walking-type power weeder after the resistance bar was took out from the machine. The cage wheel was driven by sprocket and chain transmission, which was taken from rotor shaft, then transmitted

through the intermediate shaft. The standard size rst-35 sprocket was installed in the middle of rotor weeder. Therefore, the middle of rotor weeder was not installed with the blades. The wheel was a single rim cage wheel 360 mm in diameter. The variation of slippage was designed on eight levels, which one was by Rst-bar (resistance bar) and seven were by changing the configuration of the sprockets and chain transmissions (Table III-2). By changing their combination, the slippages were designed between 80% and 93% as mention on the name of the treatment.

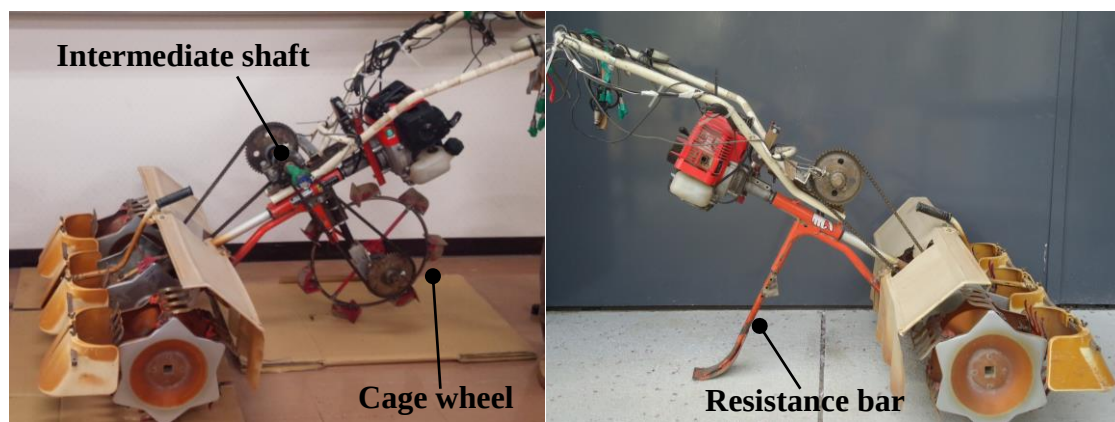


Fig. III-1 The modified (left) and existing (right) of walking-type power weeder

Table III-1 Specification of an additional cage wheel on walking type power weeder

Parameter	Value
Diameter (until rim of wheel)	360 mm
No of lug	7 units
Size of lug :	
- Height	50 mm
- Width	45 mm
- Angle of lug	30°

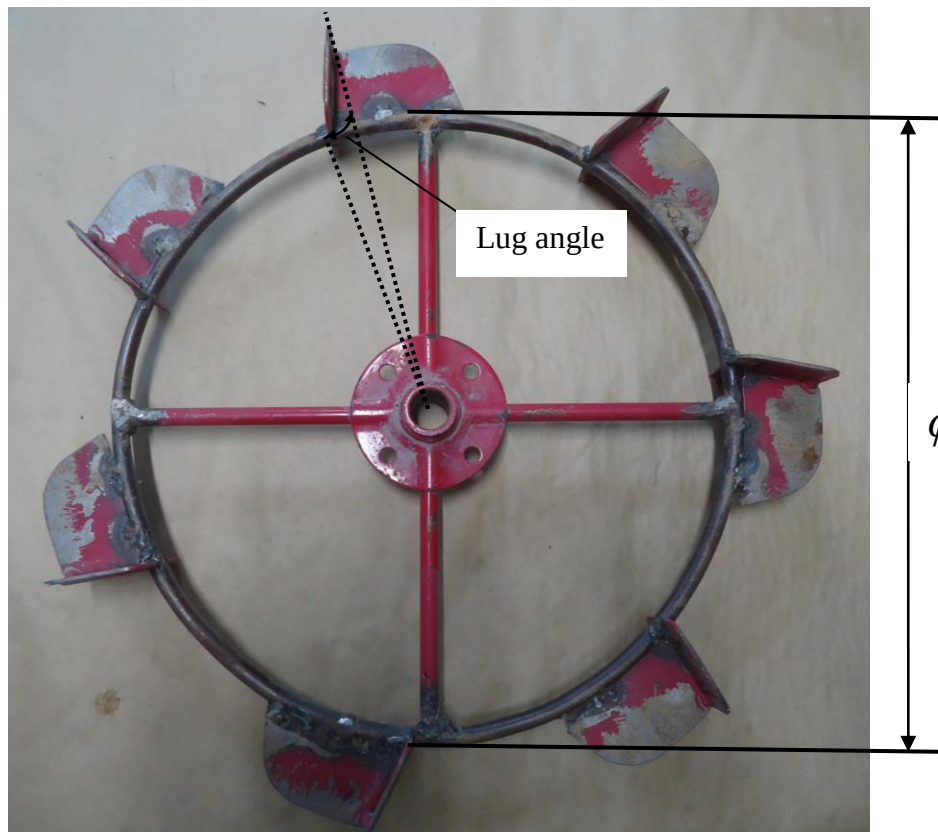


Fig. III-2 The view of cage wheel

Table III-2 Configuration of sprocket-chain transmission on the modified of weeder

The target of slippage (%)	Expected forward speed (km/h)	Device for controlling slippage	Tooth number of sprockets		
			Main rotor	Intermediate shaft	Cage wheel
> 93	< 1.00	Resistance bar	-	-	-
92.6	1.12	Cage wheel	12	36	12
91.1	1.34				12
90.1	1.49				16
87.5	1.88				12
84.6	2.32				12
83.3	2.51				16
79.5	3.09				16

The theoretical slippage of the rotor was designed by equation (III.1) :

$$S_{th} = \frac{2\pi N_r R_r - 2\pi R_w N_w}{2\pi N_r R_r} \quad (III-1)$$

where S_{th} is theoretical slippage (%), V_r is the peripheral speed of the rotor (m/s), V_w is the peripheral speed of cage wheel (m/s), R_r is radius of the rotor (m), R_w is radius of cage wheel (m), N_r is the rotational speed of the rotor (1/s) and N_w is the rotational speed of cage wheel (1/s). Because the size of rotor weeder and cage wheel are same on diameter, therefore $R_r = R_w$ and if the rotation ratio between rotor of weeder and cage wheel represent in G_r , then equation of theoretical slippage become as follow:

$$G_r = \frac{N_r}{N_w} \quad (III-2)$$

$$S_{th} = \left(1 - \frac{1}{G_r}\right) \quad (III-3)$$

The actual slippage of weeder in the paddy may be different than designed one, it's because of soil condition, it calculated by equation III-4 as follow:

$$S_a = \frac{2\pi N_r R_r - V_f}{2\pi N_r R_r} \quad (III-4)$$

where S_a is actual slippage of rotor (%), V_f is measured actual forward speed of weeder (m/s).

3.2.2 Field Test Condition

Experiments were conducted in transplanted paddy fields in the regions: Sasayama of Hyogo and Dainaka of Shiga, Japan in the 2015 cropping season. The cultivar *Khosihikari* was transplanted by 300 mm and approximately 180 mm at inter and intra-row distances, respectively. During the weeding, the water level was kept at 40 – 60 mm. The planting date for Sasayama and Shiga location were done on May 26, 2015 and June 12, 2015 respectively. The layout of test field I and II are shown in Fig. III-3 and III.4.

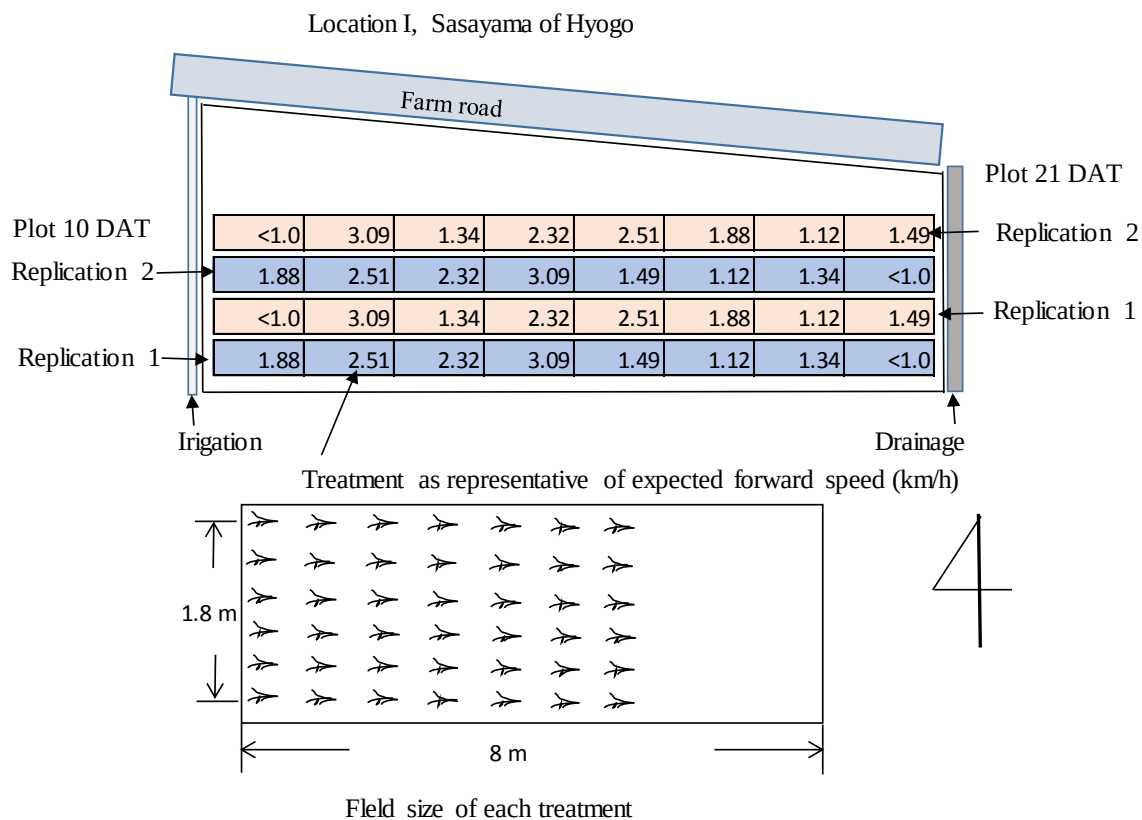


Fig. III-3 Lay out of field test in Sasayama of Hyogo

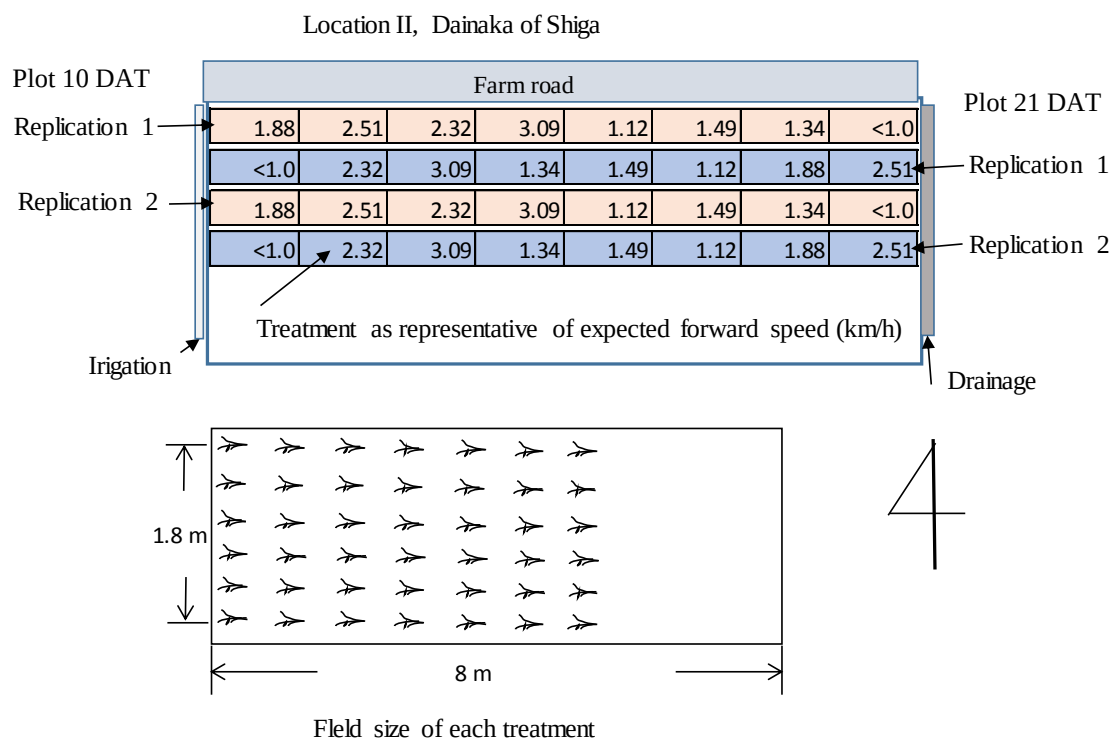


Fig. III-4 Lay out of field test in Dainaka of Shiga

Table Table III-3 presents the soil properties and weed condition in experiment field.

Table III-3 Soil condition and weed condition in experiment field.

Location	Soil texture	Previous crop	Weeding day	Weed density (m ⁻²) (SD)	
Sasayama, Hyogo	Sand 10%	Black Soybean	10 DAT	290	35
	Silt 50%		21 DAT	365	186
Dainaka, Shiga	Sand 30%	Rice	10 DAT	663	47
	Silt 45%		21 DAT	829	47
	Clay 40%				
	Clay 25%				

DAT: days after transplanting; SD: standard deviation

The cultivar *Khosihikari* was transplanted by 300 mm and approximately 180 mm at inter and intra-row distances, respectively. During the weeding, the water level was kept at 40 – 60 mm. The machine was operated at inter-row for each treatment, which for 1st pass operation covered 3 rows of paddy with remaining 1 blank row space at the middle (at the center of row uninstalled with rotor weeder). The previous blank row space was passed by outside rotor when the machine return for 2nd pass.

3.2.3 Measurement of Power Efficiency

A preliminary functional test of the modified weeder with the additional of cage wheel and the resistance bar was done in the muddy sandy soil. The test was aimed to check the functional of the cage wheel. During field testing, the engine was operated at constant rotational speed around 7000 rpm that equaled to around 200 rpm on the rotor shaft. All data related to the power performance of weeder such as engine rotational speed, rotor rotational speed, engine reaction torque (representative of torque at rotor shaft) were recorded by PC-card recorder (TEAC DR-C1 MKII) except forward speed was measured manually. The rotor shaft torque of this weeder was measured through engine reaction torque ¹⁵). The illustration of power measurement in the field is shown in Fig. III-5.



PC-Recorder hold by operator

Fig. III-5 Illustration of instrument installation for measure required power in the field.

Power required at rotor shaft was calculated by consider torque and rotational speed of rotor (III-5) :

$$P_r = \frac{2\pi T_r N_r}{60000} \quad (III-5)$$

where P_r is required rotor shaft power (kW), T_r is torque at rotor shaft (Nm) and N_r is rotational speed of rotor shaft (rpm). Ignition pulse detector was installed on the wire of spark plug of two stroke engine in order to measure rotational speed of engine and rotor after divided by gear reduction number of worm gear. While the required energy per length of operation at rotor shaft was calculated as follow (III-6) :

$$E_r = \frac{P_r}{V_f} \quad (III-6)$$

Where E_r is energy required per length of operation at rotor shaft (kJ/m), V_f is actual forward speed of weeder (m/s).

3.2.4 Measurement of Weeding Efficacy and Grain Yield

The weeding evaluation were done two times. The 1st weeding evaluation was done on immediate time before weeding for both two plot weeding 10 DAT and 21 DAT. While 2nd weeding evaluation was done before mid-term of drainage, it was on 54 day after transplanting. The formula to calculate weeding efficacy for both two methods is follow :

$$W_{\eta} = 1 - \frac{W_t}{W_{ut}} \quad (\text{III-7})$$

where W_{η} is weeding efficacy, W_t is the number or weight of weed (gr) after weeding on treated area and W_{ut} the number or weight of weed (gr) in the untreated area. The plot of field test was divided two plot i.e: plot 10 DAT and 21 DAT, the name of plot correlated with the weeding time. The experimental plot of field test and method of weeding efficacy for each plot is shown in Table III-4 and III.5

Table III-4 Experimental plot and method of weeding efficacy

Location	Weeding day	Slippage	Length of run	Replication
Sasayama,	10 DAT	8 levels (Table 1)	8 m	2
Hyogo	21 DAT			
Dainaka,	10 DAT			
Shiga	21 DAT			

Table III-5 Method of weed evaluation

		Immediate sampling	54-DAT sampling
Timing		One day after weeding	Before mid-term drainage
Basis		Plant number	Fresh weigh
Sampling tool		Soil core (80 mm in diamater)	Quadrat (130 mm x 130 mm)
Sampling location	Treated area	Inter-row space of weeded area	
	Untreated area	Inter-row space next to weeded area	Intra-row space next to weeded area

The core sample and quadrat tools which using for take weed sample are shown in Fig. III-6 Core and quadrat weed sample.

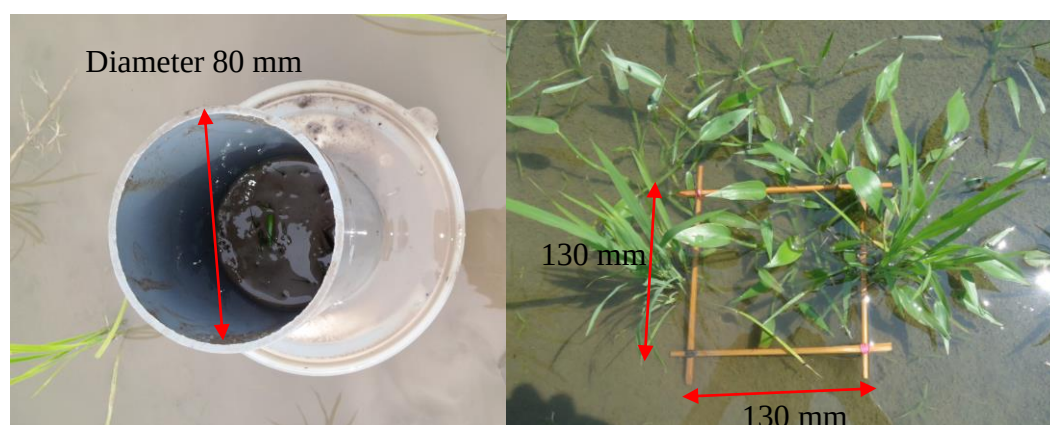


Fig. III-6 Core and quadrat weed sample.

The grain yield was measured by random sampling of 30 crops and harvested from each plot of treatment. The plants were naturally dried up to around 14% of moisture content and continued by threshing and husking. Laboratory thresher machine (KM ,Chiyoda) and husker (THU35B, Satake) were used to process the paddy to be brown rice basis.

3.3 Results and Discussion

3.3.1 Power and Energy Required

The actual forward speed of walking-type power weeder during field was measured. It was noticed that the actual forward speed were changed in line with the changed on combination of sprocket and chain on additional cage wheel. The changing of forward speed at constant rotational speed of rotor, theoretically give effect on the size of pitch tillage which resulted from blade of rotor weeder (equation I-1), the calculated of pitch tillage are presented in Table III-7. According to the result of calculated pitch tillage shows that the higher the actual forward speed the higher the pitch tillage.

Table III-6 Forward speed and calculated of pitch tillage in Sasayama field.

Targeted slippage (%)	Actual slippage (%)		Forward speed (km/h)		Rotor speed (rpm)		Calculated of pitch tillage (cm)	
	10-DAT	21-DAT	10-DAT	21-DAT	10-DAT	21-DAT	10-DAT	21-DAT
> 93	92.8	93.2	0.97	0.94	201	202	1.34	1.29
92.6	92.4	92.3	1.28	1.13	200	197	1.79	1.59
91.1	91.6	91.1	1.51	1.45	200	200	2.09	2.01
90.1	90.0	90.3	1.62	1.62	199	201	2.27	2.24
87.5	87.1	87.9	1.87	1.93	204	197	2.55	2.72
84.6	82.9	82.7	2.18	2.23	197	195	3.07	3.18
83.3	82.5	82.9	2.32	1.93	200	194	3.22	2.76
79.5	78.9	76.8	2.71	2.89	198	197	3.80	4.07

Table III-7 Forward speed and calculated of pitch tillage in Dainaka Field

Targeted slippage (%)	Actual slippage (%)		Forward speed (km/h)		Rotor speed (rpm)		Calculated of pitch tillage (cm)	
	10-DAT	21-DAT	10-DAT	21-DAT	10-DAT	21-DAT	10-DAT	21-DAT
> 93	92.8	93.2	0.97	0.94	203	201	1.32	1.30
92.6	92.1	92.3	1.21	1.19	206	202	1.63	1.64
91.1	90.9	90.1	1.46	1.33	204	203	1.99	1.82
90.1	89.8	90.4	1.64	1.46	198	204	2.30	1.99
87.5	87.4	87.4	1.79	1.82	197	202	2.52	2.50
84.6	82.6	83.2	2.22	2.10	193	196	3.19	2.97
83.3	82.1	82.8	2.35	2.19	199	195	3.28	3.11
79.5	77.9	78.6	2.65	2.65	200	199	3.68	3.69

The performance of additional cage wheel on keeping the forward speed will also effected to the actual slippage of rotor weeder. There were slight differences between actual and designed slippage, it shows that the cage wheel securely dragged the weeder against the driving force generated by the rotor as seen in Fig. III.7. At the high slippage or at the low of targeted forward speed, the rotor of weeder was imposed to be travel slowly and as the result, it became work deeper. By that condition, the cage wheel will keep the forward speed equal as the theoretically. Otherwise at the lower slippage condition, when the cage wheel was rotated at higher speed, which effected on larger pitch tillage at the rotor weeder. Regarding that condition, presumably there was drag force from the rotor weeder and assisted on the cage wheel. Therefore, it made weeder move faster and as the result, the actual slippage became less than the prediction.

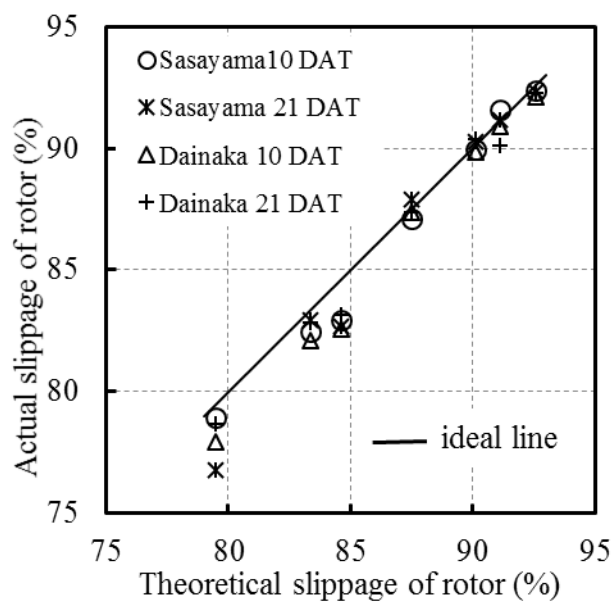


Fig. III-7 The correlation between theoretical and actual slippage of rotor.

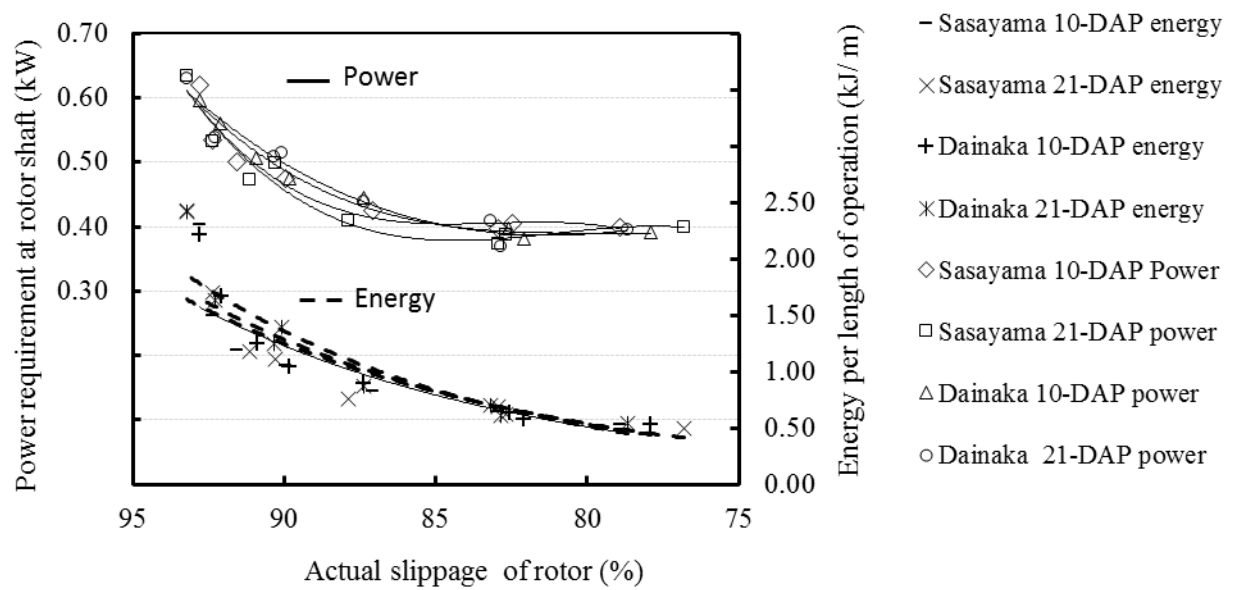


Fig. III-8 Power requirement and energy per length of operation at rotor shaft for different actual slippage of rotor with the trend line from each different location and plot.

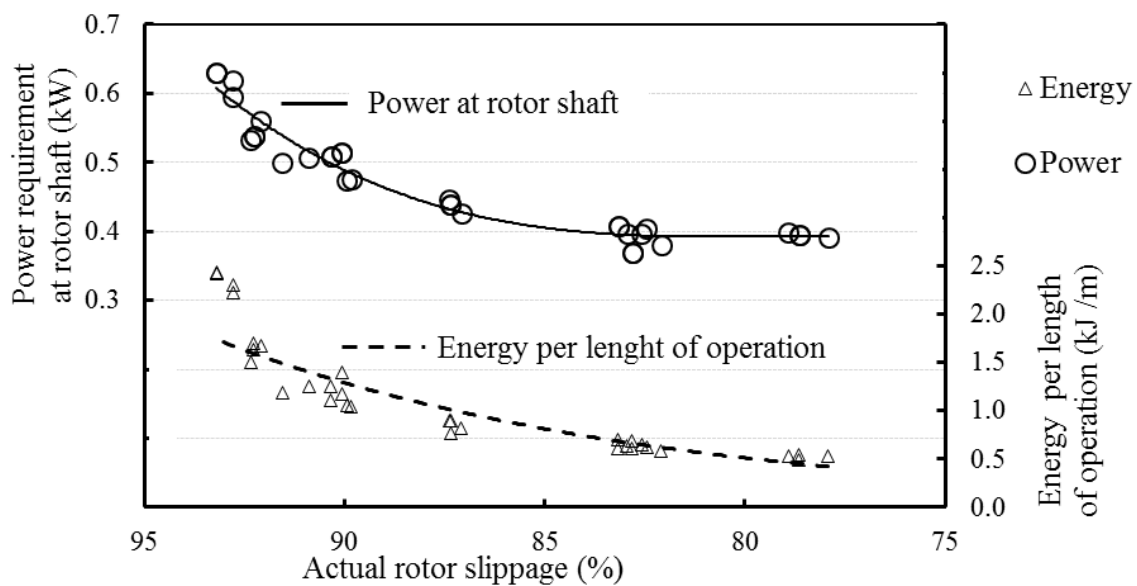


Fig. III-9 Power requirement and energy per length of operation at different actual slippages of rotor (the regression lines are based on the pooling of the locations and the weeding days).

The effect of variation of slippage on the power required and energy consumed at rotor shaft of weeder at weeding is shown in Fig. III-8. The power required at rotor shaft of weeder decrease as the number of slippage at rotor decreased. Those data were integrated from 2 different location and plots which all of them were similar on the trend as shown in Fig. III-9. The decreasing of slippage from the highest around 93 % to 89% resulted in reduction of power at rotor shaft sharply, then become flat as the number of slippage was decreased. From the illustration of trendline (Fig. III-9) show that at every 1% decreasing on slippage of rotor will share on decreasing of power at rotor shaft around 6% for range of rotor slippage 93% to 89%.

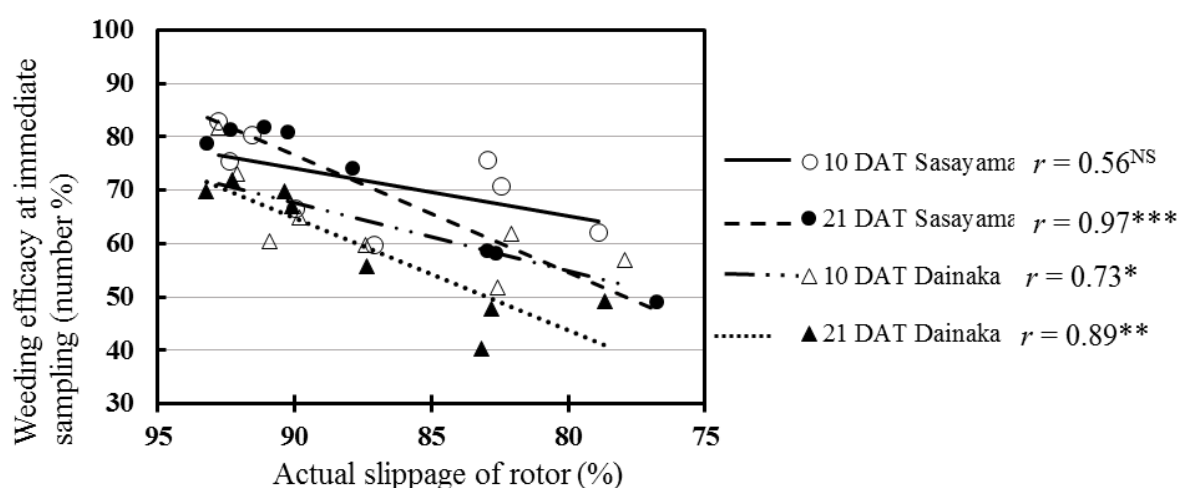
More advantageous aspect is the energy required per length of operation, define as the required of power divided by forward speed. Figure III-9 shows the trendline of required energy has more slope than trend line of power at the beginning of decreasing slippage of rotor. For instance, decreasing slippage of rotor from 93% to 89% gave a reduction of energy per length of operation around 11% for every 1% reduction of slippage. Although, reduction slippage of rotor weeder by increasing forward speed of cage wheel resulted in power and energy saving, the limitation of forward speed of weeder as walking-type machine should be considered. It should not be beyond with the comfort range of operator for walking in paddy field. According to the author experience, operating this weeder, the forward speed up to 1.6 km/h (actual slippage around 90%) was comfortable. Therefore, the operation of weeder from the slowest forward speed around 0.95 km/h (by resistance bar device) which resulted slippage of rotor around 93%, then changed by additional cage wheel at 1.6 km/h on forward speed or slippage of rotor around 90%, resulted power and energy saving 18% and 34% respectively.

Figure III.9 indicates a different result to that with a rotary tiller on two-wheel tractor. Salokhe and Ramalingan (2002) have reported that a rotary tiller operated in a clay soil

shows lower specific torque (*i.e.* the power) when the forward speed is lower where smaller pitch of tillage is generated with the blades ¹⁶). The adverse phenomenon here is suspected due to the soil condition and to the behavior of the power weeder. Assuming that the soil upon weeding was soft enough, the torque was not affected by the tilling pitch of the blades on the rotor as reported by Salokhe *et.al.* (1993) ¹⁴). Rather, since this weeder with a simple structure did not have such specific device to control the working depth as with a rotary tiller on a two-wheel tractor or with a riding-type weeder, it is possible to have worked shallower when the forward speed increased, resulting in the reduction in the torque of the rotor.

3.3.2 Weeding Efficacy and Grain yield

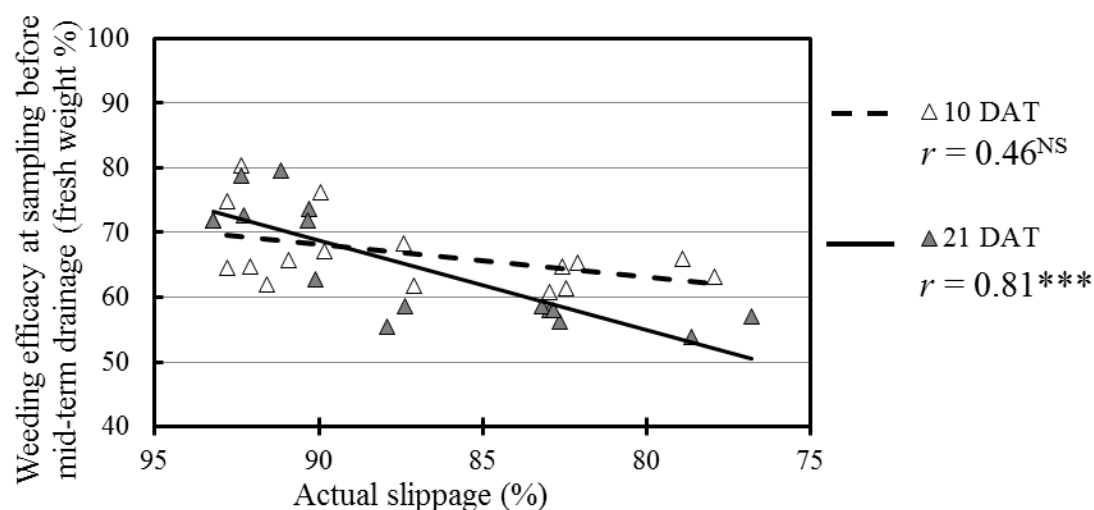
The weeds in the paddy field were dominated by *Monochoria vaginalis* and other fewer portions were *Echinochloa crus-galli*, *Cyperus difformis* and *Scirpus juncoides*. The leaf age and average of length of *M. vaginalis* were 1- 4 and 30 mm respectively at 10 DAT plot weeding, whereas at 21 DAT plot weeding, they were 3-7 and 70 mm, respectively.



***, ** and * indicate significance levels of 0.1%, 1%, and 5%, respectively, with one-sided *t*-test, NS : not significant

Fig. III-10 The weeding efficacy at different actual slippage for immediate sampling.

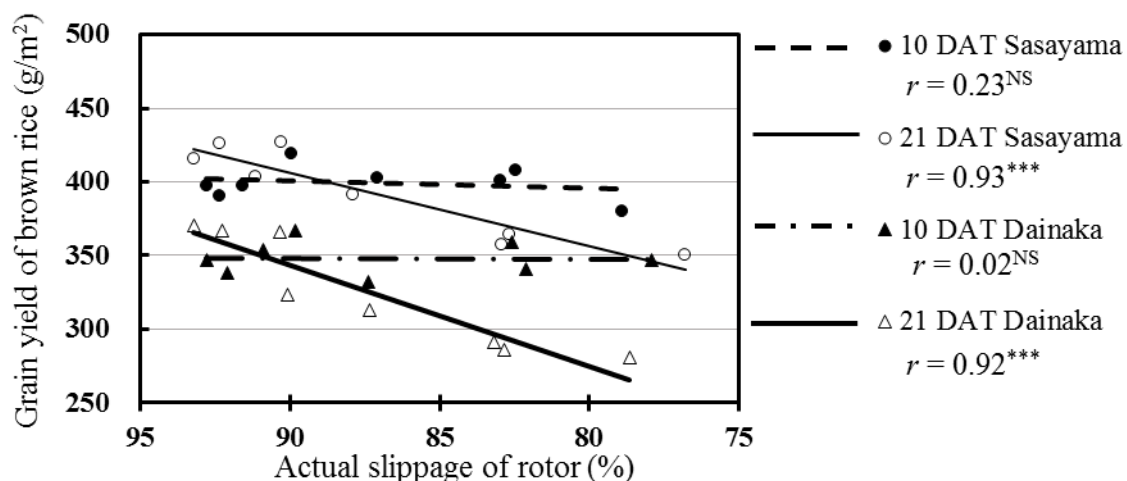
Figure Fig. III-10 shows that weeding efficacy at immediate sampling was affected on some significant level by slippage of rotor weeder except at 10 DAT plot in Sasayama location. The lower, the slippage of rotor or the faster of forward speed the lower, the weeding efficacy. The pulverizing level of muddy soil in the inter-row area where the weed existed was affected by combination of rotational speed and forward speed of the rotor, i.e., the pitch of tillage. The calculated of pitch tillage was ranging from the 1.2 cm to 3.8 cm in line with the reduction of actual slippage from 93% to 78%, which accordingly illustrated the decrease in the weeding efficacy at the immediate sample.



***, ** and * indicate significance levels of 0.1%, 1% and 5% respectively, with one-sided *r*-test. NS: not significant

Fig. III-11 The weeding efficacy at different actual slippage for 54-DAT sampling (the regression lines are based on the pooling of the locations).

Figure III-11 shows effect of slippage of rotor on the final weeding efficacy. It indicated, that at 10 DAT plot for both two different locations the slippage of rotor did not give significant effect on the final weeding efficacy, which it remains stable in line with the decreasing slippage of rotor. Unlike at 10 DAT plot, at 21 DAT plot, weeding efficacy was affected significantly by rotor slippage of weeder.



***, ** and * indicate the significance levels of 0.1%, 1% and 5% respectively, with one-side *r*-test, NS : not significant

Fig. III-12 Grain yield at different actual slippage of rotor

The relation between grain yield and slippage of rotor is shown in Fig. III-12, which base on weight of brown rice. In both difference locations, unlike at 10 DAT plot, the grain yield at 21 DAT plot and thereafter was affected significantly by slippage of rotor weeder. The decreasing of grain yield at 21 DAT plot, with decreasing in the slippage of the rotor was because the weeding was not as effective as in 10 DAT plot (Fig. III-11).

From Fig. III-10 and III-11 indicate that, since there was insignificant effect from slippage of rotor on the final weed efficacy especially at 10 DAT plot, similarly on the grain yield, the slippage of rotor was insignificant at 10 DAT plot. These results were presumed related to the condition of weed infestation at each plot (Table III-3). The average number of weed at 10 DAT plot was lower than 21 DAT plot, therefore the weeding efficacy on average at 10 DAT plot higher than at 21 DAT plot.

Operating the walking-type power weeder on several levels of slippage of the rotor have been conducted in paddy field. It resulted positive aspect on power and energy saving but gave negative effect on weeding efficacy and grain yield especially when operated at 21 DAT plot, where relatively the number of weed was found more than at 10 DAT plot.

Another fact was found that weeding efficacy and grain yield in Dainaka location was lower than in Sasayama. It was in correlation to the weed infestation, which in Dainaka was found more than in Sasayama location (Table III-3). Operating the walking-type power weeder by additional cage wheel instead a resistance bar also gave another advantage i.e., the operator could use the cage wheel while turning, than lift up and move this machine by hand.

3.4 Conclusion

The operation of the walking-type power weeder on several differences of slippage number or forward speed on paddy field had made an effect on required rotor shaft power and weeding efficacy. There are many important points could be drawn.

1. Reducing rotor slippage of weeder by changing original resistance bar with additional cage wheel give significant effect on the reducing rotor shaft power and energy per length of operation required at rotor shaft.
2. On the other hand, the consequence of reducing slippage of rotor weeder made a significant effect on reducing the immediate weeding efficacy,
3. Nevertheless, on the final weed evaluation at midterm of drainage, the reducing slippage on rotor weeder gave significant effect on reducing of the weeding efficacy and grain yield at plot weeding 21 DAT but not for plot weeding 10 DAT.
4. The reducing slippage of rotor up to 90% which equal to the forward speed around 1.6 km/h was considered as the proper setting of slippage; it's because convenience to the operator and gave saving power and energy per length of operation around 18% and 34% respectively.

IV. RECOMMENDATIONS

Base on the results of this research, the operation of walking-type power weeder by higher speed which through changing the existing resistance bar to the a additional driven wheel is recommended up to forward speed around 1.6 km/h in order for reducing power and energy requirement. The research related to the application of engine force as indicator of required torque at rotor by added a simple indicator for operator during operating this machine is recommended. However, considering the construction of transmission of a driven wheel which was taken from the center of rotor shaft, is needed to be modified by special transmission directly from engine shaft through a independence gear box, therefore the number of row same as existing machine. The further study related to the working depth of rotor weeder when it operated at a different forward speed is necessary in order to improve the weeding efficacy.

Regarding the result of this result especially on the saving power and energy at rotor shaft of walking-type power weeder, it will get effect on reducing operational cost of weeding in paddy field in some country where price of fuel on the future become important issue. The percentage of saving energy was around 34 %, it was proved by reducing number of slippage from 93% to 90% on the rotor of weeder. Therefore, the operational cost possible to be reduce around 34% due to saving of fuel.

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Summary

Weeding on paddy field by mechanical not only eradicates weed between rows, but also softens superficial soil and enhances aeration of soil. One on the appropriate machine is walking type power weeder. It because simple in construction and quite light. This machine has rotor weeder as active tool and resistance bar as a controlling working speed. The rotor only work in inter-row, therefore inter-row weeding. The total weight of this machine is less than 30 kg, which can be transport easily in to paddy field even though in less farm road. The fuel price is still big issue for developing country. Though, the fuel consumption of walking power weeder is little (1- 1.5 lt/h) but quit significant compare to the cost of farm labor and value of rice in some developing country. The objective of this research is to evaluate the working performance and efficacy of walking type power weeder relative to the consumption of energy and power. The research was divided by two steps, 1st step was a research related to the development of new alternative measurement method of power on walking type power weeder by detecting a reaction torque on body of engine. Then the 2nd step was to evaluate the weeding efficacy of walking type power weeder relative to the power consumption.

For the 1st research, here the many thing could be summarized:

1. Since this machine has simple contruction therefore to do measurement of comsuption power by put a load cell or starin gage has many difficulties. The new power measurement system was proposed instead using conventional load system system. The existing 3-row walking-type power weeder (Otake, HK4-5CKS) was used in this research. The modification is requisite because of the limited space around the main rotor shaft and the transmission shaft. It was by slightly increase the diameter of the housing from 27.0 mm into 27.3 mm to allow clearance between the pipe frame and the housing of the centrifugal clutch, so that the housing could rotate freely within the pipe frame as a sliding bearing when greased. Since the engine was not heavy, it was

supported by this simple structure, and the sliding motion of the bearing was smooth. In order to minimize the friction between pipe frame and housing the grease is applied as necessary during operation. The housing was fitted with an extended arm, then connected through two ball joints and a J-hook to a 50-N cantilever load cell, whose other end was fixed to the pipe frame of the weeder. By multiplying the force of the cantilever load cell with the length of the extended arm that was measured from the center of the engine shaft to the point of application (180 mm), the measured force was converted to engine reaction torque.

2. In the laboratory, the engine reaction torque was calibrated to the rotor shaft torque. An electromagnetic brake was installed onto the rotor shaft as the load calibrator, which received an electric current regulated through a variable resistor to generate a range of loads. The base of the brake supported by bearings was fitted with an arm at the end of which touched a 500-N load cell. The rotor shaft torque was then calculated by multiplying the force at the load cell by the length of the arm (300 mm). The output from all the transducers was processed and recorded. The sampling rate was set at 50 Hz with the low-pass cut-off frequency at 20 Hz.
3. A simple method of measuring the power of a walking-type power weeder was demonstrated by sensing the engine reaction torque by using a load cell without slip rings. The estimation of rotor shaft torque in the laboratory demonstrated that the relative error was between 2.3% and 6.5% with an average of 4.2%, whereas the standard error on the average was 0.45 Nm.
4. The measurements were also feasible in the paddy field, and differences in power requirement were clearly observed at different slippages of the rotor. The trials of measurement were done at two different settings of rotor slippage i.e. low (79%) and high (93%) slippage and gave significant results on the power consumption.

For the 2nd research, it concern about The effect of the slippage of the rotor on power requirement and simultaneously on weeding efficacy of walking-type power weeder. Therefore, in this research, the effect of variation of slippage of the rotor within operatable range will be first studied related to the power requirement. Weeding efficacy and grain yield analysis will be followed to evaluate the potential drawback associated with the reduction in the slippage. There are many point could be summarized from the 2nd research:

5. In order to get a variation of slippage on the rotor weeder of walking-type power weeder, the modification was needed. It was done by adding a driven cage wheel instead original resistance bar. The function of cage wheel is for a traveling device like on a rotary tiller. Therefore it would keep the constant forward speed on the walking-type weeder machine. The cage wheel was designed by considering the available space at the walking-type power weeder after the resistance bar was took out from the machine. The cage wheel was driven by sprocket and chain transmission, which was taken from rotor shaft, then transmitted through the intermediate shaft. The standard size rst-35 sprocket was installed in the middle of rotor weeder. Therefore, the middle of rotor weeder was not installed with the blades. The wheel was a single rim cage wheel 360 mm in diameter. The variation of slippage was designed on eight levels, which one was by Rst-bar (resistance bar) and seven were by changing the configuration of the sprockets and chain transmissions. By changing their combination, the slippages were designed between 80% and 93%.
6. Experiments were conducted in transplanted paddy fields in the regions: Sasayama of Hyogo and Dainaka of Shiga, Japan in the 2015 cropping season. The cultivar *Khosihikari* was transplanted by 300 mm and approximately 180 mm at inter and intra-row distances, respectively. During the weeding, the water level was kept at 40 – 60 mm. The planting date for Sasayama and Shiga location were done on May 26, 2015

and June 12, 2015 respectively. On every location of field test was divided into two plot of weeding date i.e. 10 and 21 DAT (day after transplanting) weeding date. The machine was operated at inter-row for each treatment, which for 1st pass operation covered 3 rows of paddy with remaining 1 blank row space at the middle (at the center of row uninstalled with rotor weeder). The previous blank row space was passed by outside rotor when the machine return for 2nd pass. The weeding evaluation were done two times. The 1st weeding evaluation was done on immediate time before weeding for both two plot weeding 10 DAT and 21 DAT. While 2nd weeding evaluation or final weeding was done before mid-term of drainage, it was on 54 day after transplanting. The grain yield was measured by random sampling of 30 crops and harvested from each plot of treatment. The plants were naturally dried up to around 14% of moisture content and continued by threshing and husking.

7. The function of additional cage wheel for keeping constant traveling speed on many different slippage treatment was quit good which. Though on low slippage treatment there was bit additional drag force from rotor to the cage wheel and resulted the actual slippage bit lower than design one. The power required at rotor shaft of weeder decrease as the number of slippage at rotor decreased. Those data were integrated from 2 different location and plots which all of them were similar on the trend. The decreasing of slippage from the highest around 93 % to 89% resulted in reduction of power at rotor shaft sharply, then become flat as the number of slippage was decreased. From the illustration of trendline show that at every 1% decreasing on slippage of rotor will share on decreasing of power at rotor shaft around 6% for range of rotor slippage 93% to 89%.
8. More advantageous aspect is the energy required per length of operation, define as the required of power divided by forward speed. The trendline of required energy has more

slope than trend line of power at the beginning of decreasing slippage of rotor. For instance, decreasing slippage of rotor from 93% to 89% gave a reduction of energy per length of operation around 11% for every 1% reduction of slippage. Although, reduction slippage of rotor weeder by increasing forward speed of cage wheel resulted in power and energy saving, the limitation of forward speed of weeder as walking-type machine should be considered. It should not be beyond with the comfort range of operator for walking in paddy field. According to the author experience, operating this weeder, the forward speed up to 1.6 km/h (actual slippage around 90%) was comfortable. Therefore, the operation of weeder from the slowest forward speed around 0.95 km/h (by resistance bar device) which resulted slippage of rotor around 93%, then changed by additional cage wheel at 1.6 km/h on forward speed or slippage of rotor around 90%, resulted power and energy saving 18% and 34% respectively.

9. The weeds in the paddy field were dominated by *Monochoria vaginalis* and other fewer portions were *Echinochloa crus-galli*, *Cyperus difformis* and *Scirpus juncoides*. The leaf age and average of length of *M. vaginalis* were 1- 4 and 30 mm respectively at 10 DAT plot weeding, whereas at 21 DAT plot weeding, they were 3-7 and 70 mm, respectively. The weeding efficacy at immediate sampling was affected on some significant level by slippage of rotor weeder except at 10 DAT plot in Sasayama location. The lower the slippage of rotor or the faster of forward speed, the lower the weeding efficacy. The pulverizing level of muddy soil in the inter-row area where the weed existed was affected by combination of rotational speed and forward speed of the rotor, i.e., the pitch of tillage. The calculated of pitch tillage was ranging from the 1.2 cm to 3.8 cm in line with the reduction of actual slippage from 93% to 78%, which accordingly illustrated the decrease in the weeding efficacy at the immediate sample.

10. While for the final weeding efficacy. It indicated, that at 10 DAT plot for both two different locations the slippage of rotor did not give significant effect on weeding efficacy, which it remains stable in line with the decreasing slippage of rotor. Unlike at 10 DAT plot, at 21 DAT plot, weeding efficacy was affected significantly by rotor slippage of weeder.
11. The relation between grain yield base on of brown rice and slippage of rotor in both difference locations, unlike at 10 DAT plot, the grain yield at 21 DAT plot and thereafter was affected significantly by slippage of rotor weeder. Insignificant effect of slippage of rotor to the grain yield at 10 DAT plot rotor has correlation to the phenomena, that final weeding efficacy was not as effective relative to the slippage of rotor in 10 DAT plot. These results were presumed related to the condition of weed infestation at each plot. The average number of existing weed at 10 DAT plot was lower than 21 DAT plot, therefore the weeding efficacy on average at 10 DAT plot higher than at 21 DAT plot.
12. Operating the walking-type power weeder on several levels of slippage of the rotor have been conducted in paddy field. It resulted positive aspect on power and energy saving but gave negative effect on weeding efficacy and grain yield especially when operated at 21 DAT plot. Another fact was found that weeding efficacy and grain yield in Dainaka location was lower than in Sasayama. It was in correlation to the weed infestation, which in Dainaka was found more than in Sasayama location. Operating the walking-type power weeder by additional cage wheel instead a resistance bar also gave another advantage i.e., the operator could use the cage wheel while turning, than lift up and move this machine by hand.