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Development of a Single Row Potato Hiller for Mountainous Farming Regions

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Abstract

Hilling potato farms require a lot of labor, tedious work, and time-consuming tasks. It requires at least 10 man-days to complete manual hilling of a hectare farm. It also does not guarantee uniform quality due to the human factor that may result in some potatoes being improperly hilled. This study was performed to develop and evaluate the performance of a single-row potato hiller for small-scale mountainous farming areas in terms of its field capacity, field efficiency, hilling efficiency, fuel consumption, and percentage damage on the potato crop. Three different moldboard designs were used in the field test of the machine: conventional moldboard, moldboard with curved top, and moldboard with curved top and soil carrier. The performance evaluation revealed that the moldboard with a curved top and soil carrier performed favorably with an actual field capacity of 234 m²/hr, field efficiency of 80%, hilling efficiency of 77%, 0% damage on the crop, and fuel consumption of 1.81 L/hr. In comparison with manual hilling, the performance of the machine is lower in terms of hilling efficiency since farmers always make sure that potato plants are properly hilled (100%) in manual hilling. However, the machine performs the work faster compared to the 107 m²/hr manual hilling capacity. With the result of this study, the developed potato hiller for sloping and mountainous potato farms is not ready to replace manual hilling yet, but it has the potential for further enhancement, specifically the moldboard design. Designers and researchers may consider the result of this study for further development to help ease the burden of potato farmers on the laborious, tedious, and time-consuming potato crop production.

Introduction

Solanum tuberosum L., commonly known as the potato, is a globally significant food crop that originated from South America. Introduced to Europe in the 16th century and later in Asia, potato cultivation is concentrated in Asia with approximately 96 million hectares (de Haan & Rodriguez, 2016). It has become one of the most commonly planted tuber crops in the Philippines, particularly in hilly regions such as the Cordillera Administrative Region, Davao, Northern Mindanao, and SOCCSKSARGEN, with Benguet being the major producer (Wustman et al., 2010). Potato production in the Philippines covers approximately 7,867 hectares, with prominence in highland and mid-elevated areas like Benguet, Davao, and Northern Mindanao. Benguet alone contributes 75% of the total production cultivating 4,969 ha in 2014 (Gonzales et al., 2016). Despite being the third tuber crop in the country, local potato production falls short of meeting demand, leading to imports by major industries like McDonald's, Jollibee, and Liwayway from countries like Canada and Australia (Wustman et al., 2010).

The Cordilleras witness the majority of potato cultivation, occurring mainly from November to April due to rainfall constraints. In the fourth quarter of 2024, national production reached 55.85 MT, with 86.4% originating from the Cordillera Administrative Region and the remainder from Davao (8.5%), Northern Mindanao (4.2%), and small percentages from BARMM, Soccsksargen, Cagayan Valley, and Zamboanga Peninsula (Philippine Statistics Authority [PSA], 2025).

Benguet leads the Cordillera in potato production, with key municipalities being Mankayan, Atok, Buguias, Bakun, Kibungan, and Kabayan. A comparison between Cordillera and Mindanao farming reveals better prospects in Mindanao due to flat, accessible farms with greater mechanization potential, attracting commercial interests and investors.

The Philippines lags behind other countries in mechanizing the potato production process, allocating only 2% of farm costs for machinery (Wustman et al., 2010). While farmers in the Cordillera region typically use manual methods, there is a growing trend toward employing small-scale farm machines like hand tractors, power sprayers, and knapsack sprayers. The process involves land preparation, planting seed potatoes, applying fertilizers, hilling, crop establishment, and harvesting, with manual hilling taking about 10 man-days and involving the use of grab hoes (Mehta & Singh, 2016).

In Benguet, the major potato-producing province, topographical challenges prevent the use of large farm machines. Farmers, therefore, rely on manual hilling with grab hoes, a laborious and time-consuming process. Just like any other potato-producing region in the country, a hectare farm takes at least 10 man-days for hilling and fertilizer application (Wustman et al., 2010), and manual methods may result in uneven quality due to human factors.

Effective land preparation involving ploughing to a depth of 30cm is crucial for sufficient loose soil for hilling. Proper spacing, planting, and hilling techniques are emphasized, with rows spaced 70-75cm apart and tubers 30cm within the row. Farmers in Buguias, Benguet, employ single or double-row planting on beds with specific spacing and hilling practices, influenced by factors like the grab hoe size and seasonal considerations.

Hilling or earthing up potatoes is an important activity performed in potato production. It is the process of molding soil around the potato plant base to loosen soil, promoting tuber development, pest protection, plant stability, weed suppression, and facilitating fertilizer application. Another specific purpose of hilling is preventing the development of green potato tuber when tubers are exposed to sunlight, wherein green tuber has a high toxin level of solanine.

Hilling, a crucial cultivation practice, demands significant time and energy. Farm cost distribution reveals the highest expenditure on seeds (44%), followed by fertilizer and labor (13% each), and fungicides and insecticides (13%). Mechanization represents a mere 2% of the overall cost, signifying poor farm mechanization in the Cordilleras (Wustman, 2010).

The timing of hilling is variable, ranging from when the potato reaches 4 inches (10-15cm), as shown in Figure 1 (Feed the Future, 2018), to 12 inches (Carling & Walworth, 1990) tall, depending on local practices and weather conditions. Attention to proper hilling is emphasized to prevent sun exposure, which can turn tubers green, particularly for cultivars that produce tubers away from the stem (Wustman, et al., 2010). Thus, the second hilling (Figure 2) is recommended to be performed locally; however, in Benguet, typically only one hilling is practiced.

The moldboard plow, regarded as a pivotal tillage implement, stands out as one of the oldest agricultural tools, renowned for its efficiency in soil loosening and pulverization. As it moves forward, the double wedging action exerts upward and lateral pressure, causing soil blocks to be sheared loose. This primary shearing action, coupled with the moldboard's upward movement, leads to the breakdown of soil blocks, facilitating further pulverization through their sliding motion (Koolen, 1977). In addition, the moldboard plow excels in creating turning and inversion. With

Figure 1

Change in the Height and Size of Potato Plots After 1st Hilling (Feed the Future, 2018)

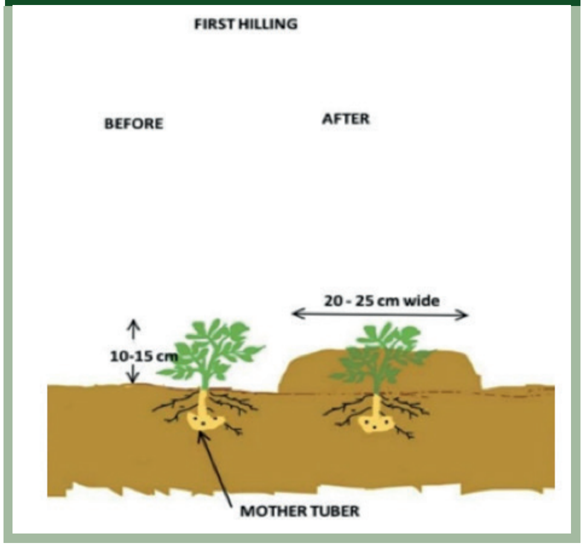
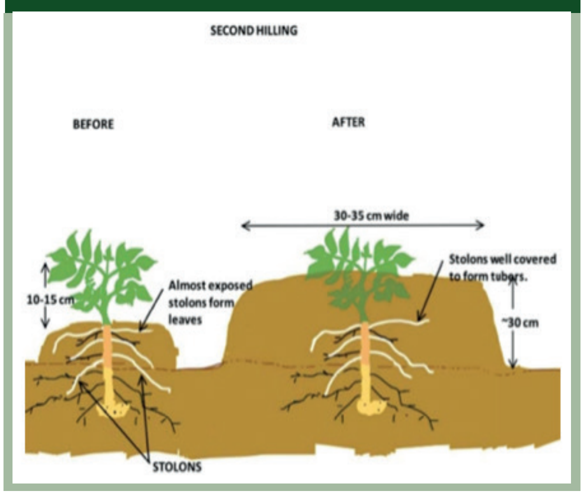


Figure 2

Change in the Height and Size of Potato Plots After 2nd Hilling (Feed the Future, 2018)



the cutting edge of the shear at a 45-degree angle to the direction of travel, the upper part of the moldboard predominantly accomplishes turning (Raheman & Sarkar, 2024). The final step involves pushing or throwing the soil, and the extent of this action depends on the forward speed and the release direction of the soil. In a group of typical plows, the turning and inversion of the furrow slice on the upper portion of the moldboard are achieved through uniform pressure curves (Koolen, 1977).

With this, the study aims to design and fabricate a single-row potato hiller that is adapted to the farming topography of Benguet, Philippines, evaluate its performance, and compare it with manual hilling. The study also aims to conduct a simple cost analysis of the machine for its feasibility for the purchasing farmers.

Methodology

Design Consideration

The design of the single row potato hiller was carefully considered the following criteria to adapt to the local community and the easy access of the purchasing farmer.

1. The machine should be made up of locally available materials.
2. The machine components to be fabricated should be easily replicated.
3. The machine should be easy to operate.
4. The machine components must be easy to attach and detach from the body frame for easy cleaning and transporting.

Machine Design

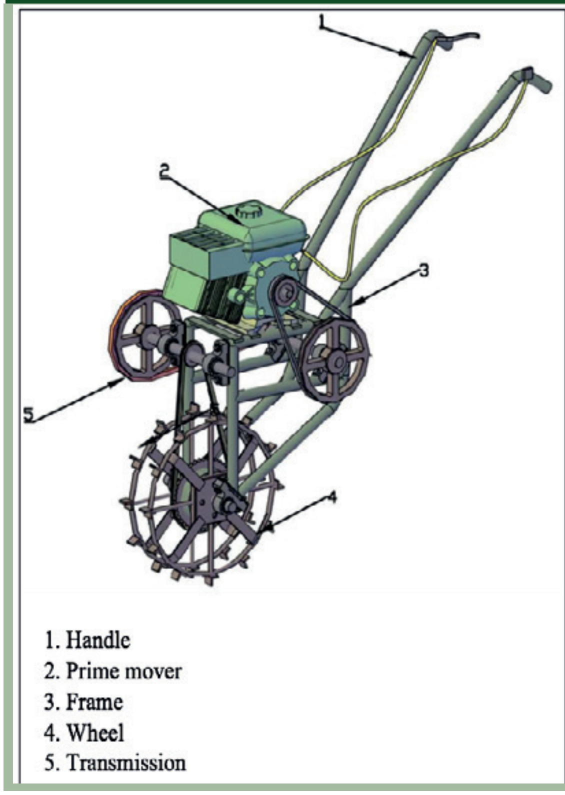
The designed machine (Figure 3) is a push-type machine. The concept design of the single row potato hiller comprises the moldboard plow, wheel, and prime mover. The prime mover of the machine is a 5.5 hp gasoline engine. The operation begins when the prime mover starts to deliver power to the wheel through a connecting chain, making the wheel move forward. As it moves forward, the wheel also tills the soil on its path on the canal or furrow between two plant beds. The moldboard at the back of the machine carries and lifts the soil towards the base of the potato plant, covering each of the plant beds.

Research Design

The study utilized a single-factor experiment arranged in a completely randomized design (CRD) with three replications. The data gathered was analyzed using Analysis of Variance (ANOVA) at 5% level of significance. Least Significant Difference (LSD) was used of the post-hoc analysis.

Figure 3

Perspective View of the Single Row Potato Hiller Without the Hilling Implement



The machine was tested at a fixed speed level using three different moldboard designs as shown in Figure 4, which are (a) conventional moldboard, (b) moldboard with curved top, and (c) moldboard with curved top and soil carrier. Each treatment had three replications.

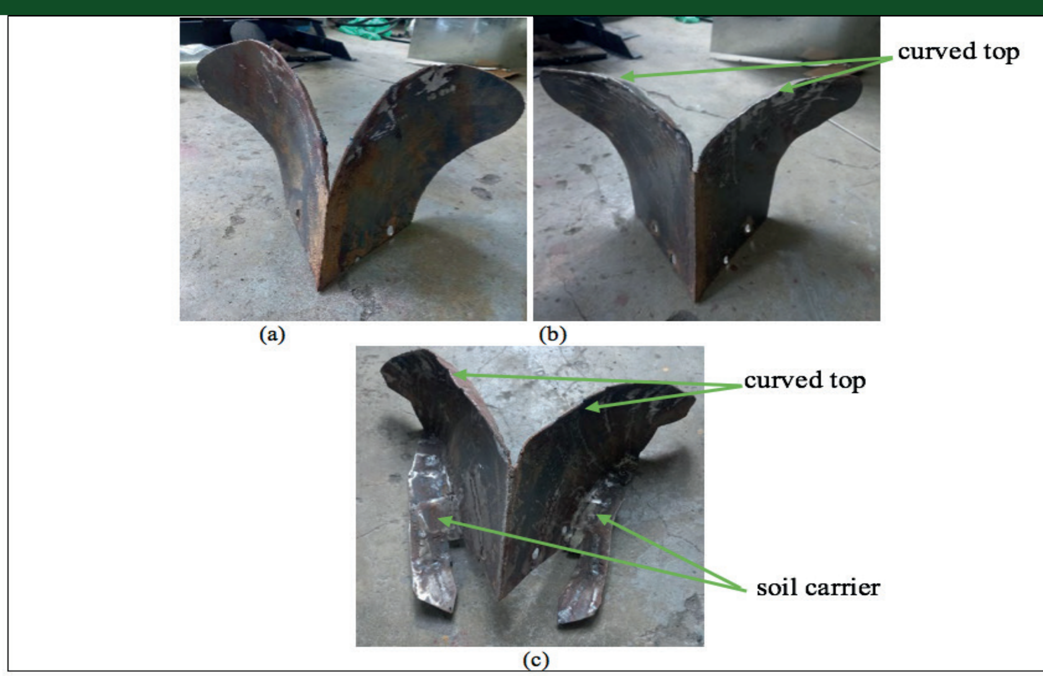
Evaluation Performance Parameters

The machine was evaluated in a clay loam soil potato plant beds with an average dimension of 6m long and 0.34m wide. There were four plant beds for each experimental unit. Three replications were used for each treatment. The average forward speed of the machine was 1.25 km/hr without pulverizing the soil; however, during the hilling process, the hilling speed of the machine is 0.20 km/hr. This is because the machine needs to pulverize the soil first using the wheel before the moldboard scrapes and turns it to the plant bed controlled by the operator.

The single row hiller was evaluated in terms of its actual field capacity, field efficiency, hilling efficiency, percentage damage, and fuel consumption. Performance parameters of the machine were based on Philippine Agricultural Engineering Standard (PAES, 2001) and PAES (2004).

Figure 4

The Different Moldboard Design Used in the Study



Actual Field Capacity (AFC)

This gauges a machine's performance under real/actual field conditions, expressed in hectare per hour (ha/hr). It was calculated using Equation 1,

$$C_{af} = A / (T_1 + T_2) \quad (1)$$

Wherein: C_{af} = actual field capacity; A = area covered (ha); T_1 = productive time (hr); T_2 = non-productive time (hr)

Field Efficiency (FE)

It is determined by calculating the ratio between actual field capacity (AFC) and the theoretical field capacity (TFC), expressed in percentage (%). The TFC of the machine was estimated to be 296 m^2/hr. This was calculated using equation 2,

$$FE = AFC/TFC \quad (2)$$

Wherein: FE = field efficiency; AFC = actual field capacity (ha/hr); TFC = theoretical field capacity (ha/hr)

Hilling Efficiency (HE)

It is defined as the percentage (%) difference between the area of the plot to be hilled and the area left unhilled, relative to the total hilling area (Equation 3).

$$HE = (A_h - A_{nh}) / A_h \times 100 \quad (3)$$

Wherein: HE = hilling efficiency; A_h = Area of plot to be hilled; A_{nh} = area unhilled

Damage Percentage (DP)

This was assessed by considering the ratio of the number of damaged tubers, including scratches and broken stems, planted to the total number of potato tubers, expressed in percentage (%).

$$DP = P_d / P_t \times 100 \quad (4)$$

Wherein: DP = damage percentage; P_d = number of damaged tubers; P_t = total number of potato tubers

Fuel Consumption (Fc)

Fuel consumed by the machine during the operation per unit time (L/hr). The fuel consumed during the operation was gathered by refilling the fuel tank after each experimental unit using a graduated cylinder as recommended in PAES (2015). Equation 5 was used to calculate the fuel consumption.

$$Fc = V / t \quad (5)$$

Wherein: Fc = fuel consumption (L/hr); V = volume of fuel consumed (L); T = time of operation (hr)

Simple Cost Analysis

Simple cost analysis was performed to assess the economic feasibility of the potato hiller. Important parameters such as revenue, net income, break-even point, and payback period were evaluated (Añar et al., 2025; Hunt, 2001; Titiwa et al., 2019).

Revenue (R)

This is the gross income in using the machine, expressed in Philippine peso per year (Php/yr). It was calculated using Equation 6,

$$R = CR \times C \quad (6)$$

Wherein: R = revenue (Php/yr); CR = custom rate (Php/ha); C = capacity (ha/hr)

Net Income (N)

This is the annual net profit calculated by obtaining the difference of the total annual revenue and the annual operating cost, shown in equation 7. The annual operating cost is the sum of the annual fixed cost (depreciation cost, interest on investment, and tax and insurance) and the annual variable cost (labor cost, and repair and maintenance), calculated using equation 8,

$$N = R - AOC \quad (7)$$
$$AOC = AFC + AVC \quad (8)$$

Wherein: N = net income (Php); R = revenue (Php); AOC = annual operating cost (Php); AFC = annual fixed cost (Php); AVC = annual variable cost (Php)

Break-Even Point (BEP)

This is the number of hectares that must be hilled annually to recover the cost of the machine. It is calculated using equation 9,

$$BEP = AFC / (CR - VC / C) \quad (9)$$

Wherein: BEP = break-even point (ha/yr); AFC = annual fixed cost (Php/yr); CR = custom rate (Php/ha); VC = variable cost (Php/hr); C = machine capacity (ha/hr)

Payback Period (PP)

This is the time of the machine utilization to return the payment of its investment which was calculated using equation 10,

$$PP = C_i / N \quad (10)$$

Wherein: PP = payback period (yr); C_i = initial cost (Php); N = net income (Php)

Survey on the Performance of the Potato Hiller by Farmers

To evaluate the performance of the potato hiller on the level of satisfaction to perform the operation as perceived by potato farmers, a survey questionnaire was formulated using a 5-point Likert scale. Volunteer farmer participants who are experts in potato farming were gathered during the field test after they were informed of the study. The volunteer farmers rated 30 plots hilled by the potato hiller from strongly dissatisfied to strongly satisfied based on their perception of whether the base of potato plants was covered with soil or not.

Results and Discussions

The fabricated potato hiller machine shown in Figure 5 was designed and fabricated to aid the tedious and time-consuming operation of hilling. It is intended for small-scale farm operations in the sloping and mountainous farm areas. The machine was fabricated using locally available materials. It comprises the handle, prime mover, frame, wheel, transmission system, and moldboard as the hilling implement. The specifications of the machine is shown in Table 1.

Performance Evaluation of the Single-Row Potato Hiller

Table 2 shows the summary of the results of the performance evaluation in terms of the field capacity, field efficiency, hilling efficiency, damage percentage, and fuel consumption.

The result of the actual field capacity of the machine shows that the treatments have no significant differences from each other. Comparison among the treatments shows that the highest capacity was 237 m^2/hr when operated using the moldboard with a curved top. This result was due to the observed unsteady operator's pacing, operator's stop, and turning, creating a slight difference in the capacity. Hancock et al. (1991) also reported some factors that affect the said result, such as interruptions due to turning and breakdowns by the machine.

In terms of field efficiency, the treatments do not have significant differences with the moldboard with curved top having 80.52% field efficiency. With the same theoretical field capacity (average of 296 m^2/hr) of the machine, the field efficiency is dependent on the field capacity, which was affected by the operator's performance. The same report was disclosed by Hanna (2016) wherein interruptions, including breakdowns, cleaning the plugged machine, checking the machine's performance and adjusting, waiting for the machine to move forward, turning, operator rest stops, and others cause failure, lowering the field efficiency.

Hilling efficiency shows that the moldboard with a curved top and soil carrier has the highest mean of 77.06 %. The treatment means have no significant difference. This low hilling efficiency is attributed to the fixed dimension of the moldboard and the uneven width of the canal (PAES, 2015) since the plant beds were prepared manually using a grab hoe. Given that all of the designed moldboards' width is 0.41m, scraping the soil and delivering it to the base of the potato plant is affected especially at the wider part of the canal. The slightly higher hilling efficiency of the moldboard with a curved top and soil carrier is affected by the characteristics of the design that helps carry the soil up to the roots of the potato plants.

The damage percentage of the machine on the potato plant was observed on the conventional moldboard design, having 0.69% damage due to the operator's error when turning, while the other two treatments did not have any damage.

Figure 5

Fabricated Single Row Potato Hiller with the Implement

Table 1

Specifications of the Single Row Potato Hiller

Parts	Specification
Main structure	
Overall dimensions, mm	
Length	1,169.40
Width	342.90
Height	77.80
Prime mover	
Engine	
Brand	Golden Horse GH550
Type	Gasoline engine
Rated Power, hp	5.5
Rated Speed, rpm	3,600.00
Power transmission	
Engine to the shaft	V-belt and pulley
Shaft to the wheel	Chain and sprocket
Transmission system Accessories	
Sprocket, teeth	14
Sprocket, teeth	42
Pulley Shaft, mm	
Diameter	19
Length	355.6
Wheel shaft, mm	
Diameter	25
Length	254
Chain (pitch), mm	12.7

Table 1 *Continuation...*

Parts	Specification
Input pulley, mm	
Diameter	76.2
Bore	19
Output pulley, mm	
Diameter	203.2
Bore	19
Frame	
Dimensions, mm	
Length	990.6
Width	342.9
Height	700
Material (main)	G.I. pipe
Diameter	25.4
Moldboard Implement	
Drawbar	
Dimensions, mm	
Height	420
Length	70
Material	Flat bar
Thickness, mm	5
Moldboard	
Dimensions, mm	
Height	270
Width	410
Length	381
Material (share), mm	Flat bar
Height	203.2
Width	177.8
Length	5
Material (moldboard)	Metal plate
Thickness, mm	3

Performance of the Potato Hiller vs. Manual Hilling

The performance evaluation showed that the moldboard design with a curved top and soil carrier have the highest hilling efficiency among the treatments, hence it was recommended in this study. Table 3 presents the comparison of the potato hilling machine to manual hilling. In terms of hilling efficiency, manual hilling has a 100% hilling efficiency when compared to mechanical hilling using the moldboard with a curved top andsoil carrier design, which has a hilling efficiency of 77.06% because the farmer makes sure the base of the potato plant is fully covered with soil before moving to the other plant when hilling manually. However, in terms of time spent hilling the potato plants, manual hilling is time-consuming, which takes 0.11 km/hr compared to machine hilling, which takes 0.20 km/hr, with a difference of 0.09 km/hr. As a result, using a machine to do the work in the field speeds up the process.

A survey was taken from 15 respondents who have been engaged in potato farming to further evaluate the performance of the hilling machine. Their level of satisfaction with the hilled plots was gathered using the Likert scale 1 represents strongly dissatisfied, while 5 means strongly satisfied. A total of 30 plots were individually evaluated by the respondents.

With the survey gathered, it came out that 64% of the respondents were satisfied with the hilling performance of the moldboard with curved top and soil carrier design, 60% for the moldboard with curved top design, and 55% for the conventional moldboard design. The remaining percentages for each design are those dissatisfied. This result of satisfaction rating from the respondents was correlated with the uneven thickness of hilled soil along the plots, hence, futher assessment on the quality of harvested potatoes like occurrence of green tubers may be conducted.

Simple Cost Analysis

To determine if potential users of this machine, which are the farmers, would benefit from its acquisition, a simple cost analysis was performed. The study used a 10% salvage value as stated in the Food and Agriculture Organization (FAO) training session module that the salvage value is 10 to 20 percent of the initial purchase

Table 2

Summary of the Results of the Performance Evaluation of the Potato Hiller

Treatment (Moldboard)	Actual Field Capacity (AFC) (m^2/hr)	Field Efficiency (FE) (%)	Hilling Efficiency (HE) (%)	Damage Percentage (DP) (%)	Fuel Consumption (Fc) (L/hr)
Conventional	231	77.72	51.27	0.69	1.81^b
Curved Top	237	80.52	63.40	0	1.57^a
Curved Top + Soil Carrier	234	79.56	77.06	0	1.81^b

Means with the same letter vary significantly at 5% level of significance.

Table 3

Comparison Between the Performance of the Potato Hiller and the Manual Hilling

Mode of Hilling	Hilling efficiency	Hilling speed (km/hr)	Per one hectare area: Capacity (ha/hr)	Labor Cost (Php.)	Days of hilling
Manual	100%	0.11	0.0107	4,560.00	12
Machine	77.06%	0.20	0.0237	10,167.00	6

price (Sessions, 1986). The latter source also stated that a tractor could usually stay up to 20 years or range from 10,000 to 12,000 hours for track-type tractors. The machine was estimated to work 7 hours a day, according to local farmers asked by the researchers, which will give 126 annual operating hours in 3 potato cropping seasons. The computed custom rate of the machine was Php5,167 per hectare. Lastly, the average price of fuel in the Philippines is Php 55.00. The initial cost of the potato hiller is Php21,558.00 covering the materials and the labor of fabrication. Table 4 shows the assumptions and the result of the simple cost analysis of the machine.

With this result of simple cost analysis, it is recommended to further analyse the economics of the machine for commercialization. Considering the mass production of the machine, lifecycle cost analysis for ownership-to-use, and cost-benefit analysis for ownership-to-rent, or other methods may be used. This will aid the farmers in their decision-making of purchasing the potato hiller.

Conclusions

Based on the study, the best design for the moldboard to be used in hilling potato plants is the moldboard with a curved top design, having the following: 63.40% hilling efficiency; 0.0295ha/hr theoretical field efficiency; 237m²/hr effective field capacity; 80.52% field efficiency; 1.57L/hr fuel consumption; and 0% potato damage.

The initial cost of the potato hiller is Php21,558.00 covering the materials and the labor of fabrication. It has a capacity of 0.0237ha/hr. A simple analysis of the study using the assumptions and equations for the cost analysis indicated a break-even point of 0.54ha/yr, revenue of Php20,669.31 per year, net income of Php2,795.79 per year, and payback period of 7 months and 21 days.

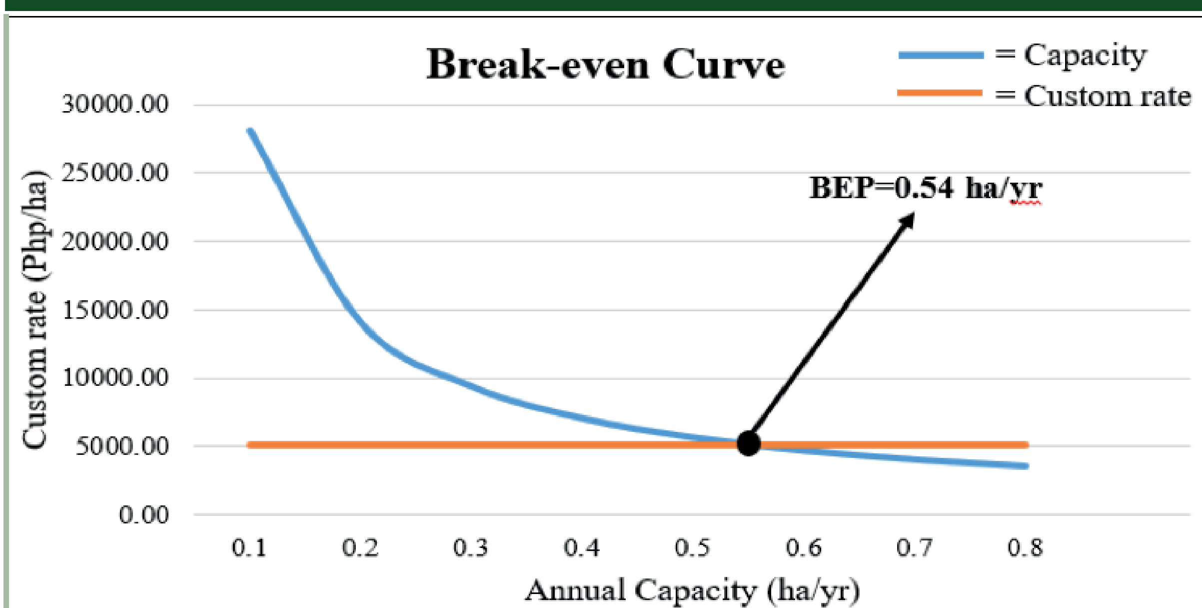
Table 4

The Result of the Simple Cost Analysis

PARAMETERS	VALUE
Revenue, Php	20,669.31
Net Income, Php	2,795.79
Break-even Point, ha/yr	0.54
Payback Period	7 mos. and 21 days

Figure 6

Relationship of the Custom Rate and the Capacity of the Potato Hiller



Recommendations

Based on the study's outcomes, the following technical recommendations are advanced for optimizing potato hilling machine performance: Firstly, the adoption of a moldboard with a curved top and soil carrier design is advocated, as it exhibits commendable outcomes in hilling efficiency, field efficiency, and minimal damage percentage. Secondly, meticulous attention to furrow and ridge spacing, ranging from 17cm to 25.4cm and 30.48cm to 40.64 cm, respectively, is advised to ensure optimal soil distribution during hilling operations. Additionally, the incorporation of an assisting wheel at the rear of the moldboard is suggested to enhance the machine's forward propulsion. Thirdly, strategic hill approaches accommodating potatoes with varying growth rates are recommended. Furthermore, widening the moldboard is proposed to augment soil coverage during hilling, with a caveat to avoid damage to plant stems. To safeguard the machine's transmission system situated at the wheel, a protective cover is advised to prevent potential damage from contact with stones or debris. Finally, comprehensive testing under diverse soil conditions is advocated to validate the machine's functionality across varying environmental parameters.

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