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Design, Fabrication, and Performance Evaluation of a Weeder for Upland Rice Production

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ABTRACT

The weeding machine made of locally available materials using local manufacturing technology was designed, fabricated, and tested to evaluate its performance in terms of operating time, actual field capacity, field efficiency, weeding efficiency, percent damaged plants, and fuel consumption rate at different ranges of angular speed of the engine; three ranges of the engine's angular speed (1501-2000 rpm; 2001-2500 rpm; and 2501-3000 rpm) were used. The experimental design was completely randomized design. The performance of the weeder was evaluated using three (3) to four (4) week-old rice plants. Results indicated that when the machine was operated at angular speed from 1501 to 3000 rpm will result in a mean operating time, actual field capacity, field efficiency, and fuel consumption rate of 155.23 seconds, 888.99 m2/hr, 74.53, and 0.75 L/hr, respectively. Further, the mean weeding efficiency is 88.42%, and the mean percent damaged plants is 0.46%. The weeding efficiency of the machine surpasses the minimum standard for weeding efficiency and the percent damaged plants is lower than the maximum standard for percent damaged plants of 80% and 6%, respectively as specified in the Philippine National Standard (PNS) for weeders. When focusing mainly on manufacturing, assembling, and selling the machine, the investment model resulted in the following figures: Php 14,601.69 net income per year, Php 242,457.93 and 9 units break-even sales, 4.53 years payback period, and 18.07% return on investment. On the other hand, when considering machine rental as part of the investment model, the figures changed to Php 28,266.29 net income per year, 5.92 ha break-even point, 0.59 years payback period, 1.69 benefit-cost ratio, and 169% return on investment. Additionally, a comparative performance evaluation between using a weeding machine and manual weeding revealed that using the machine resulted to an increased capacity and efficiency and a savings of Php 4,840.00 in labor cost.

Keywords: *weeding machine, upland rice, field capacity*

INTRODUCTION

Rice (Oryza sativa) is considered to be the staple crop consumed by estimated 3.5 billion people across the different countries in the world. Approximately there are 480 million metric tons of milled rice have been produced annually (Muthayya et al., 2014). By the year 2030, it is expected that the demand for rice production will rise to at least 25% to keep up with the growth and demand of the global population especially in developing countries (Seck et al., 2012).

In terms of production, Asia contributes about 90% of the total rice production and the Philippines ranks eighth as the world's largest rice producer (IRRI, 2013) with an estimated production of 18 million tons (Statista Research Department, 2021). The largest contribution of rice production across the country comes from Central Luzon with an estimated production of 18.7% and Cagayan Valley comes second at an estimated production of 11.4% (IRRI, 2013). It is estimated that 70% of the total rice area is being irrigated and the remaining 30% is rainfed and upland. Most of the rainfed upland rice production is found in the northern part of Luzon, particularly in the Cagayan Valley.

Weed management practices, especially in upland rice production, have become an important factor affecting yield and harvest. Research in the Philippines has shown that rice production can be reduced to zero if weeds are not controlled (Gianessi et al., 2012). To further improve the production, weeds have to becontrolled thoroughly. New cultivars and weed control techniques have been introduced to fully achieved the value and use of fertilizer which could lead to a 67% increase in yield as compared to not having weed control in the field. In addition, Johnson et al. (2022) asserted that losses of yield due to uncontrolled growth and the emergence of weeds are between 45-75%. Historically, hand pulling of weeds is the common practice executed by many farmers in removing weeds which is often not very thorough because weeding is tedious and time-consuming. For farms of 2 to 3 hectares, 3 to 4 workers are needed to work full time for two weeks which makes the weeding operation labor-intensive and costly. More manpower is needed to complete the task efficiently; however, laborers are not always available when needed (Rao et al., 2017).

Applying herbicide is another common practice used by farmers in eliminating and removing weeds however continuous usage of chemicals can have negative environmental impacts. These chemicals may be carried by and leached into the soil which may pollute the groundwater. Herbicides can also accumulate in the food chain and are very toxic, especially to man (Morales, 2013).

Recent studies regarding weeding machines show effectiveness in removing weeds but demonstrate weaknesses and disadvantages. Weakness associated with the use of the machine includes the absence of the provision of uprooting weeds making it just fall and not incorporated into the soil. Some existing designed machine also lacks the mechanism for thorough removal of creeping weeds such as bind weeds. Also, when the surface of the field is uneven the possibility of weeds not being cut efficiently may happen. Another disadvantage associated with existing machines is the high production and investment cost which restrain farmers from purchasing this weeding machine (Kazeem, 2017).

With the foregoing, the researcher would like to address the present circumstance by introducing a weeding machine that considers the given constraints and disadvantages in the design of the said machine.

Objectives of the Study

The study's overarching goal was to design, fabricate, and subsequently assess the performance of a weeder tailored for upland rice production. In pursuit of this objective, the study undertook several specific tasks. Firstly, it comprehensively examined the weeder's performance through a range of parameters, including operating time in seconds, actual field capacity measured in square meters per hour (m2/h), field efficiency represented as a percentage (%), weeding efficiency also quantified as a percentage (%), the proportion of damaged plants indicated by percent damage plants (%), and the fuel consumption rate measured in liters per hour (L/h).

Secondly, the study engaged in an in-depth investment and economic analysis of the developed machine, aiming to ascertain its viability and potential impact within the context of upland rice production. This analysis encompassed various factors related to cost, benefit, and overall economic feasibility.

The study embarked on a comparative assessment, pitting the performance of the newly developed weeding machine against the manual method traditionally employed for weeding in upland rice production. By systematically comparing these two approaches, the study aimed to elucidate the relative advantages, disadvantages, and overall efficiency of the mechanized weeder in relation to the well-established manual technique.

MATERIALS AND METHODS

Research Design

A. Design of the Weeding Machine for Upland Rice Production

The weeding machine as shown in Figure 1. It consists of 6 major components, namely: the prime mover (1), the main frame (2), the ground wheel (3), the clutching unit (7), the handle (6), and the weeding unit (9,11). The weeding machine has a total dimension of 1820 mm x 570 mm x 790 mm (L x W x H). It was constructed using tubular bar, angle bar, flat bar, G.I sheet, round bar, shaft, v-belt and pulley, chain and sprocket, and pillow block bearing.

The prime mover (1) was the source of mechanical power for the machine. It has a rated capacity of 6.5 horsepower and rated speed of 3600 rpm. The main frame (2) which was made up of 25 mm x 40 mm x 1.5 mm hallow rectangular bar, 25 mm x 25 mm x 1.5 mm hallow square bar, 40 mm x 40 mm x 3 mm angle bar and 40 mm x 3 mm flat bar, serves as a support for the other components of the machine.

The ground wheel (3) facilitates the movement or transportation of the weeder. The rims of the wheel were constructed using 12 mm solid round bar and was connected to a 25 mm diameter steel pipe hub by a 12 mm diameter solid round bar. The external surface of the rim was surrounded by lugs that are made of 20 mm x 3 mm flat bar which provide traction during the movement of the machine.

The ground wheel was attached to the main frame by a 20 mm diameter steel shafting (8) and a pair of PO4 pillow block bearings. The weeding machine was equipped with a clutching unit (7) whose function is to connect and disconnect power from the prime mover (1) to the transmission system and to facilitate headland turning during the weeding

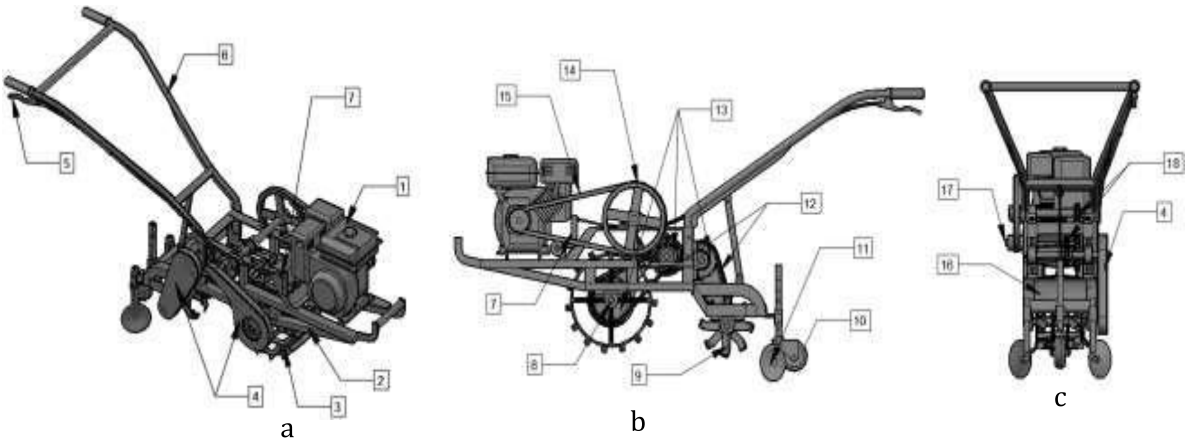

Figure 1. Component parts of the weeding machine in different views (a) *perspective view*, (b) *side view* and (c) *rear view*.

operation. The clutching unit (7) was controlled by an aftermarket clutch lever (5) attached to the handle (6). The handle (6) was constructed using 25 mm diameter steel pipe, 20 mm x 3mm flat bar and 25 mm x 25 mm x 1.5 mm hallow square bar. It was responsible for the steering control of the machine, and it provided a mounting place for the clutch lever (5) and the throttle control of the prime mover (1). The weeding unit consists of a primary weeding mechanism (9) and a pair of disc harrow (11). The primary weeding mechanism (9) of the machine was composed of an arrangement of L-shape blades and is responsible for cutting and incorporating any type of weeds into the soil. Each blades were constructed using 25 mm x 3 mm flat bar and is assembled in a 25 mm diameter steel pipe. The disc harrow (11) gives an additional working width and was used for weeding areas that cannot be reached by the primary weeder. The frame of the weeding unit was made of a 40 mm x 40 mm x 3 mm angle bar and a covering (16) which was made of 0.50 mm GI sheet to prevent the splashing of soil during the operation.

B. Principles of Operation

Referring to Figure 1, the source of power for the machine is a 6.5 hp gasoline engine (1). After the prime mover (1) is started, the clutching unit (7) gives tension to the v-belt (15) to transmit the torque to the transmission system of the machine. The ground wheel (3) and the primary weeding mechanism (9) then receive the power and start to perform their respective functions. As the ground wheel (3) rotates, the weeding unit (9) starts to remove weeds between the rows of the rice crop with a working width of 254 mm and a maximum depth of cut of 64 mm. The weeding process continues until the end of each crop row is reached. At the end of the rows, the clutching unit (7) is added to facilitate headland turning. The process continues until the desired area was covered.

C. Design Calculations and Performance Evaluation

The following formulas and equations were used in the conduct of the study.

1. *Operating Time* (T). It refers to the total time required to finish the weeding operation. The total operating time was recorded to determine the actual capacity of the machine and to estimate the fuel consumption rate of the prime mover.

2. *Actual Field Capacity* (C). It refers to the amount of productivity that is actually done during the weeding operation. It was calculated using the formula:

C=T/E (PAES 150:2010)

Where:

- C = Actual field capacity (m^2/h)
- E = Effective area accomplished (m^2)
- T = Operating time (h)

3. *Field Efficiency* (Eff). It is the ratio between the productivity of the weeding machine under field conditions and the theoretical maximum productivity. It was calculated using the formula:

Eff= C/(CoC)×100

Where:

- Eff = Field efficiency (%)
- C = Effective field capacity (m^2/h)
- Co = Theoretical field capacity (m^2/h)

4. *Weeding Efficiency* (Ɛw). It is the percentage of weeds removed or destroyed per unit area. It can be calculated using the formula:

εw=(W1-W2/W2)×100

Where:

- εw = Weeding efficiency (%)

- W1 = Number of weeds before operation per unit area
- W2 = Number of weeds after operation per unit area

5. *Percent Damage Plants* (PDP). It refers to the number of crops that are injured during the weeding operation. It was calculated using the formula:

PDP=(A/P) × 100

Where:

- PDP = Percent damaged plants (%)
- p = Number of plants in a 10-meter row length before weeding
- q = Number of damaged plants in a 10-meter row length after weeding

6. *Fuel consumption Rate* (Fc). It is the total amount of fuel consumed divided by the total weeding time. It was calculated using the formula:

Fc=Tf/t

Where:

- Fc = Fuel consumption rate (L/h)
- Tf = Total amount of fuel consumed per replication (L)
- t = Total weeding time (h)

7. *Investment and Economic Analysis*. The investment analysis was done to evaluate the economic viability of the machine as a source of income for potential users. Two models were used in the analysis, the Investment Analysis Model 1 which includes manufacturing and selling of the weeding machine and the Investment Analysis Model 2 which includes renting of the weeding machine. The parameters that were gathered in the conduct of the investment analysis are the following: the Break-Even Point (BEP), the Benefit- Cost Ratio (BCR), the Payback Period (PBP), and the Return on Investment (ROI.

8. *Comparative Performance Evaluation of the Weeding Machine and Manual Method of Weed Removal.* Comparative performance evaluation was done to determine the possible advantages of the weeding machine over the manual method of removing weeds. The difference in the total operating time and the actual field capacity between the two weeding methods were considered.

a

b

Figure 2. The researcher while operating the weeder during:
(a) the preliminary testing prior to final testing, and (b) during the final testing.

D. Characteristics of the Site for the Field Testing of the Machine

The selected area for the performance evaluation is an agricultural land that is being used in cultivating rice and various types of vegetables and is located at barangay Abbangkeruan, Pamplona, Cagayan. It has a nearly levelled soil surface with a soil type of clay loam. The total land area of the location is about 900 m2.

E. Functionality and Field Testing

The weeding machine was subjected to preliminary testing to determine its functionality, the possible problems encountered during the operation and the adjustments deemed necessary. After which, a series of actual weeding operation of the machine was conducted to access its performance. Figure 2 a shows the operation of the machine during preliminary testing while Figure 2 b shows operation of the machine during final testing.

RESULTS AND DISCUSSION

Operating Time, s

The operating time of the upland rice weeding machine operated at a different angular speed of the engine is shown in Table 1. The average operating time which comprises of 166.43 seconds, 154.17 seconds, and 145.39 seconds were achieved at 1501-2000 rpm, 2001-2500 rpm, and 2501-3000 rpm of the engine's angular speed, respectively. It can be noted that there is the relative decrease in operating time as the engine's angular speed increases.

The result of the Analysis of Variance, however revealed that varying range of the engine's angular speed of 1501-3000 rpm caused no significant effect on the machine's operating time. The insignificant effect could be due to the machine's forward speed being almost the same.

Actual Field Capacity, m^2/h

The actual field capacity of the weeding machine when operated using different angular speed of the engine was shown in Table 1. As presented in the table, the mean actual field capacities of the machine were 824.36 m2/h, 893.04 m2/h, and 949.57 m2/h achieved at 1501-2000 rpm, 2001-2500 rpm, and 2501-3000 rpm, respectively.

The result of the Analysis of Variance revealed that the actual field capacity of the weeding machine does not significantly differ from each other. Hence, it shows that increasing the angular speed of the prime mover will not significantly affect the actual field capacity of the machine.

Table 1. Summary table of the performance of the weeder.

Treatment (rpm)	PARAMETERS					
	Operating Time (s)	Actual Field Capacity (m^2/hr)	Field Efficiency (%)	Weeding Efficiency (%)	Percent Damaged Plants (%)	Fuel Consumption Rate (L/hr)
T_1 (1501-2000)	166.43	824.36	76.58	86.50	0	0.66^a
T_2 (2001-2500)	154.17	893.04	73.71	90.56	0.48	0.74^a
T_3 (2501-3000)	145.39	949.5	73.30	88.19	0.9	0.84^b
Grand Total	1327.96	8000.89	670.77	795.74	4.14	6.67
Grand Mean	155.23	888.99	74.53	88.42	0.46	0.75
ANOVA	ns	ns	ns	ns	ns	**
LSD	-	-	-	-	-	0.096

Note: a.) Treatment means carrying different letters are significantly different at 1 percent level.
*b.) ** - significant at 1 percent level*
c.) ns - not significant

This can be explained by the insignificant effect of angular speed on operating time, where the actual field capacity was calculated.

Field Efficiency, %

The field efficiency of the machine at varying angular speed of the engine is presented in Table 1. with a grand mean of 74.53%. It can be observed from the data that there is a relative decrease in field efficiency of the machine when the machine was operated at relatively higher rpms. This observation was noted by Misr (2010) on the study (Effect of Combine Forward Speed on the Field Capacity and Field Efficiency of Agricultural Cutting Machines).

The result of the Analysis of Variance, however revealed that the field efficiency was not significantly affected by the angular speed of the engine.

Weeding Efficiency, %

The weeding efficiency of the machine at a different angular speed of the engine is shown in Table 1. The mean weeding efficiency of 86.50%, 90.56%, and 88.19% were attained at 1501-2000 rpm, 2001- 2500 rpm, and 2501-3000 rpm of the angular speed of the engine, respectively. It can be observed from the data that the weeding efficiency of the machine was higher than the standard weeding efficiency of weeders which was 80% (PAES 141:2004).
The result of the Analysis of Variance, however revealed that operating the weeder from 1501 rpm to 3000 rpm caused no significant effect on the weeding efficiency of the machine.

Percent Damaged Plants, %

The percent damaged plants caused by the weeding machine is shown in Table 1, with a grand mean of 0.46%. It can be observed from the data that there is a relative increase in the percent damage plants as the angular speed of the engine increases.

The result of the Analysis of Variance, however revealed that operating the weeder at different angular speed of the engine from 1501 rpm to 3000 rpm caused no significant effect on the number of damaged rice plants during the weeding operation.

Fuel Consumption Rate, L/hr

The fuel consumption rate operated at a different angular speed of the engine is shown in Table 1. The results showed that the mean fuel consumption rate of 0.66 L/hr, 0.74 L/hr, and 0.84 L/hr were attained at 1501-2000 rpm, 2001-2500 rpm, and 2501-3000 rpm, respectively. It can be observed from the data that there is a positive relationship between the angular speed of the engine and fuel consumption rate. That is, as the engine's angular speed increases the fuel consumption rate also increases. This is associated to the fact that heat engines produce high power at higher rpm which in turn consumes more amount of fuel (Cohen, 2021).

The result of the Analysis of Variance revealed that varying range of the angular speed of the engine between 1501-3000 rpm have significantly affected the machines fuel consumption rate at 1% level. In addition, comparison of the treatment means using LSD reveal that T1 was statistically the same as T2. This implies that operating the machine from 1501-2500 rpm will not significantly affect the fuel consumption rate of the weeder. On the other hand, T3 is statistically different from all the other treatment means.

Investment and Economic Analysis

The investment and economic analysis of the weeding machine was undertaken to evaluate if the machine can be considered economically viable.

In the investment analysis model 1, it was assumed that 3 units of weeding machine will be sold annually. The unit price of each weeding machine was Php 26,939.77. Fixed cost of producing each machine was Php 3,232.77 while variable cost was Php 18,839. The total annual net income generated was Php 14,601. The payback period, break-even sales in units, break-even sales in Php, and return on investment were 4.53 years, 9 units, Ppp 242,457.92, and 18.07%, respectively.

On the other hand, in the investment analysis model 2, the weeding machine is assumed to be used on a 5-hectare area per cropping cycle. It operates for 8 hours a day, requiring 1.5 days to cover one hectare based on its field capacity. Following the usual rice production system, the machine is expected to be used for an average of 112 hours per year. The total fixed cost for operating the machine is Php 4,445.07 annually, while the total variable cost is Php 12,288.64 per year. Utilizing the machine for 112 hours generates an annual net income of Php 28,266.29. The payback period, break-even point, benefit-cost ratio, and return on investment are calculated as 0.59 years, 5.92 hectares per year, 1.69, and 169%, respectively. Using the machine can save Php 4,840.00 in labor costs when weeding an area of 1 hectare.

Table 2. Comparison of results of the different methods of operation.

Methods of Operation	Actual Field Capacity (m^2/h)	Theoretical Field Capacity (m^2/h)	Field Efficiency (%)	Time Required (s)
Weeder	888.99	1192.79	74.53	155.33
Manual pulling of weeds	46.84	-	-	2928.08

a b c

Figure 3. (a) The experimental area before weeding operation, (b) after weeding operation using the machine, and (c) during manual weeding.

Table 2 reveals significant differences in various parameters. The upland weeding machine completes the operation in 155.33 seconds, whereas manual weeding takes 2928.08 seconds, making it 19 times slower compared to using the machine. Additionally, the weeding machine has an actual field capacity of 888.99 m2/hr, which is 19 times higher than the traditional method's total capacity of 46.84 m2/hr. Furthermore, a cost comparison was performed between manual weeding and using the machine. It was found that using the machine can save Php 4,840.00 in labor costs when weeding an area of 1 hectare.

CONCLUSIONS

Based on the findings of the study, several key conclusions can be drawn. First, it was observed that the operating time, actual field capacity, field efficiency, percent damaged plants, and weeding efficiency of the machine were not significantly influenced by the angular speed of the engine. However, a notable effect was seen in the fuel consumption rate of the machine, which increased as the angular speed of the engine increased, signifying a significant impact at the 1 percent level.

Furthermore, the economic analysis demonstrated that utilizing the machine was economically viable. In comparison to the manual method of removing weeds, the machine performed the weeding operation at a notably faster rate. Moreover, the weeding machine exhibited a satisfactory overall performance and is highly recommended for use in upland rice weeding operations.

In terms of specific performance metrics, the weeding efficiency of the machine surpassed the standard weeding efficiency for weeders, which is set at 80% according to the Philippine National Standard (PNS/PAES 141:2004). Additionally, the percent of damaged plants resulting from the machine's operation was lower than the standard of 6% specified in the same Philippine National Standard (PNS/PAES 141:2004). These findings collectively underscore the effectiveness and economic feasibility of employing the weeding machine in upland rice cultivation.

RECOMMENDATIONS

Based on the results and findings of the study, the following are recommended:

For operation

• The machine is recommended to be utilized for weeding operations in upland rice production as it shows effectivity in removing weeds and is economically viable.

• For the blade to penetrate deeper into the soil, the operator may exert a downward force on the handle of the machine.

• The machine can be operated for weeds up to 30 cm high, however, it is recommended to operate the machine before the weeds reach a height of 20 cm for best results.

For further improvement/modification

• The ratio of the angular speed of the weeding blades over the angular speed of the ground wheel can be increase so that there will be enough time for the blades to cut the weeds properly.

• A soil fertilizer applicator can be added to the operation of the machine so that weeding and fertilizer application can done simultaneously.

For further study

• The machine can be evaluated for weed control in corn or other crops.

• A study can be conducted by using different orientation of cutting blades and by considering a higher range of angular speed of the engine.

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