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Adaptation and Performance Evaluation of Tractor Drawn Rigder for Potato Hilling

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ABSTRACT

This study was carried out to adapt and performance evaluation of tractor-drawn rigder for potato Hiller at predetermined row spacing and operating speed. The fabricated ridger consisting of a main frame, tyne, frog, mouldboard, share, and hitching system. The performances of the hiller were evaluated in terms of ridge height and width, plant damage, draft and power requirement, field capacity, field efficiency, labour cost and economics owning and operating. The experimental design used was completely randomized design (three levels of speeds of operation with three replications). The hiller was evaluated at tractor forward speed of 2, 2.5, 3 km/hr. Forward speed of the tractor had significant effect on the height of ridge formed at $p < 0.05$.. The average theoretical field capacity, effective field capacity, field efficiency, and fuel consumption were 0.32 ha/hr, 0.30 ha/hr, 92.57%, and 1.5 l/hr respectively at speeds of 2km/hr and 93.63% of weeding observed during the field test. Depending on the results of performance evaluation, it is concluded that the constructed potato ridger can be efficiently and economically used by the majority of farmers.

INTRODUCTION

Potato is one of the tuber crops grown in Ethiopia. It is grown by approximately 1 million farmers (CSA 2008/2009). Ethiopia has a suitable edaphic and climatic condition for potato production. About 70% available agricultural land is located at an altitude of 1800-2500m which is suitable for potato production (FAO and Endale, G. *et al*., 2008). It has an area coverage of 66, 745 ha and production of 784,993 tonnes in the country (FAO 2013).
Ethiopian farmer's main objective of growing potato is to ensure adequate food supply during food shortage months and as well as an important source of cash income (Gebremedhin W. *et al*., 2013.), because of its ability to provide a high yield of high-quality product per unit of input with a shorter crop cycle than major cereal crops like maize (Adane H., *et al*., 2010). Potato has been considered as a strategic crop by the Ethiopian government aiming to enhance food security and economic benefits to the country (EIA 2012). It is among the major vegetable export products (EEI 2015).
Arsi is one of the potential potato growing areas in Southern parts of Ethiopia. Despite the potential of potato production in the zone, there are several constraints that are drastically affected to the low production and productivity of potato crops by smallholder farmers. The way of hilling soil is one of the problems seen during potato plantation time as it is one of the most important tasks must be done when growing potatoes. Hilling is the mechanism of creating a mound around the base of the potato plant. Traditionally potatoes are hilled in the production cycle between emergence and closure of the canopy. Hilling can be accomplished with disks, sweep shovels, or similar tools that lift soil and deposit it on the top of the row.
The importance of hilling are improved weed control, improve drainage, minimization of greening of tubers and rising of soil temperatures. Hilling or earthing up carried out twice or thrice during the crop season, accompanied by weeding and side dressing the crop with fertilizers, under irrigated conditions, whereas in rain-fed conditions, weeding, earthing up, and mulching are carried out simultaneously. Usually, earthing up is done during 45–60 days after planting (DAP), 90–105 DAP and 120–135 DAP. This intercultural operation helps to form and enlarge finger rhizomes and also ensures adequate aeration to roots. Also protects rhizome from the attack by scale insects and check weed growth (Panigrahi *et al*., 1987). Flatbed, followed by earthening up and proper management of each of these factors was found to be the best practice to maximize quality and quantity of tuber yield (Ajai *et al*., 2002).
In potato production areas of the country hilling potato crop performed by the traditional method by either manual method by the help of a slatted short handle hoe, an axe, cutlasses spade and some other local tools or by a pair of Oxen drawn maresha. Traditional method of hilling adopted in potato cultivation is slow, time consuming, tedious, inefficient and involve drudgery, hence increases, the cost of production. In order to overcome this problem, it is essential to adapt and modify the existing tractor drawn ridger to potato hiller and evaluating its performance for small scale farmer.
The tractor mounted Ridger imported by Kaleb services farmer's House Company was used for furrow making and has single ridger per row. In order to utilize and address the demand of farmers involved in potato production, double row ridger is ecential for potato hilling and weeding purpose must be adapted, modified and evaluated for the better earthening up process of potato hilling. Therefore, this research project is aimed to

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construct proper tractor drawn ridger for potato hilling with the objectives of.

To adapt Tractor drawn Rigder for potato Hiller and evaluate the performance of the adapted tractor drawn potato hiller.

MATERIALS AND METHODS

Descriptions of Study Area

The design, fabrication, testing and evaluation was carried out at Assella Agricultural Engineering Research Center located in the Arsi zone of Oromia Region and it has 6° 59' to 8° 49' N latitude and longitude of 38° 41' to 40° 44' E and an elevation of 2,430 meters above sea level.

Description of the Hiller

The materials available in local market were used for the construction of different parts of the tractor drawn potato hiller. The main parts of adapted tractor drawn hiller are; main frame, three point hitch system, Tyne, Share and Frog.

Figure 1: Developed prototype of potato hiller

Main Frame

Frame is the skeletal structure of the ridger on which all other components are mounted. The two design factors considered in the determination of the material required for the frame was the weight and strength. In this case, mild steel square hollow section of 60 mm x 60 mm and 5 mm thickness were used to give the required strength.

Tyne

It is made from mild steel flat iron having 730mm x 60mm x 20mm thickness dimensions so as to withstand the load encountered in actual field condition during the hilling operation. Three tynes were fixed on the main frame of the ridger using bolt and nuts with provisions to adjust the width and depth by moving the tyne in both horizontally and vertically respectively.

The upper end of the tyne was welded to MS sheet metal having 100 x 100 mm x 6mm thickness. MS sheet metal were provided with hole of 16 mm diameter and 80 mm center to center distance and so that the tyne were attached to main frame with bolt and nut through these holes.

Share

It is the part which penetrates the soil and makes cut below the surface. The share of hiller was made as a slip type which was made of MS sheet metal of 6 mm thickness. The share was provided a shape at the end such that it makes an angle of 30° with the horizontal.

Frog

The frog is made from mild steel sheet metal having 4 mm thickness. Both share and mould-board were bolted to the frog and connected to upper part of landside.

During the ridging operation, draught force 'D' acts at the angle of the shovel which cause a bending stress (σ) due to resistance of the soil at the bended side initiating twisting of the rod.

For calculation purpose soil resistance Ko was assumed to be horizontal and acts in the axis of symmetry of shovel and it was assumed to be 0.25 kg/cm^2 for heavy soil.

Table 1: Specific Soil Resistances up to a Depth of 15 cm

S.No.	Soil type	Specific resistance, kg/cm^2
1	Light soil	about 0.12 kg/cm^2
2	Medium soil	about 0.15 kg/cm^2
3	Heavy soil	about 0.20 kg/cm^2
4	Very heavy soil	about 0.25 kg/cm^2

Source: Dubey, 2003

The draft force applied to the tip of share was determined using the following equation (Kurtz *et al.* 1984).

$$D = K_o * n * w * d \quad (1)$$

$$D = \left[0.25\ x3\ x\left(\frac{2+6}{2}\right)x11\right]x9.81$$

$$D = 323.73N$$

Hence factor of safety was assumed to be 3. Thus, total draught exerted on the shovel was calculated as follows.

$$D = 323.73x3$$
$$D = 971.2N$$

The draft force applied on each opener was determined as follows.

$$D = \frac{971.2N}{3}$$
$$D = 323.73N$$

Where, D=draft force, N
Ko=specific soil resistance, W= width of opener, cm; d=depth of opener, cm; n=number of furrow openers
Hence, square hollow pipe M.S furrow openers of 730mm x 60mm x 20 mm thickness size was quite safe and the size was available in the market.

Hitching System Design

Potato hiller was connected or hitched to a tractor through three point linkage provided at the rear end of tractor, which is hydraulically controlled. The geometry dimensions for mast height, lower hitch point span, mast and linch pin hole distance were determined according to (ASAE S217.12 DEC01 (ISO/DIS 730: 2007).

Performance Test and Evaluation

Field performance tests were carried out to obtain actual data on overall implement's performance and working capacity in the field. The field trials of tractor drawn potato hiller were conducted at Tiyo districts of Arsi Zone. Plant height, moisture content of the soil, soil bulk density, ridging width, ridge height speed of operation, total area of hilling, total operating time and plant damaged/injured were observations recorded at the field.

Figure 2: Field performance evaluation

Moisture Content of the Soil

Samples of the soil were collected at 25 cm depth of soil surface before hilling operations for bulk density and soil moisture content determination. Five soil samples were collected randomly from the experimental plot. Then, the soil samples were kept in oven for 24 hours at temperature of 105°C and weighed before and after drying. The moisture content (Db) was determined by (Rangapara J., 2014).

$$Mc = Ww - Wd/Wd \quad (2)$$

Where,
Mc = Moisture content of soil, % db; Ww = Weight of wet soil, g; and Wd = Weight of oven dry soil, g.

Bulk Density of Soil

Bulk density of the soil is the oven dry mass per unit volume of the soil. It was measured by using core sampler by taking different soil samples randomly from each test plots . The bulk density was calculated by using following formula.

$$\delta = M/V \quad (3)$$

Where, δ = bulk density of soil, g/cm^3; M = oven dry mass of soil, g; and
V = volume of core sampler, cm^3.

Plant Height

The plant height of potato crop during hilling operation in potato field was randomly measured by the help of measuring tape and replicate five times.

Speed of Operation

Speed of operation of tractor drawn hilling implement was measured by recording the time required to cover 20m distance. Speed was calculated by using the following formula.

$$Speed(km/hr) = \frac{3.6 x \, distance \; travelled\,(m)}{Time\,(s)} \quad (4)$$

Theoretical Field Capacity

It is the rate of field coverage that was obtained if implements performing its function 100 % of the time at the rated speed and always covering 100 % of its rated width.

$$TFC = (W \times S)/10 \quad (5)$$

Where,
TFC = Theoretical Field Capacity, ha/h; S = Speed of Operation, km/h; and W = Theoretical width of implement, m.

Effective Field Capacity

It is the actual average rate of coverage by the implement. The total time required to complete the operation were recorded and effective field capacity was calculated as follows.

$$EFC = A/T \quad (6)$$

Where,
EFC = Effective field capacity, ha/h; A = Actual area covered, ha; and T = Total time required to cover the area, h.

Field Efficiency

It is the ratio of theoretical and effective field capacity and calculated by using the following formula.

Field Efficiency = (EFC/TFC) x 100 (7)

Draft and Power Measurement

Draft was measured using a spring dynamometer attached to the tractor on which the implement was mounted. Another auxiliary tractor was used to pull the implement mounted tractor through the dynamometer. The auxiliary tractor pulls the implement-mounted tractor with the later in neutral gear and the implement in the operating position. Draft was recorded in the 20 m distance. On the same field, the implement was lifted off the ground and the draft was recorded. The difference between the two readings, gives the draft of the implement as expressed by (Rangapara J., 2014).

Draft (KN) = Dl - Du (8)

Where, D_l= draft of under loaded condition, D_U= draft of under unloaded condition

The tractor power consumption was also determined by following formula:

power (W) = Draft (N) x speed (m/s) (9)

Fuel Consumption

The fuel consumption was measured by graduated cylinder by refilling method that filling a fuel tank to its full capacity before test run and then, by refilling a known volume of fuel to the fuel tank and the volume of fuel refilled was taken as fuel consumed per plot.

Weeding Efficiency

It was determined by the weed count method at 5m length of row were measured by marking the field and the number of weeds and stubbles enclosed within the range of marked length were counted before starting the test and on the same row it was counted after the test run. Randomly five observations were taken within the test plot.

The weeding efficiency was calculated as follows

Weeding efficiency (%) = $(W_1 - W_2)/(W_1)$ x 100 (10)

Where,

W_1 = Number of weeds per 5m row length counted before ridging; and

W_2 = Number of weeds per 5m row length counted after ridging.

Measurements of Height and Width of Ridging

Height and width of ridging were measured by setting the level that controls the lifting mechanism at a level corresponding to the required depth of cut and driven at a predetermined forward speeds fo2, 2.5 and 3 km/hr. The depths of cut (height of ridge) were measured with a measuring tape, from the bottom of the furrow to the surface level of the soil at randomly selected points and three observations were recorded at each speed of operation.

Plant Damaged

During hilling operation plant damaged/injured in selected row were counted and three observations were taken at different forward speed of operation and the percentage of plant damage was calculated.

Cost Estimation

Estimation of annual and hourly operational costs of the Tractor and fabricated hiller were depending on capital cost of the tractor and the implement, interest on capital, cost of repairs and spare parts, labor cost, and depreciation. The operational cost components of the hiller prototype and 25-hp tractor were estimated in Birr (EB) according to Wen-yuan Huang *et al* (1979). An economic life of 10 years and 260 hours per year for tractor is assumed, and the implement is expected to be used 260 hours per year.

I. Fixed Cost

Depreciation

It was a measure of the amount by which value of the implement decreased with the passage of the time. The annual depreciation was calculated according to Kepner et .al. (2005) as follows:-

$$D_P = \frac{PP - SV}{LxH}, (EB / h) \quad (11)$$

Interest

Interest was determined on the average investment of the machine taking into account the value of the implement in the initial and final year. These are usually calculated on yearly basis. The annual interest on the investment was calculated according to Kepner *et al.* (2005) as follow:-

$$I = \left(\frac{PP + SV}{2}\right) \times \left(\frac{I\%}{H}\right), (EB / h) \quad (12)$$

Insurance & Taxes (IT)

The annual insurance and taxes on the investment was calculated according to Kepner*et al.* (2005) as follow:-

IT = 1% of PP (13)

Housing

Housing = 1% of PP (14)

Total fixed cost t = D_p + I + IT + Housing (15)

II. Variable Cost

Repair and Maintenance Cost

The repair and maintenance cost of the implement and tractor was taken as 10% of the cost of the purchasing price (Kepner*et al.*, 2005 and Kamboj*et al.*, 2012).

RM = 10% of PP (16)

Wages of Operator

Wages was determined based on actual wages of workers per day or hourly paid.

Total Cost of Potato Ridging Per Hour

The total cost of potato ridging per hour was calculated from the summation of total fixed cost per hour and total variable cost per hour as follows.

Total Cost/h= Fixed Cost per hour + variable Cost per hour

Where,

Purchase price (Pp): 123,000 EB, Salvage value (SV): 10%, Interest rate: 10 %, Repair and maintenance (RM): 10% , Insurance & taxes (IT): 1% of PP, Housing: 1 % of PP, Fuel consumption: 3.46 lit/hour , FC = 23.06 EB per lit Lubrication cost (L.C): 140 EB per lit, Lubrication consumption: 25% of fuel ,Labor cost (LaC): 200 EB per day and Dp = Depreciation

Experimental Design

The experimental design was factorial with complete randomized design with three replications. The three levels of forward speed of tractor (2 km/hr, 2.5 km/hr and 3 km/hr) were used as treatments with three replications. The experimental design was laid as 31 with three replications and had total of 9 test runs (3x3 = 9).

Data Analyzing

The collected data were subjected to analysis of variances following a procedure appropriate for the design of the experiment (Gomez and Gomez, 1984) and using GenStat 15th edition statistical software. The treatment means that were different at 5% levels of significance were separated using least significant difference (LSD 5%) test. The least significant difference (LSD) test was performed for the mean values of height of ridge and plant damage in relation to forward speed and hiller's working capacity.

RESULTS AND DISCUSSION

Moisture Content of the Soil

Five soil samples were collected randomly at 0-25 cm depth of soil surface before hilling operations by using core sampler. As shown in the table1, the mean moisture content at 25 cm depth was found 19.67 % on dry basis.

Bulk Density of Soil

Bulk density of the soil is the dry mass per unit volume of the soil. It was measured by core cutter method before starting the hilling operation. Soil samples were taken randomly from experimental plot by using a core cutter having 7 cm inner diameter and 12 cm height. Five soil samples were taken at the depth of 0 to 25 cm before hilling operation. The soil samples were weighed before placing into an oven for 24 hours at 105^0 C and after drying the weight of the sample was measured again. The average bulk density was found to be 1.39 g/cm^3 as shown in Table 2.

Table 2: Soil moisture content and bulk density at the field condition (Dry basis)

Replication	Soil moisture content, %	Bulk density, g/cc
1.	18.04	1.39
2.	17.86	1.44
3.	20.86	1.37
4.	21.75	1.37
5.	19.86	1.38
Mean	**19.67**	**1.39**

Speed of Operation

Operation speed of tractor drawn hilling implement was measured by recording the time required to cover 20m distance. The operation speed was recorded on the speed range at 2 km/h, 2.5 km/h and 3 km/h as shown in the table 3. The stopwatch was used to record the time of operation. The optimum operational speed of tractor drawn potato hiller for hilling operation was found to be 2 km/h, which results better ridging height.

Table 3: Ridger performance evaluation results on (10 x 50) m^2 plot

S/no	Parameter	Mean values at different speed level		
		2 km/hr	2.5 km/hr	3 km/hr
1	Ridge height, (cm)	21.33	17.33	13.33
2	Ridge width, (cm)	41.5	48.6	51.2
3	Plant damage (%)	5.77	7.69	10.00
4	Effective field capacity (ha/hr)	0.30	0.36	0.41
5	Theoretical field capacity, (ha/hr)	0.32	0.39	0.46
6	Field efficacy, (%)	92.57	91.06	88.37
7	Weeding efficiency, (%)	93.63	93.63	93.63
9	Draft requirement (N)	560	617.67	660.50
10	Power requirement (Hp)	0.42	0.57	0.74
11	Fuel consumption (lit/hr)	2.5	3.1	3.8

12	Man-hr, (hr/ha)	3.33	2.78	2.44
13	Cost of operation, (Birr/hr)	259.64	259.64	259.64
14	Cost of operation, (Birr/ha)	864.60	721.80	633.52

Field Capacity and Efficiency of Potato Hiller

The average theoretical field capacity of the hiller at 2, 2.5, 3 km/hr were 0.32, 0.39, and 0.46 ha/hr, respectively. Whereas, the effective field capacity at forward speed level of 2, 2.5, 3 km/hr were observed as 0.30, 0.36, and 0.41ha/hr respectively (table 2). This indicated that both the theoretical field capacity and effective field capacity of the implement increased with an increase in operational speed as shown in figure 3. Generally, the implement can hill or ridge a hectare of land in range of 2.44 to 3.33 working hours based on the forward speed of tractor. The mean values of field efficiency were shown in table 2. The lowest field efficiency recorded at 3 km/hr forward speed was 88.37% and the higher field efficiency was obtained at a speed of 2 km/hr was 92.57%. Figure 3reveals that, field efficiency decreased as speed increases. Rangapara J. (2014) suggested that as the size of the field was decreased; number of passes of the implement increased too, which results in increase in time losses and gave lower values of field efficiency. The main reason for the decrease in field efficiency by increasing operational speed was due to the less theoretical time consumed in comparison with the other test plots.

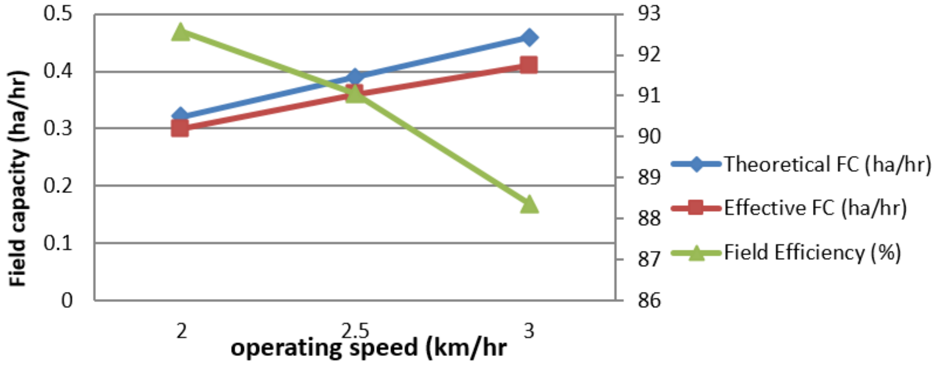

Figure 3: Effects of tractor linear speed on theoretical, effective field capacity and field efficiency

Draft and Power Measurement

The draft required to operate the potato ridger was measured using spring dynamometer. The mean values of the draft were measured as 560N, 617.67N and 660.50N at the speeds of 2, 2.5 and 3 km/hr, respectively as shown in the table 2. The higher draft was measured as 170.50 at 3 km/hr and the lower 140 N at 2 km/hr forward speeds. Besides that, power required to operate the implement was determined based on the forward speed and the required draft to operate the implement. The power required was found to be 0.42, 0.57 and 0.74 hp at 2, 2.5, and 3 km/hr respectively. The observed pattern of both draft and power requirements are shown in Fig.4. It can be seen from the figure that both draft and power required to operate the implement was increased with increase in the operational speed.

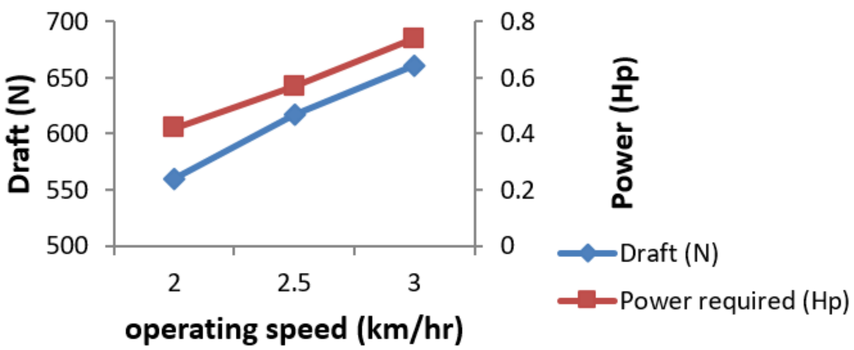

Figure 4: Effects of tractor linear speed on draft and power

Fuel Consumption

The results obtained for forward speed indicated that mean fuel consumption was increased with increase in operating speed as depicted on the fig.5. Mean fuel consumption was recorded as 2.5, 3.1 and 3.8 l/h at the operating speed of 2, 2.5 and 3 km/hr, respectively. Almost similar (3.83 l/hr) finding was reported by Raghavendra *et al.* (2013).

Effects of Operating Speed on Height and Width of Potato Hilling

The average ridge height and width of ridge were found to be 21.33 cm and 41.5 cm respectively at operating speed of 2 km/hr as shown in Table 2 which was nearly similar with

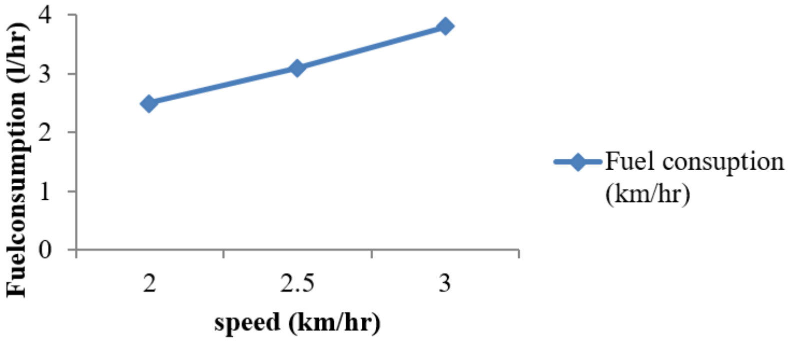

Figure 5: Effects of tractor linear speed on fuel consumption

the findings of Makki and Sulieman (2008). The analysis of variance (ANOVA) in table 4, shows that the implement forward speed level had significant effect ($p < 0.05$) on ridge height as shown in figure 6. The height of soil ridge was tend to decrease as the forward speed increases, whereas, width of soil ridge was increased with increase in speed. These indicated that, as the speed increases, the volume of soil disturbed and lifted for hilling deformed to flat tip shape rather than making cone shape and in this case, the width of hilled soil increases whereas, height of soil ridge decreases as the speed increase and vice versa.

Table 4: Effects of operating speed level on height of ridging

Parameter	Source of variation		Measure of differences	
Height of ridge (cm)	Speed level	Height of ridge	LSD (5%)	SE(M)
	V_2	21.33[a]	1.998	0.577
	$V_{2.5}$	17.33[b]		
	V_3	13.33[c]		

Means followed by the same letter (or letters) do not have significant difference at 5% level of probability.

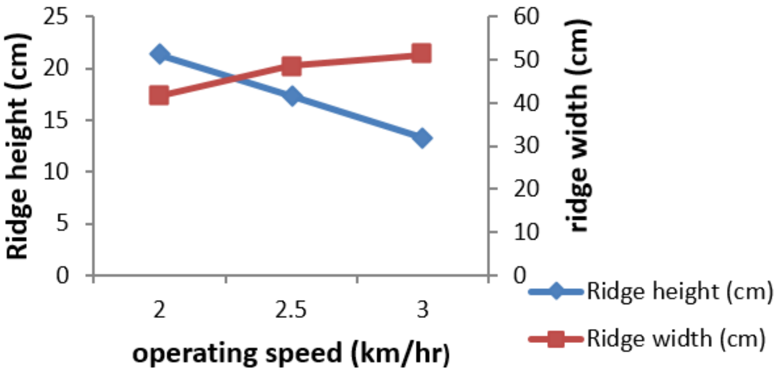

Figure 6: Effects of tractor linear speed on height and width of potato hilling

Weeding Efficiency

Beside soil ridging or hilling operation, weeding operation is also done by tractor drawn potato ridger and as indicated in the table 2, the weeding efficiency was determined by considering the number of weed before and after weeding operation. The average value of weeding efficiency for potato hiller was found to be 93.63%.

Plant Damaged

The percentage of plant damage during ridging operation at different operating speed was shown in table 2. The average percentage of the plant damage as 5.77, 7.69 and 10 was obtained 2, 2.5 and 3 km/hr respectively. It can be seen from the table 2; plant damaged was increased with increase in the operational speed. The plant damage may also occur due to narrow spacing between the root areas that disturbed by the implement during operation and based on the experience of operator.

Cost Estimation

Potato ridging or hilling cost by tractor drawn ridger for potato hilling was determined in view of fixed and variable costs. The production cost of tractor drawn ridger for potato hilling was determined by calculating the cost of different parts and its construction cost was 1,248.13 birr. The fixed cost for ridger per hour (80.86 birr) and variable cost (178.78 birr) were found from the calculation. Annual operation of the ridger was considered as 260 hour based on 33 actual days annually for potato hilling operation with 8 working hours (informal communication with experts). Annually coverage area was determined by multiplication of the effective field capacity and annual hours of operation.

CONCLUSION

A double-row tractor drawn ridger for potato hiller has been fabricated and tested. The production of the implement was made from available material in the local market that makes it an adaptable and affordable technology for farmers who participate in production of root and tuber crops in Ethiopia. The operation speed had a significant effect ($p < 0.05$) on height of the ridge. Increasing speed of operation from 2 to 3 km/hr decreases the height of ridge, whereas, width of hilled soil increased. This clearly shows that operating speeds higher than 3 km/hr would results in less soil ridge height and greater width of soil ridge. Therefore, it can be concluded that, optimum ridge height of 21.33 cm and 41.5 cm ridge width can be hilled at 2 km/hr of operational speed. The mean theoretical field capacity of the implement at 2, 2.5, 3 km/hr were 0.32, 0.39, and 0.46 ha/hr, respectively. As well as effective field capacity at the same speed level of 2, 2.5, 3 km/hr were found to be 0.30, 0.36, and 0.41 ha/hr respectively. This indicated that both theoretical field capacity and effective field capacity of the implement increased with increase in speed. Generally, this shows that the implement can hill the soil on a hectare of land of 2.44 to 3.33 working hours based on the forward speed. The lower field efficiency occurred at 3 km/hr speed was 88.37% and the maximum field efficiency observed at a speed of 2.5 km/hr was 92.57%.It can be seen that, field efficiency decreased as speed increased.

From results obtained, it can be concluded that the fabricated ridger implement can be efficiently, effectively and economically used by the majority of farmers.

RECOMMENDATIONS

The performance test the implement shows that the implement can be performing hilling operation well on farms. Nonetheless, the following issue must be addressed to make the implement more popular, adaptable and usable among the farmers.

- Further research is essential to establish the effect of different soil type and moisture contents on the performance of the ridger for potato hiller and
- Comparative performance evaluation is necessary to establish the economic and technical performance of the ridger and other soil-engaging implements

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