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Fabrication and Performance Evaluation of an Engine-Operated Weeding Machine for Wheat plantation

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ABSTRACT

Wheat crops are severely hampered by weeds, which also significantly reduce productivity. Manual weeding requires a lot of time and effort. Chemical weed management is harmful to both the environment and people. Today's agriculture sector needs non-chemical weed management to meet consumer demand for premium food items and pay close attention to food safety. The objectives of the study was to evaluate the performance of an-engine operated weeder by evaluating the weeding efficiency, plant damage, effective field capacity, field efficiency, fuel consumption, performance index, energy consumption, and cost economics of engine operated weeder in wheat crop. The experimental design was a randomized complete block design and evaluation was conducted at three weeder forward speeds (1.5, 2, and 2.5 km/hr), two depths of operation (from 0 to 20 and from 0 to 40 mm), and three levels of soil moisture content (9.4, 12.34 and 15.25%). The performance of the weeder was found to be optimum at 15.25 percent soil moisture content with 0 to 40 mm depth of operation at a forward speed of 1.5 km/hr. The results revealed that maximum weeding efficiency of 90.1 percent was obtained with lower plant damage of 3.31 percent whereas the effective field capacity, field efficiency, fuel consumption, performance index, and energy consumption were found to be 0.052 ha/hr, 85.99%, 0.41 l/hr, 276.78 ha/hp, and 481.71 MJ/ha, respectively. The analysis revealed that forward speed, depth of operation, and soil moisture had significant effects on weeding efficiency, plant damage, effective field capacity, and fuel consumption at $P<0.05$ level of significance. The cost of weeding per hectare were 758 ETB/ha and 1920 ETB/ha for engine-operated weeders and traditional weeding methods, respectively. Based on the performance results, it can be concluded that the weeding machine is efficient, effective, and economically viable option with high scope for acceptability among small and medium scale farmers

INTRODUCTION

Wheat (*Triticum aestivum L.*) is one of the most important food crops of the world and a part of the family Poaceae that includes major cereal crops of the world such as maize, wheat, and rice. It is the staple food of the diet of several Ethiopians and provides about 15% of the caloric intake of the population of more than 90 million countries (FAO,2015). Wheat is one of the most important crops in Ethiopia, ranking fourth in total cereal production after maize, sorghum, and teff which contribute 10-12% each (Minot *et al.*, 2015). More than 4.7 million households are involved in wheat production each year, producing about 3.9 million tons of wheat on 1.6 million hectares of land, with a mean yield of 2.6 tons/ha (CSA, 2013).

After South Africa, Ethiopia is the second-largest wheat producer in Sub-Saharan Africa (FAO,2015). Wheat is mainly grown in the highlands of Ethiopia, with latitudes 6 up to 16° N, longitude 35 to 42°E, at altitudes 1500-2800 meters above sea level, and an average minimum temperature of 60C to 110C (MoA, 2012). In Ethiopia, wheat covered an area of 1,696,082.59 hectares, with average productivity of 2.6 tons/ha during the main cropping season of Meher and a total production of 45,378,523.39 quintals (CSA, 2016). According to (CSA, 2014) reported that in the Oromia region, wheat covered an area of 875,641.45 hectares and total production was 24,703,210.41 quintals, and in Arsi, 208,308.22 hectares which produce 6,484,360.05 quintals. Out of the total grain crop area, 522,857.64 hectares were under cereals.

Despite its importance in Ethiopia, the national average wheat yield is 2.6 tons/ha, which is 12% below the average wheat yield in Africa and 24% below the average wheat yield in the world (CSA, 2016). Factors that reduce wheat yields are soil fertility decline, weeds, diseases, and insects. Weeds are one of the major constraints of wheat production and weed control is an important factor in increasing yields. There are many reasons for low wheat yields, but weed infestation is a fundamental and major factor in low yields in the crop production system (Shehzad *et al.*, 2012). Weed infestation has been reported as a major problem to Ethiopia's wheat production in both rural and governmental agricultural sectors. Weed control is one of the most difficult tasks in agricultural production. Weed losses exceed those caused by any other agricultural pest. In Ethiopia, crop yield losses due to weeds vary from crop to crop and from region to region, due to different biotic and abiotic factors, it has been estimated that weeds cause a yield reduction due to delaying weeding 15 percent to 62 percent (Kebede,2000). The weed controls are mainly done by manual, chemical, and mechanical methods. In manual weeding, weeds are removed by using an indigenous tool, which is more effective but it is expensive, labor-intensive as well as time-consuming. In addition, the labor requirement for weeding depends

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on the weed flora, weed intensity, weeding time, and soil moisture content at the time of weeding.

Nowadays, the use of herbicides is increasing day by day. It is preferred as a quick and effective weed control method without damaging the plants. But, it has adverse effects on human health and the environment. Today, the agricultural sector requires weed control without using chemicals to ensure food safety. Consumers demand high-quality food products and are particularly concerned about food safety. However, mechanical weeder is expected to encourage subsistence farmers leading to increased production and hence reducing poverty (Olukunle and Oguntunde, 2006). Mechanical weed control is very effective as it helps to reduce the drudgery involved in manual weeding, kills the weeds and also keeps the soil surface loose ensuring soil aeration and water intake capacity (Hegazy *et al.*, 2014). Availability and cost of labour for weed control are limiting its progress, and therefore development of suitable mechanised weeding method is imperative. The cost of weeding by engine operated weeder is about one-third of weeding by manual labours (Tajuddin, 2006). But this method of weed control has received much less scientific attention compared to the other weeding method in Ethiopia. In Ethiopia, weed control is done by manual weeding and chemicals using herbicides. Manual weeding tools are still popular in Ethiopia. Manually operated row crop weeder was developed at Asella Agricultural Engineering Research Center (AAERC) and is being used to control weeds which are more effective and affordable than traditional weeding methods but, labor-intensive and time-consuming (less field capacity), high drudgery and stress on labor (bending all the time to remove weeds). Generally, a few hand weeding is accomplished for cultivating wheat contingent on the type of weeds and their density of invasion. Notwithstanding, these techniques are difficult, less agreeable, tedious, and costly too. Nowadays herbicide usage is increasing. It is preferred as a quick and effective weed control method without damaging the crops. But, it has adverse effects on human health and the environment. It has consequences like cancer disease, environmental air pollution, increased acidity, and salinity of the soil. It can contaminate the soil and the rainwater can carry these chemicals to other areas which will eventually pollute the air we breathe, the food we eat, and the water we drink. A mechanical rotary blade weeder for row-planted cereal crops was developed. But these types of blades also are not efficient in weeding operations.Now mechanical wheat sowing machine is expanding in Ethiopia due to different government programs for mechanization. It is now necessary to develop an engine-operated weeding machine for row sowing wheat crops. The use of a mechanical weeder is reducing drudgery, ensures ease of operation during weeding, and resultantly increases production. Therefore, to assess the possibility of mechanization of the weeding operation, an engine-operated weeding machine was proposed to be designed and developed considering the optimum shape, size, and location of the weeding blade, and performance evaluation was conducted for the end-users. Here comes the relevance of mechanized weeding, which is reducing the time, and cost of weeding operation, and significantly improves weeding efficiency as well as the quality of weeding. Therefore, to increase agricultural production and reduce the time and cost of weeding operations there need to be adopting mechanical weeding. Hence, the study was taken to fabricate and evaluate the performance of the developed weeding machine based on weeding efficiency, plant damage, effective field capacity, performance index, and energy consumption, and to carry out the cost analysis of the developed weeding machine.

MATERIALS AND METHODS

The study site was located 168.7 km away southeast of Addis Ababa, Asella Agricultural Engineering Research Center (AAERC). Fabrication and performance evaluation of the prototype was made at Asella Agricultural Engineering Research Center. The center was located at 6° 59’ to 8°49’ N latitudes and 38° 41’ to 40° 44’ E longitudes, having an elevation of 2430 meters above sea level. The study was undertaken at farmers’ field Huruta Doro Kebele, Jaju Woreda in the Arsi Zone of Oromia Regional State.

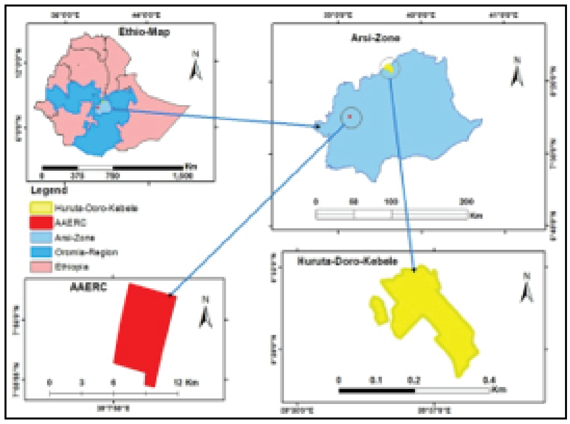


Figure 1: Location of the study area.

The engine-operated row weeding machine was easy to operate, better to handle, reduce drudgery, manufactured from locally available materials, and easily maintained. The power is transmitted from the engine to an intermediate shaft which should connect to the bevel gear and from the bevel gear shaft to the chain and sprocket then the ground wheel starts forward direction and the weeder was started and weeding operations were performed. It consisted of the following main components; mainframe, weeder tine, ground drive wheel, power transmission system, handle, engaging and disengaging unit, bevel gear mechanism, and chain and sprocket mechanisms. The specifications of the engine operated weeder were given in Table 1.

Table 1: Specifications of an engine-operated weeder

Sr. No.	Particulars	Details
1	Name of machine	Engine operated weeder
2	Make of machine	AAERC
3	Overall dimension of the machine (L × W × H)	1650 × 800 × 1050 mm
4	Weight of machine	34.4 kg
5	Power source	5 hp petrol start diesel run engine
6	Fuel used	Diesel
7	Fuel tank capacity	3.9 lit
8	Engine details	4 stroke, 1 cylinder
9	Speed at engine	2800 rpm
10	Displacement	197 cm3
11	PTO shaft rotation	Counter-clockwise from drive end
12	Weight of engine	14 kg
13	Gear type	Bevel
14	Chain drive	ISO 10 B bush roller chain
15	Clutch	Dog clutch
16	Axle	20 mm in diameter
17	Ground wheel	500 mm in diameter
18	Lug	33 no. 25 × 25 mm in size lugs welded at the periphery of the ground wheel
19	Details of weeding components	
	Frame dimension (L × B) mm	960 × 240 mm
	Type of blade	Sweep type
	No of blade	3
	Distance between blade	Adjustable
20	Shank	25 mm × 25 mm × 2.5 mm in dia. and 500 in length

Performance Evaluation of the weeding Machine

The performance of the engine-operated weeder was evaluated under field conditions. The parameters recorded before the weeding operations were the crop parameters (plants height) and field parameters (type of soil, moisture content, bulk density, length, and width of the field). The plant height was recorded by measuring the height of the crop randomly in the field. Row to row spacing, length, and width of the field were measured directly by using a standard measuring tape. The soil sample was taken randomly at different places within the experimental field to determine the moisture content and bulk density of the soil. To compare the field performance of the weeder, different parameters: time taken for operation, plant damage and weed population, weeding efficiency, effective field capacity, field efficiency, performance index, fuel consumption, energy consumption, and cost of weeding operation were calculated as per the procedure

Figure 2: Performance testing during weeding.

Operational Parameter

Moisture content of the soil

Moisture content of the soil was determined using five samples collected randomly from the field. The moisture content of each sample was calculated by using the standard oven-dry method. The weight of the sample with the box was taken and placed in the oven for drying. After 24 hours the oven-dry weight was taken and the moisture content was calculated by using the following formula (Rangapara J., 2014).

$$M \text{ (dry basis)} = ((W_w - W_d)/W_d) \times 100 \quad (1)$$

Where,

M = Moisture content of soil, %

W_w = Weight of wet soil, gm and

W_d = Weight of oven-dry soil, gm.

Bulk Density of Soil

The bulk density of a soil indicates the degree of compactness of the soil and is defined as mass per unit volume. Soil samples were collected randomly from treatments of experimental plots with a core sampler. The core sampler was driven vertically deep enough (0 to 15 cm) into the ground to fill the sampler can in the sampler. The weight of each sample was measured and kept in an oven at a constant temperature of 1050C till the soil sample attained constant weight and the weight of the oven-dried sample was taken. The bulk density of each sample was calculated by using the following relationship (Rangapara J., 2014).

$$\rho_b = M/V$$

Where, ρ_b = bulk density of soil, g/cm^3

M = oven dry mass of soil, gm and

V = volume of core sampler, cm^3

Plant population

The total numbers of plants were counted in an area of one square meter by a quadrate of 1m^2 from randomly chosen places in each plot, before and after every weeding operation to observe plant damage percentage.

Machine performance parameters

The machine performance parameters such as weeding efficiency, plant damage, effective field capacity, theoretical field capacity, field efficiency, performance index, energy consumption, and fuel consumption of power weeder were determined for the performance evaluation as follows.

Theoretical field capacity

It depends upon the speed and theoretical width of the implement. It is the rate of field coverage that should be obtained if implements perform its function 100% of the time at the rated speed and always cover 100% of its rated width. The theoretical field capacity was calculated as (Kepner *et al.*, 2005).

$$TFC = (W \times S)/10 \quad (3)$$

Where, TFC = Theoretical Field capacity, ha/h

S = Speed of operation, km/hr and

W = Theoretical width of implement, m

Effective field capacity

For calculating the effective field capacity, the time taken for actual work and the time used for other activities such as turning, cleaning, adjustment of the machine, and time spent for machine trouble are taken into consideration. The length and width of the plot were measured and the area covered in that time was calculated. By calculating the area covered per hour, the actual field capacity was calculated. It is the actual average rate of coverage by the implement. The total time required to complete the operation was recorded and effective field capacity was calculated as follows, (Kepner *et al.*, 1978)

$$EFC = A/(T_p + Ti) \quad (4)$$

Where: EFC = Effective field capacity, ha/hr

A = Actual area covered, ha and

T_p = Productive time, hr

T_i =Non-productive time, hr

Field Efficiency

The field efficiency is the ratio of the effective field capacity to the theoretical field capacity, usually measured in terms of percentage. It includes the effect of time lost in the field and of failure to utilize the full width of the machine (Kepner *et al.,* 2005)

$$\eta = (EFC/TFC) \times 100 \quad (5)$$

Where: η = Field efficiency (%)

TFC = Theoretical field capacity (ha/h)

EFC = Effective field capacity (ha/h)

Weeding Efficiency

It is the ratio of the numbers of weeds removed by a weeder to the number present in a unit area and it was expressed as a percentage. A square metallic frame of 1 m2 was randomly cast in the test field and the numbers of weeds included in the frame were counted before and after weeding. Three sets of observations were taken in each replication of the treatments. The weeding efficiency was calculated by the following formula (Tajuddin, 2006).

$$\text{Weeding efficiency (\%)} = ((W_1 - W_2)/W_1) \times 100 \quad (6)$$

Where: W_1 = Number of weeds counted per unit area before weeding operation

W_2 = Number of weeds counted in the same unit area after the weeding operation

Plant Damage

It is the ratio of the number of plants damaged in a row to the number of plants present in that row. It was expressed in percentages. The plant damage was calculated by the following formula (Yadav & Pund, 2007)

$$\text{Plant damage (\%)} = (1 - q/p) \times 100 \quad (7)$$

Where:

p = Number of plants in a 10 m row length of the field before weeding,

q = Number of plants in a 10 m row length of the field after weeding

Fuel Consumption

Fuel consumption has a direct effect on the economics of the weeding machine. It was measured by the top-fill method. The fuel tank was filled before the testing at level condition. After completion of the test operation, the amount of fuel required to top fill again is the fuel consumption for the test duration. This observation was used for the computation of fuel consumption in l/hr (Nkakini *et al.*, 2010)

$$Fc = fr/t \quad (8)$$

Where: Fc= fuel consumption (l/hr)

fr= Re-filled quantity of fuel (l)

t= Total time of weeding (hr)

Energy Consumption

For the engine-operated weeder, the total time taken for the operation, total fuel consumption, and the number of laborers required were taken for energy calculation. Measurement of fuel consumption in respect of power was done on the plot size of the field. The direct energy use per hectare for intercultural operation consists of human labor energy and mechanical energy was computed by the following equation Karale *et al.*, (2008).

$$ED = ED_F + ED_O \quad (9)$$

Where, ED_F = Mechanical energy based on fuel consumption (MJ/ha), ED_O = Direct energy input of operator (human energy) (MJ/ha), ED = Specific direct energy use for field operation (MJ/ha),

Human labor (man-hours) was converted into energy units by multiplying the number of total human labor with working hours to the energy equivalent. The energy equivalent of an adult man is 1.97 MJ/h and for an adult woman, it is 1.57 MJ/ha. The following equation was used for the conversion of the physical unit of human labor into energy unit according to Singh *et al.*, (2002)

Human Energy (MJ/ha)= (NL×EE × Time (hr))/(weeding area (ha)) (10)

Where, NL =No.of labour

EE = Energy equivalent of person (MJ/manhr)

Mechanical energy inputs were calculated based on the fuel consumption (liter/hour) of the machine and working hours per operation as well as the number of operations in the weeding area. The energy equivalent of fuel 48.23 MJ/L for gasoline and 56.3MJ/L for diesel was given to convert the factor unit into the energy unit according to Singh *et al.*, (2002).

Mechanical Energy(MJ/ha)= (FC×EE ×time (hr))/(weeding area (ha)) (11)

Where, FC = Fuel consumption (l/hr), EE = Energy equivalent of fuel (MJ/manhr)

Performance Index

The performance index of the weeder was calculated by multiplying field capacity, weeding efficiency, and plant damage percentage and dividing the result with the power input of the weeder (Monalisha *et al.*, 2017)

$$PI=(a \times q \times e)/p \quad (12)$$

Where: PI = Performance index, ha/hp

a = Field capacity of weeder, ha/h

e = Weeding efficiency, %

q=plant damage, %, p = Power input, hp

Experimental Design and Treatment

The field experiment was conducted at selected farmer fields at Jaju district in Arsi Zone of Oromia Regional State. The experiments were conducted in the field with three levels of the forward speed of the weeder (1.5, 2, and 2.5 km/hr), two depths of operation (from 0 to 20 mm and 0 to 40 mm), and three levels of soil moisture content (9.4, 12.34, and 15.25%). Irrigation water was applied by using Parshall flume on the soil to maintain desired soil moisture. The experimental fields were divided into eighteen plots at once and each should have a 20 m by 5 m size. The experiment had three replications of each treatment by using randomized complete block design (RCBD). Relevant observations of each treatment regarding field conditions of each were recorded before and after the weeding operation. The experimental design was laid as (3×2×3) with three replications and had a total of 54 test runs.

Statistical Analysis

Results of the performance of the engine-operated weeder under different treatments were analyzed by analysis of variance (ANOVA) using statistical R-software (version 3.4.3, 2017). Statistical differences in effects of treatment mean were tested at 5% levels of significance and separated using the least significant difference (LSD). The least significant difference (LSD) tests were performed for the mean values of effective field capacity, weeding efficiency, plant damage, field efficiency, fuel consumption, energy consumption, and performance index. The level of significance (P) for these relations was obtained by F-test based on analysis of variance. The mean values and standard deviation (Mean ± Standard deviation) were used to present the results.

Costs Estimation of Engine Operated Weeder

The initial cost of engine operated weeder was calculated by adding up the cost of individual components involved in the prototype fabrication at the prevalent market price. The cost of the engine-operated weeder was divided under the two heads known as a fixed cost and variable cost. Estimates of annual and hourly operational costs of the weeder were based on the capital cost of the weeder, interest on capital, cost of repairs and spare parts, labor cost, fuel cost, and depreciation. The operational cost components of the prototype weeder were estimated in Birr (ETB) as follows;

a) Depreciation cost (D_p): It was a measure of the amount by which the value of the machine decreases with time. The depreciation cost was calculated as follows:

Dp=(CC-SVC)/(EL × H),(ETB/hr) (13)

b) Interest on capital (IC), Interest was calculated on the average investment of the machine taking into consideration the value of the machine in the first and last year. The interest on capital was calculated as follows:

IC=((CC+SVC)/2)×((I%)/NAOHW),(ETB/hr) (14)

c) Shelter, insurance, and tax cost was calculated by 1.5% of the initial cost

Total fixed cost = (a+ b + c)

d) The fuel cost of the weeder was calculated in fuel cost per hour by multiplying by the fuel consumption of the engine-operated weeder (in liters per hour) by fuel cost (in Birr/liters)

e) cost of repairs and spares (Repair and maintenance at 5% of the initial cost)

CRS=(CC × 5%)/AWHW,(ETB/hr) (15)

f) Labor wages: Wage was calculated based on actual wages of workers per hour

LW=DLW/DWH,(ETB/hr) (16)

Total variable cost = (d + e + f)

The total cost of weeding per hour of the developed power weeder was calculated by summation of total fixed cost per hour with total variable cost per hour.

The total cost of weeding = variable cost of the weeder + fixed cost of the weeder, Finally the cost of operation of the weeder was calculated by the multiplication of the average effective field capacity of the weeder with the total cost of operation of the weeder.

Where:

Dp = Depreciation, ETB/hr

CC = Capital cost, ETB/hr

SVC = Salvage value 10% of initial cost

CRS = Cost of repairs and spares

EL= Estimate life (hr) (assume that estimate life 10 years)

IC = Interest on capital (ETB/hr)

LW = Labor wages

H = Number of working hour per year

I = Interest, %

NAOHW = Number of the annual operating hours of the weeder (ETB/hr)

AWHW = Annual working hours of the weeder

DLW = Daily labor wage

RESULTS AND DISCUSSION

This study was undertaken to evaluate the performance of an engine-operated weeder for the wheat farm. The performance evaluation of an engine-operated weeder, the results obtained and their discussions were presented in this section. The performance indicator of the engine-operated weeder was expressed in terms of weeding efficiency, plant damage, field efficiency, fuel consumption, performance index, and energy consumption. The costs of operation were calculated and the effects of the machine and operational parameters on soil physical properties are presented. The performance of the prototype weeder was evaluated under field conditions and the results obtained were analyzed and discussed under the following sub-headings

Physical Properties of Soil

The performance of the prototype was evaluated under field conditions in sandy loam soil. Soil physical properties concerning machine parameters are important from the design point of any weeding system. Soil moisture content was an independent parameter while bulk density as a dependent parameter was measured at respective soil moisture content. The interactions between these parameters directly affect the performance of the weeding system in terms of weeding efficiency and power requirement to operate the machine under field conditions.

Soil Moisture Content

Five soil samples were taken randomly at 5 different locations in the plot using a core sampler. The moisture content observed values were 15.25±0.26, 12.34±0.07, and 9.4±0.11% (d.b), respectively, and denoted by M1 in the range of 9.4±0.11%, M2 in the range of 12.34±0.07%, and M3 in the range of 15.25±0.26%, respectively.

Effect of Soil Moisture on Soil Bulk Density

Bulk density is an indicator of soil compaction and soil health. Before conducting each experiment, the bulk density of soil was observed for each experiment randomly at 5 locations at each soil moisture content level for studying the effect of soil bulk density on different parameters. The observed values are presented in Figure 3 which shows the variations in soil bulk density at different soil moisture contents. It was observed that bulk density decreased with an increase in soil moisture content

The interactions between these parameters had a direct effect on the performance of weeding efficiency and the power required to operate the machine under field conditions. Soil bulk density measured in the field at different soil moisture levels showed an inverse linear relationship. The soil bulk density measured were 1561, 1448, and 1385 kg/m^3 at the soil moisture content of 9.4, 12.25, and 15.25% (db), respectively as shown in Appendix Table 13. Bulk density decreased by 12.7% with an increase in soil moisture content from 9.4 to 15.25%. The relationship between soil moisture content and bulk density was given by y = -88x +1640.7 with an R^2 of 0.9738.

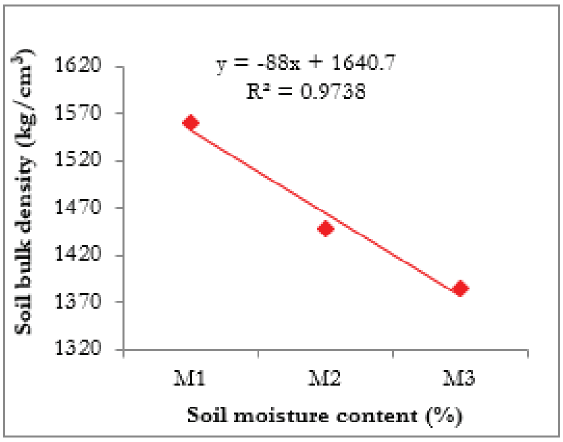


Figure 3: Diagram showing soil bulk density change with soil moisture.

Evaluation of an Engine Operated Weeder

The engine-operated weeder was tested under field conditions to determine the operational performance parameters. The parameters selected for the study included three forward speeds (1.5, 2, and 2.5 km/hr), two depths of operation (varied from 0 to 20 mm and 0 to 40 mm), and three levels of soil moisture content (9.4, 12.34, and 15.25%). The test procedure was explained in the above section. The effect of operational parameters was studied to evaluate the performance of the weeder in terms of weeding efficiency, plant damage, effective field capacity, field efficiency, fuel consumption, energy consumption, performance index, and cost of the weeder, and also the results were discussed below.

Weeding Efficiency

The combined effects of soil moisture and machine operational parameters on weeding efficiency are presented in Table 7. It is evident that as the depth of operation increased from 0 to 20 and from 0 to 40 mm, the weeding efficiency increased from 73.2 to 78.99% and from 75.74 to 90.1% with 1.5 km/hr weeder forward speed increased soil moisture content from 9.4% to 15.25% respectively. This shows that weeding efficiency decreased with increasing weeder forward speed. Weeding efficiency values decreased from 73.2 to 71.97% and from 75.74 to 74.74% when the weeder forward speed increased from 1.5 to 2 km/hr for two depths of operation from 0 to 20 and 0 to 40 mm respectively. From Table 7, the minimum value of weeding efficiency was 70.98% and obtained with a 2.5 km/hr weeder forward speed at depth of operation ranging from 0 to 20 mm and soil moisture content of 9.4% whereas the maximum value of weeding efficiency was 90.1% and obtained with a 1.5 km/hr weeder forward speed at depth of operation varied from 0 to 40 mm and 15.25% soil moisture content. These findings are in close agreement with the result reported by Hegazy *et al.*, (2014). Generally, weeding efficiency increased as moisture content increased. The main reason behind it was that when moisture content increases slippage of the ground wheel of the weeder which considerably affects the turning length of the weeder. As a result, weeding efficiency was more in the case of 12.34 and 15.25% soil moisture contents when compared with 9.4% soil moisture content. As the depth of operation increased, the weeding efficiency increased. Similar results were observed for all depths of operation. The individual and combined effect of operational parameters on weeding efficiency was analyzed statistically and presented in Table 3 and 7. ANOVA revealed that the depth of operation (D) and moisture content (M) had a significant effect on weeding efficiency at ($P<0.05$) level of significance and each variable individually had a significant effect on weeding efficiency whereas the speed of operation had no significant effects on weeding efficiency, but there was a significant difference between lower and higher values at ($p<0.05$). The interaction effect of (S×D), (S×M), and (D×M) are presented in Tables 4, 5, and 6 respectively. The interaction effect of (S×D), (S×M), and (D×M) had no significant effect on the weeding efficiency. The combined effect of variables (D×S×M) also did not significantly influence the weeding efficiency at a 5% level of significance.

Results of the interaction effect of forward speed and depth of operation varied from 74.58 to 81.61% with non-significant ($P>0.05$) differences among the values of weeding efficiency. The lowest value was obtained from the combination of forward speed (2.5 km/hr) and depth of operation (from 0 to 20 mm) whereas the highest value was at the combination of forward speed (1.5 km/hr) and depth of operation of (0 to 40 mm). The data showed that depth of operation had a stronger influence on weeding efficiency than forward speed.

Plant Damage

The effects of depth of operation, forward speed, and soil moisture on plant damage are presented in Table 7. It was observed that the minimum value of plant damage obtained was 2.78% at 1.5 km/hr weeder forward speed when the soil moisture was 15.25% and the depth of

Table 2: Main effect of forward speed, depth, and soil moisture content on performance parameters of weeder machine

Speed (km/hr)	WE (%)	PD (%)	EFC (ha/hr)	FE (%)	FC (l/hr)	PI (ha/hp)	EC (MJ/ha)
S_1	78.84±5.78^a	3.53±0.43^c	0.047±0.0041^c	82.35±5.38^a	0.45±0.06^c	234.8±25.51^c	585.91±101.37^a
S_2	77.34±4.56^{ab}	3.73±0.90^b	0.058±0.0068^b	78.91±5.66^b	0.53±0.06^b	288.1±42.38^b	555.44±91.15^b
S_3	77.13±4.88^b	5.61±1.21^a	0.064±0.0054^a	75.31±5.48^c	0.59±0.05^a	306.4±23.29^a	557.59±63.62^{ab}
Soil moisture							
M_1	73.57±2.04^c	4.92±1.54^a	0.056±0.0086^a	73.47±3.83^c	0.58±0.05^a	265.3±33.59^c	627.15±63.69^a
M_2	77.28±2.72^b	4.23±1.16^b	0.056±0.0097^a	78.21±4.71^b	0.52±0.06^b	271.7±39.21^b	568.65±71.68^b
M_3	82.45±5.11^a	3.71±0.87^c	0.055±0.0088^a	84.88±3.28^a	0.47±0.07^c	292.2±53.26^a	503.14± 76.81^c
LSD (5%)	1.23	0.13	0.003	0.19	0.01	15.80	28.42
Depth							
D_1	75.35± 3.56^b	4.19±0.90^b	0.057±0.0093^a	78.94±6.21^a	0.51±0.07^b	271.4±41.99^a	543.22±69.80^b
D_2	80.19±5.23^a	4.39±1.61^a	0.055±0.0084^b	78.76±6.16^a	0.53±0.09^a	281.4±45.35^a	589.40±96.01^a
CV (%)	2.33	5.29	7.31	0.36	2.44	8.44	7.41
LSD (5%)	1.00	0.10	0.002	0.16	0.01	12.90	23.21

Where, WE = Weeding efficiency, PD = Plant damage, EFC = Effective field capacity, FE =Field efficiency, FC = Fuel consumed, PI =Performance index, EC=Energy consumption, Speed (S1= 1.5 km/hr, S2= 2 km/hr, S3= 2.5 km/hr), Depth (D1= 0 to 20 mm, D2= 0 to 40 mm), Soil moisture content (M1= 9.4%, M2= 12.34% and M3= 15.25%), CV = coefficient of variation; LSD = least significance difference, SEM= Standard error of the mean, Values are Mean ± SD. Mean values comparison arranged according to descending order with the same letter in a column are not significantly different at 5% level of significance.

operation varied from 0 to 20 mm. The maximum value of plant damage 7.56% was recorded with 2.5 km/hr at depth of operation ranging from 0 to 40 mm and 9.4% soil moisture. It is evident that as the depth of operation increased, the plant damage percentage increased whereas soil moisture content increased, the plant damage percentage decreased. However, it was observed that as forward speed and depth operation increased, the plant damage percentage increased. This is mainly due to high speed and depth, the movement of the weeder did not remain a straight line but sideward also, resulting in damage to plants.

The mean comparison for the main effect of variables on plant damage is summarized in Table 3. From this table, the higher plant damage 5.61% was obtained at 2.5 km/hr forward speed of operation. The same trend occurred for the forward speeds of 1.5 and 2 km/hr which obtained 3.53 and 3.73 percent of plant damage respectively. However, the lowest plant damage was obtained at the forward speed of 1.5 km/hr, and the depth of operation ranged from 0 to 20 mm. The individual effect of operational parameters on plant damage was analyzed statistically and presented in Table 3. ANOVA revealed that forward speeds (S), depth of operation (D), and soil moisture content (M) had significant effects on plant damage at ($p<0.05$) level of significance. Results revealed that there was a significant difference ($P<0.05$) in plant damage at the two depths of operation. The interaction effects of forward speed and depth of operation (S×D), forward speed and soil moisture (S×M), depth of operation, and soil moisture (D×M) on plant damage are presented in Tables 4, 5, and 6 respectively. The results revealed that the interaction effect of variables (S×D) and (S×M), had significant effects on the plant damage at ($P<0.05$) level of significance. The interaction effect (D×M) had no significant influence ($P>0.05$) on plant damage. The results of the combined effect of variables (D×S×M) are presented in Table 7 and revealed that there was no significant effect on the plant damage at ($P>0.05$).

Effective Field Capacity

The effective field capacity decreased as the depth of the operation increased, as shown in Figure 2. The effective field capacity increased with the increase in forward speed, due to more area covered in less time. With a 1.5 km/hr weeder forward speed, the effective field capacity decreased from 0.047 to 0.045 ha/hr at 9.4 percent soil moisture content when the depth of operation increased (from 0 to 20 and 0 to 40 mm). The results also revealed that at all levels of soil moisture content, the effective field capacity increased with increasing weeder forward speed, whereas the effective field capacity decreased as the soil moisture level increased in all treatments. This may be due to the frequent sliding of tines under higher moisture conditions. Values of effective field capacity increased from 0.047 to 0.059 and from 0.045 to 0.055 ha/hr when

Table 3: Interaction effect of forward speed and depth of operation on performance parameters of weeder

Speed (km/hr)	Depth (mm)	WE (%)	PD (%)	EFC (ha/hr)	FE (%)	FC (l/hr)	PI (ha/hp)	EC (MJ/ha)
S_1	D_1	76.07±3.15^c	3.25±0.19^e	0.046±0.001^c	84.31±4.64^a	0.46±0.06^e	225.12±3.56^c	592.88±72.14^a
	D_2	81.60±6.62^a	3.80±0.42^d	0.047±0.006^c	80.39±5.59^c	0.44±0.07^f	244.42±34.08^c	578.92±128.54^a
S_2	D_1	75.39±3.73^c	4.49±0.52^c	0.057±0.005^b	75.76±5.10^e	0.51±0.06^d	272.24±22.12^b	532.62± 66.14^b
	D_2	79.29±4.65^b	2.97±0.41^f	0.058±0.008^b	82.05±4.43^b	0.55±0.04^c	303.88±52.59^a	578.25±110.03^a
S_3	D_1	74.58±3.99^c	4.80±0.87^b	0.067±0.002^a	76.75±5.36^d	0.57±0.04^b	316.92±22.1^a	504.15±40.44^b
	D_2	79.68±4.47^b	6.38±1.00^a	0.059±0.004^b	73.85±5.49^f	0.61±0.04^a	295.85±20.37^a	611.02±23.22^a
CV (%)		2.33	5.29	7.31	0.36	2.44	8.44	7.41
LSD (5%)		1.73	0.18	0.004	0.27	0.01	22.35	40.20
SEM		0.60	0.06	0.001	0.09	0.004	7.78	13.99

Where, WE = weeding efficiency, PD = plant damage, EFC= effective field capacity, FE = field efficiency, FC = fuel consumed, PI = performance index, EC= Energy consumption, SEM= Standard error of the mean, CV = coefficient of variation; Speed (S1= 1.5 km/hr, S2= 2 km/hr, S3= 2.5 km/hr), Depth (D1= 0 to 20 mm, D2= 0 to 40 mm), values are Mean ± SD, LSD = least significance difference. Means value comparison arranged according to descending order with the same letter in a column are not significantly different at 5% (p>0.05) level of probability the weeder forward speed increased from 1.5 to 2 km/hr and depths of operation ranged from 0 to 20 and 0 to 40 mm respectively at 9.4% soil moisture content. At the different levels of soil moisture content 9.4, 12.34 and 15.25% the values of effective field capacity were 0.047, 0.046, and 0.046 ha/hr for 1.5 km/hr weeder forward speed at 0 to 20 mm depth of operation.

The maximum value of effective field capacity was 0.068 ha/hr at 2.5 km/hr weeder forward speed at depth of operation ranging from 0 to 20 mm and soil moisture content at 9.4 percent whereas the minimum value of effective field capacity was 0.044 ha/hr and achieved with 1.5 km/hr weeder forward speed at depth of operation varied from 0 to 40 mm and soil moisture content at 12.34 percent. These findings are in close agreement with the result reported by Manian et al., (2004). The individual and combined effect of operational parameters on effective field capacity was analyzed statistically and presented in Table 3. Analysis of variance revealed that forward speed (S) had a significant influence on the effective field capacity at ($p<0.05$) level of significance while the depth of operation (D) and soil moisture content(M) had no significant influence on the effective field capacity at ($p>0.05$) level of significance.

The interaction effects in forward speed and depth of operation, forward speed and soil moisture (S×M), depth of operation and soil moisture (D×M) on effective field capacity are presented in Tables 4, 5, and 6 respectively. However, the interaction effect of variables (Speed×Depth), (Speed×Moisture), and (Depth×Moisture) were not significant influences ($p>0.05$) on the effective field capacity. The results of the combined effect of variables (D×S×M) are presented in Table 7. The results revealed that the combined effect of forward speed, depth of operation, and soil moisture content had no significant effect on the effective field capacity at ($p>0.05$) level of significance. In general, the effective field capacity increased with increasing forward speed and decreased with increasing soil moisture and depths of operation.

Field Efficiency

Effects of forward speeds, depths of operation, and soil moisture on the field efficiency of the engine-operated weeder are presented in Figure 3. Field efficiency decreased with the increase in forward speed from 1.5 to 2.5 km/hr and depth of operation varied (from 0 to 20 mm and 0 to 40 mm) whereas field efficiency increased as soil moisture content increased from 9.4 to 15.25 percent. Table 3 shows that the average field efficiency of the engine-operated weeder at forward speeds of 1.5, 2, and 2.5 km/hr were found to be 82.35±5.38, 78.91±5.66, and 75.31±5.48% respectively. The average field efficiencies at the soil moisture content of 9.4, 12.34, and 15.25% were found to be 73.47±3.83, 78.21±4.71, and 84.88±3.28% respectively whereas the depths of operation varied from 0 to 20 and 0 to 40 mm were obtained 78.94±6.21 and 78.76±6.16%. However, the field efficiency of the weeder increased with an increase in soil moisture content and decreased with an increase in forward speed and operating depth.

Results indicated that the minimum field efficiency of 68.54% was recorded with a 2.5 km/hr weeder operating speed at depth of operation varied from 0 to 40 mm at 9.4% soil moisture. The maximum field efficiency of 89.49% was recorded with a 1.5 km/hr weeder operating speed at depth of operation varied from 0 to 20 mm and soil moisture content of 15.25%. The results revealed that the field efficiency decreased as the forward speeds increased for all soil moisture levels. The major reason for the reduction in field efficiency by increasing forward speed was due to the less theoretical time consumed in comparison with the other test plot. These findings are in close agreement with the result reported by Nkakini et al. (2010).The individual and combined effect of operational parameters on the field efficiency were analyzed statistically and presented in Table 3. ANOVA revealed that forward speed (S) and moisture content (M) had significant effects on field efficiency at a 5% ($p<0.05$) level of significance and each variable individually influenced the field efficiency. The significance was observed in the order of speed (S) followed by moisture content (M) and depths of operation (D).

The interaction effects of operating speed and depth of operation (S×D), forward speed and soil moisture content (S×M), depth of operation, and soil moisture content (D×M) on the field efficiency are presented in Tables 4, 5, and 6 respectively. The results showed that the interaction effect of variables (Depth×Moisture) had significant effects ($p<0.05$) on field efficiency. The interaction effect of variables (Speed×Depth) and (Speed×Moisture) had significant effects ($p<0.05$) on field efficiency. The results of the combined effect of variables (Speed× Depth×Moisture) are presented in Table 7 and revealed that the combined effect of depth of operation, forward speed, and soil moisture content had significant effects on field efficiency at ($p<0.05$) level of significance.

Effective Field Capacity

The effective field capacity decreased as the depth of the operation increased, as shown in Figure 2. The effective field capacity increased with the increase in forward speed, due to more area covered in less time. With a 1.5 km/hr weeder forward speed, the effective field capacity decreased from 0.047 to 0.045 ha/hr at 9.4 percent soil moisture content when the depth of operation increased (from 0 to 20 and 0 to 40 mm). The results also revealed that at all levels of soil moisture content, the effective field capacity increased with increasing weeder forward speed, whereas the effective field capacity decreased as the soil moisture level increased in all treatments. This may be due to the frequent sliding of tines under higher moisture conditions. Values of effective field capacity increased from 0.047 to 0.059 and from 0.045 to 0.055 ha/hr when the weeder forward speed increased from 1.5 to 2 km/

hr and depths of operation ranged from 0 to 20 and 0 to 40 mm respectively at 9.4% soil moisture content. At the different levels of soil moisture content 9.4, 12.34 and 15.25% the values of effective field capacity were 0.047, 0.046, and 0.046 ha/hr for 1.5 km/hr weeder forward speed at 0 to 20 mm depth of operation.

The maximum value of effective field capacity was 0.068 ha/hr at 2.5 km/hr weeder forward speed at depth of operation ranging from 0 to 20 mm and soil moisture content at 9.4 percent whereas the minimum value of effective field capacity was 0.044 ha/hr and achieved with 1.5 km/hr weeder forward speed at depth of operation varied from 0 to 40 mm and soil moisture content at 12.34 percent. These findings are in close agreement with the result reported by Manian *et al.*, (2004).

The individual and combined effect of operational parameters on effective field capacity was analyzed statistically and presented in Table 3. Analysis of variance revealed that forward speed (S) had a significant influence on the effective field capacity at ($p<0.05$) level of significance while the depth of operation (D) and soil moisture content(M) had no significant influence on the effective field capacity at ($p>0.05$) level of significance.

Table 4: Interaction effect of forward speed and soil moisture content on performance parameters

Speed (km/hr)	Soil Moisture (%)	WE (%)	PD (%)	EFC (ha/hr)	FE (%)	FC (l/hr)	PI (ha/hp)	EC (MJ/ha)
S_1	M_1	74.47±1.90^{de}	3.79±0.54^{e}	0.046±0.001^{d}	76.16±3.05^{e}	0.52±0.02^{d}	224.03±4.89^{e}	677.55±50.47^{a}
	M_2	77.49 ±2.14^{c}	3.53±0.35^{f}	0.045±0.001^{d}	83.14±1.81^{c}	0.44±0.02^{f}	228.19±8.09^{de}	596.45±43.16^{bc}
	M_3	84.54±6.42^{a}	3.25±0.15^{g}	0.049±0.006^{d}	87.74±2.05^{a}	0.38±0.03^{g}	252.07±9.69^{cd}	483.71±88.24^{e}
S_2	M_1	73.35±1.73^{e}	4.27±0.95^{e}	0.057±0.005^{c}	74.05±3.80^{f}	0.59±0.02^{b}	274.79±9.16^{bc}	617.14±66.86^{b}
	M_2	76.98±2.02^{cd}	3.66±0.83^{ef}	0.056±0.006^{c}	77.93±3.73^{d}	0.53±0.03^{cd}	272.32±8.35^{bc}	571.79±93.88^{bcd}
	M_3	81.69 ±4.65^{b}	3.27±0.75^{g}	0.061±0.008^{bc}	84.74±3.18^{b}	0.47±0.04^{e}	317.06±12.34^{a}	477.37±52.53^{e}
S_3	M_1	72.89±2.45^{e}	6.71±0.99^{a}	0.064±0.003^{ab}	70.19±2.01^{g}	0.64±0.02^{a}	297.01	586.75±40.58^{bcd}
	M_2	77.38±4.04^{c}	5.51±0.89^{b}	0.065±0.005^{a}	73.55±1.71^{f}	0.59±0.03^{b}	314.67	537.69±68.57^{d}
	M_3	81.12±4.23^{b}	4.62±0.72^{c}	0.060±0.006^{bc}	82.17±1.85^{c}	0.54±0.03^{c}	307.47±5.05^{a}	548.32±76.24^{cd}
CV (%)		2.33	5.29	7.31	0.36	2.44	8.44	7.41
LSD (5%)		2.12	0.22	0.005	0.33	0.02	22.35	49.23
SEM		0.74	0.08	0.002	0.12	0.01	9.52	17.13

Where, WE = weeding efficiency, PD = plant damage, EFC= effective field capacity, FE = field efficiency, FC = fuel consumed, PI = performance index, EC= energy consumption; CV = Coefficient of variation; LSD = least significance difference, Speed (S1= 1.5 km/hr, S2= 2 km/hr, S3= 2.5 km/hr), soil moisture content (M1= 9.4%, M2= 12.34% and M3= 15.25%), values are mean ± SD. Mean values comparison arranged according to descending order with the same letter in a column are not significantly different at 5% level of significance.

The interaction effects in forward speed and depth of operation, forward speed and soil moisture (S×M), depth of operation and soil moisture (D×M) on effective field capacity are presented in Tables 4, 5, and 6 respectively. However, the interaction effect of variables (Speed×Depth), (Speed×Moisture), and (Depth×Moisture) were not significant influences ($p>0.05$) on the effective field capacity. The results of the combined effect of variables (D×S×M) are presented in Table 7. The results revealed that the combined effect of forward speed, depth of operation, and soil moisture content had no significant effect on the effective field capacity at ($p>0.05$) level of significance. In general, the effective field capacity increased with increasing forward speed and decreased with increasing soil moisture and depths of operation.

Field Efficiency

Effects of forward speeds, depths of operation, and soil moisture on the field efficiency of the engine-operated weeder are presented in Figure 3. Field efficiency decreased with the increase in forward speed from 1.5 to 2.5 km/hr and depth of operation varied (from 0 to 20 mm and 0 to 40 mm) whereas field efficiency increased as soil moisture content increased from 9.4 to 15.25 percent. Table 3 shows that the average field efficiency of the engine-operated weeder at forward speeds of 1.5, 2, and 2.5 km/hr were found to be 82.35±5.38, 78.91±5.66, and 75.31±5.48% respectively. The average field efficiencies at the soil moisture content of 9.4, 12.34, and 15.25% were found to be 73.47±3.83, 78.21±4.71, and 84.88±3.28% respectively whereas the depths of operation varied from 0 to 20 and 0 to 40 mm were obtained 78.94±6.21 and 78.76±6.16%. However, the field efficiency of the weeder increased with an increase in soil moisture content and decreased with an increase in forward speed and operating depth.

Results indicated that the minimum field efficiency of 68.54% was recorded with a 2.5 km/hr weeder operating speed at depth of operation varied from 0 to 40 mm at 9.4% soil moisture. The maximum field efficiency of 89.49% was recorded with a 1.5 km/hr weeder operating speed at depth of operation varied from 0 to 20 mm and soil moisture content of 15.25%. The results revealed that the field efficiency decreased as the forward speeds increased for all soil moisture levels. The major reason for the reduction in field efficiency by increasing forward speed was due to the less theoretical time consumed in comparison with the other test plot. These findings are in close agreement with the result reported by Nkakini et al. (2010).The individual and combined effect of operational parameters on the field efficiency were analyzed statistically and presented in Table 3. ANOVA revealed that forward speed (S) and moisture content (M) had significant effects on field efficiency at a 5% ($p<0.05$) level of significance and each variable individually influenced the field efficiency. The significance was observed in the order of speed (S) followed by moisture content (M) and depths of operation (D).

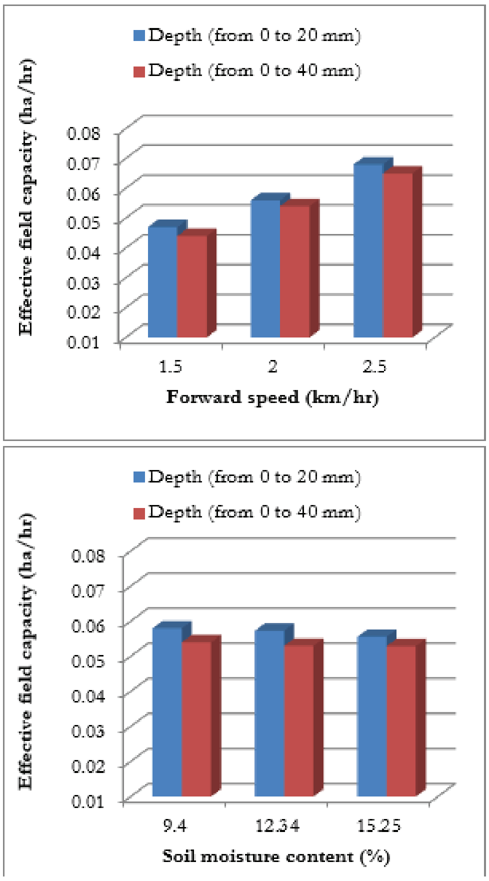


Figure 4: Effect of soil moisture and machine operational parameter on effective field capacity.

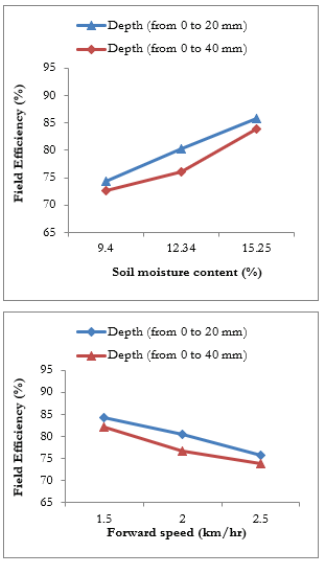


Figure 5: Effect of soil moisture and machine operational parameters on the field efficiency.

The interaction effects of operating speed and depth of operation (S×D), forward speed and soil moisture content (S×M), depth of operation, and soil moisture content (D×M) on the field efficiency are presented in Tables 4, 5, and 6 respectively. The results showed that the interaction effect of variables (Depth×Moisture) had significant effects ($p<0.05$) on field efficiency. The interaction effect of variables (Speed×Depth) and (Speed×Moisture) had significant effects ($p<0.05$) on field efficiency. The results of the combined effect of variables (Speed× Depth×Moisture) are presented in Table 7 and revealed that the combined effect of depth of operation, forward speed, and soil moisture content had significant effects on field efficiency at ($p<0.05$) level of significance.

Fuel Consumption

Effects of forward speed, depth of operation, and soil moisture on fuel consumption of the engine-operated weeder are presented in figure 4 and Table 7. The figure revealed that fuel consumption for depth of operation from 0 to 20 mm and 0 to 40 mm with a forward speed of 1.5 km/hr was varied in the range of 0.53 to 0.39 l/hr and 0.51 to 0.41 l/hr when the soil moisture content increased from 9.4 to 15.25% respectively. The fuel consumption for depth of operation from 0 to 20 mm and 0 to 40 mm with a forward speed of 2 km/hr was varied in the range of 0.57 to 0.44 l/hr and 0.60 to 0.50 l/hr when the soil moisture content was varied from 9.4 to 15.25% respectively.

The fuel consumption for depth of operation varied from 0 to 20 mm and 0 to 40 mm with a forward speed of 2.5 km/hr varied in the range of 0.62 to 0.52 l/hr and 0.65 to 0.57 l/hr, respectively. It is evident that fuel consumption increased as forward speed and depth of operation increased from 1.5 to 2.5 km/hr and from 0 to 20 and 0 to 40 mm respectively. The means comparison for fuel consumption in all treatments is shown in Table 7. Results indicated that the minimum value of fuel consumption 0.39 l/hr was recorded at 1.5 km/hr weeder forward speed, depth of operation varied from 0 to 20 mm, and soil moisture content 15.25%. While the maximum value of fuel consumption 0.65 l/hr was recorded at 2.5 km/hr weeder forward speed, depth of operation of 0 to 40 mm, and soil moisture content of 9.4 percent. Hence, maximum fuel consumption was obtained at a maximum forward speed and depth of operation. Similar results were reported by Manuwa *et al.*, (2009).

The main effect of operational parameters on fuel consumption was analyzed statistically and presented in Table 3. Analysis of variance revealed that the influence in forward speed, depths of operation, and moisture

Table 5: Interaction effect of soil moisture content and depth of operation on performance parameters

Speed (km/hr)	Soil Moisture (%)	WE (%)	PD (%)	EFC (ha/hr)	FE (%)	FC (l/hr)	PI (ha/hp)	EC (MJ/ha)
M_1	D_1	72.05±1.58^d	4.77±1.17^b	0.058±0.01^a	73.80±3.96^e	0.58±0.04^a	265.97±37.29^b	601.25±67.55^b
	D_2	75.27±1.60^c	4.12±0.69^d	0.058±0.01^a	78.00±5.01^d	0.51±0.05^c	276.59±45.67^b	531.32±66.10^c
M_2	D_1	78.72±3.71^b	3.70±0.41^e	0.055±0.01^{abc}	85.02± 3.55^a	0.45±0.06^e	271.71 ±46.81^b	497.09± 23.66^c
	D_2	75.09± 1.08^c	5.08±1.90^a	0.054±0.01^{bc}	73.14±3.90^f	0.59±0.06^a	264.58 ±31.73^b	653.04± 50.48^a
M_3	D_1	79.30±2.01^b	4.35±1.53^c	0.053±0.01^c	78.41±4.69^c	0.53±0.08^b	266.86 ±33.59^b	605.97±58.42^b
	D_2	86.18±3.65^a	3.73±1.21^e	0.057±0.01^{ab}	84.75±3.18^b	0.48±0.08^d	312.69 ±53.78^a	509.19±109.06^c
CV (%)		2.33	5.29	7.31	0.36	2.44	8.44	7.41
LSD (5%)		1.73	0.18	0.004	0.27	0.01	22.35	40. 20
SEM		0.60	0.06	0.001	0.09	0.004	7.78	13.99

Where, WE = weeding efficiency, PD = plant damage, EFC= effective field capacity, FE = field efficiency, FC = fuel consumed, PI = performance index, CV = coefficient of variation, LSD = least significance difference, SEM = standard error of the mean, values are mean ± SD, Depth (D1= 0 to 20 mm, D2= 0 to 40 mm),soil moisture content (M1= 9.4%, M2= 12.34% and M3= 15.25%), and Mean values comparison arranged according to descending order with the same letter in a column are not significantly different at 5% level of significance.

content had a significant influence on fuel consumption at ($p<0.05$) level of significance. Each variable significantly affects the fuel consumption in the order of speed (S) followed by depths of operation (D). The interactive effect of variables, forward speed and depth of operation (S×D), forward speed and soil moisture content (S×M), depth of operation and soil moisture content (D×M) on fuel consumption are presented in Tables 4, 5, and 6 respectively. The results showed that the interaction effect in forward speed and depth of operation(S×D) had significant effects ($p<0.05$) whereas the interaction effect (Depth×Moisture) and (Speed×Moisture) had no significant effects ($p>0.05$) on fuel consumption. Table 7 shows the results of the combined effect of variables (Speed× Depth×Moisture). It revealed that the combined effect of depth of operation, forward speed, and soil moisture was not significant effects on fuel consumption at a 5% ($p>0.05$) level of significance.

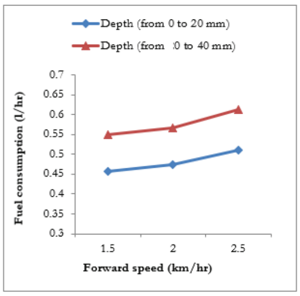
Performance Index

Effects of soil moisture, forward speed, and depth of operation on performance index are presented in Table 7 and the result showed that the highest performance index of 366.69 ha/hp was obtained at 2 km/hr forward speed and depth of operation varied from 0 to 40 mm. The next was at the forward speeds of 2.5 km/hr which recorded 320.3 ha/hp performance index at the soil moisture content of 15.25%. However, the lowest performance index of 221.6 ha/hp was recorded at a forward speed of 1.5 km/hr and the depth of operation ranged from 0 to 20 mm at soil moisture content 9.4 percent.

From Figure 5, it was observed that performance index increased with increase in forward speed and depth of operation at all levels of soil moisture content. However, the performance index increased as the soil moisture level increased at all the treatments because of the high-performance index at higher speeds. The same trend was observed at all levels of soil moisture content and forward speeds.

Analysis of variance (ANOVA) revealed that the effect of forward speed (S) had a significant influence on the performance index at a 5% ($p<0.05$) level of significance. It was also observed that there was no significant difference in performance index with depths of operation (D) and soil moisture content (M) at ($p>0.05$) level of significance.

The interaction effects in forward speed and depth of operation (S×D), forward speed and soil moisture content (S×M), depth of operation, and soil moisture content (D×M) on the performance index are presented in Tables 4, 5, and 6 respectively. The mean results observed from the data revealed that the interaction effect (Speed×Depth), (Depth×Moisture), and (Speed×Moisture) were not significantly influenced by the performance index at $p>0.05$ level of significance. Analysis of variance revealed that the combined effect of forward speed, depth of operation, and soil moisture content



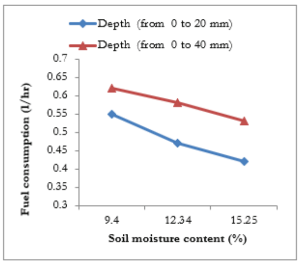


Figure 6: Effect of soil moisture and machine operation parameter on fuel consumption.

Table 6: Combined effect of forward speed, depth of operation and soil moisture content on performance of the weeder

Speed (km/hr)	Depth (mm)	Moisture (%)	WE (%)	PD (%)	EFC (ha/hr)	FE (%)	FC (l/hr)	PI (ha/hp)	EC (MJ/ha)
1.5	20	M_1	73.20 ± 1.52^{ghi}	3.32 ± 0.37^{ij}	0.047 ± 0.001^{hij}	78.89 ± 0.82^{g}	0.53 ± 0.01^{efg}	221.63 ± 4.22^{e}	671.50 ± 35.03^{ab}
		M_2	76.01 ± 1.76^{efg}	3.00 ± 0.38^{jk}	0.046 ± 0.001^{hij}	84.54 ± 0.88^{cd}	0.45 ± 0.00^{h}	226.36 ± 2.06^{e}	591.88 ± 18.19^{abcde}
		M_3	78.99 ± 3.03^{de}	2.78 ± 0.55^{k}	0.046 ± 0.001^{hij}	89.49 ± 0.67^{a}	0.39 ± 0.02^{i}	227.36 ± 0.68^{e}	515.28 ± 30.89^{efgh}
	40	M_1	75.74 ± 1.36^{efgh}	4.27 ± 0.12^{fg}	0.045 ± 0.002^{ij}	73.43 ± 0.57^{hi}	0.51 ± 0.03^{g}	226.43 ± 4.96^{e}	622.66 ± 15.75^{abc}
		M_2	78.98 ± 1.35^{de}	3.83 ± 0.10^{h}	0.044 ± 0.002^{i}	0.53±0.01efg 0.53±0.01efg $0.53\pm0.01efg.22^{f}$	0.43 ± 0.03^{h}	230.04 ± 12.21^{de}	601.03 ± 65.29^{abcde}
		M_3	90.1 ± 1.17^{a}	3.31 ± 0.09^{ij}	0.052 ± 0.008^{ghi}	85.99 ± 0.96^{bc}	0.41 ± 0.02^{i}	276.78 ± 45.90^{c}	481.71 ± 12.34^{gh}
2	20	M_1	71.97 ± 0.34^{hi}	5.12 ± 0.11^{d}	0.059 ± 0.006^{cdef}	70.67 ± 1.29^{j}	0.57 ± 0.01^{cd}	274.49 ± 20.24^{c}	581.42 ± 72.24^{bcdef}
		M_2	75.36 ± 1.43^{efgh}	4.41 ± 0.08^{ef}	0.058 ± 0.005^{defg}	74.63 ± 1.35^{h}	0.50 ± 0.02^{g}	274.79 ± 19.04^{c}	522.16 ± 77.91^{defgh}
		M_3	78.85 ± 4.24^{de}	3.94 ± 0.11^{gh}	0.055 ± 0.005^{efg}	81.98 ± 1.40^{ef}	0.44 ± 0.03^{h}	267.43 ± 33.64^{cd}	494.28 ± 16.40^{fgh}
	40	M_1	74.74 ± 1.27^{fghi}	3.42 ± 0.27^{i}	0.055 ± 0.005^{efg}	77.43 ± 0.45^{g}	0.60 ± 0.02^{bc}	275.09 ± 22.53^{c}	652.86 ± 46.13^{ab}
		M_2	78.60 ± 0.51^{de}	3.15 ± 0.02^{ijk}	0.053 ± 0.006^{fgh}	81.23 ± 0.60^{f}	0.54 ± 0.01^{def}	269.84 ± 21.48^{c}	621.42 ± 92.61^{abc}
		M_3	84.53 ± 3.46^{b}	3.11 ± 0.05^{ijk}	0.066 ± 0.008^{abc}	87.49 ± 0.75^{b}	0.50 ± 0.00^{g}	366.69 ± 34.58^{a}	460.47 ± 75.96^{gh}
2.5	20	M_1	70.97 ± 1.93^{i}	5.86 ± 0.51^{c}	0.068 ± 0.003^{a}	71.84 ± 1.03^{ij}	0.62 ± 0.01^{ab}	301.79 ± 12.30^{bc}	550.83 ± 0.54^{cdefg}
		M_2	74.44 ± 1.80^{ghi}	4.71 ± 0.13^{e}	0.067 ± 0.001^{ab}	74.84 ± 1.22^{h}	0.56 ± 0.02^{de}	328.63 ± 11.25^{b}	479.91 ± 38.53^{gh}
		M_3	$78.33\text{-}\pm4.04^{de}$	3.96 ± 0.18^{gh}	0.065 ± 0.002^{abcd}	83.58 ± 1.08^{de}	0.52 ± 0.01^{fg}	320.32 ± 33.32^{b}	452.15 ± 24.59^{h}
	40	M_1	$74.81\pm0.51f^{gh}$	7.56 ± 0.26^{a}	$0.062\pm0.00b^{cde}$	68.54 ± 0.95^{k}	0.65 ± 0.02^{a}	292.22 ± 0.57^{bc}	683.60 ± 70.95^{a}
		M_2	80.33 ± 3.40^{cd}	6.32 ± 0.17^{b}	0.061 ± 0.001^{bcde}	72.26 ± 0.89^{ij}	0.61 ± 0.01^{ab}	300.71 ± 11.68^{bc}	595.47 ± 15.91^{abcde}
		M_3	83.90 ± 2.26^{bc}	5.27 ± 0.02^{d}	0.055 ± 0.005^{efg}	80.75 ± 1.17^{f}	0.57 ± 0.03^{cd}	294.62 ± 38.29^{bc}	614.94 ± 32.68^{abcd}
CV (%)			2.23	5.29	7.31	0.36	2.44	8.44	7.41
LSD (5%)			3.00	0.38	0.01	0.47	0.02	38.71	69.62

Where, WE = weeding efficiency, PD = plant damage, EFC= effective field capacity, FE = field efficiency, FC = fuel consumed, PI = performance index, CV = coefficient of variation; values are mean ± SD and mean values with the same letter in a column are not significantly different at 5% level of significance; LSD = least significance difference, soil moisture (9.4, 12.34 and 15.25%) and Mean values comparison arranged according to descending order with the same letter in a column are not significantly different at 5% level of significance.

(Speed×Depth×Moisture) had no significant effects on the performance index at ($p > 0.05$) level of significance.

Energy Consumption

The use of energy per hectare for weeding operation by the engine-operated weeder was estimated at different intervals of crop period. From Table 7, it is observed that the energy consumption for weeding operation at 1.5 to 2.5 km/hr forward speed of the engine operated weeder was in the range of 671.50 to 550.83 MJ/ha and 515.3 to 452.15 MJ/ha with the depth of operation varied from 0 to 20 mm at 9.4% and 15.25% soil moisture content respectively. The result showed that energy consumption for weeding operation at 1.5 to 2.5 km/hr forward speed of weeder was in the range of 683.60 to 622.66 MJ/ha and 548.30 to 452.2 MJ/ha with the depth of operation varied from 0 to 40 mm at 9.4% and 15.25% soil moisture content respectively. Energy consumption at the initial stages of the plant was less because of obstruction-free travel between the rows. Whereas in the case of a fully grown field, it was difficult to travel between the rows, and as a result, energy consumption is higher.

The mean comparison for energy consumption in all treatments is shown in Table 7. A result indicated that the minimum energy consumption of 452.2 MJ/ha was obtained by using a 2.5 km/hr weeder forward speed at depth of operation varied from 0 to 40 mm and soil moisture content 15.25%. The maximum value of energy consumption of 683.6 MJ/ha was obtained by using a 1.5 km/hr weeder forward speed at depth of operation varied from 0 to 40 mm and soil moisture content 9.4%. The results trend obtained and represented on Figure 6 revealed that as forward speed and moisture content increased, energy consumption decreased. As the depth of operation increased, energy consumption for the machine increased. Therefore, depth of operation and energy consumption is a positive relationship.

The main and combined effects of operational parameters on energy consumption were analyzed statistically and presented in Table 3. Analysis of Variance (ANOVA) revealed from the tables that the effect of forward speed (S) had no significant effects on energy consumption

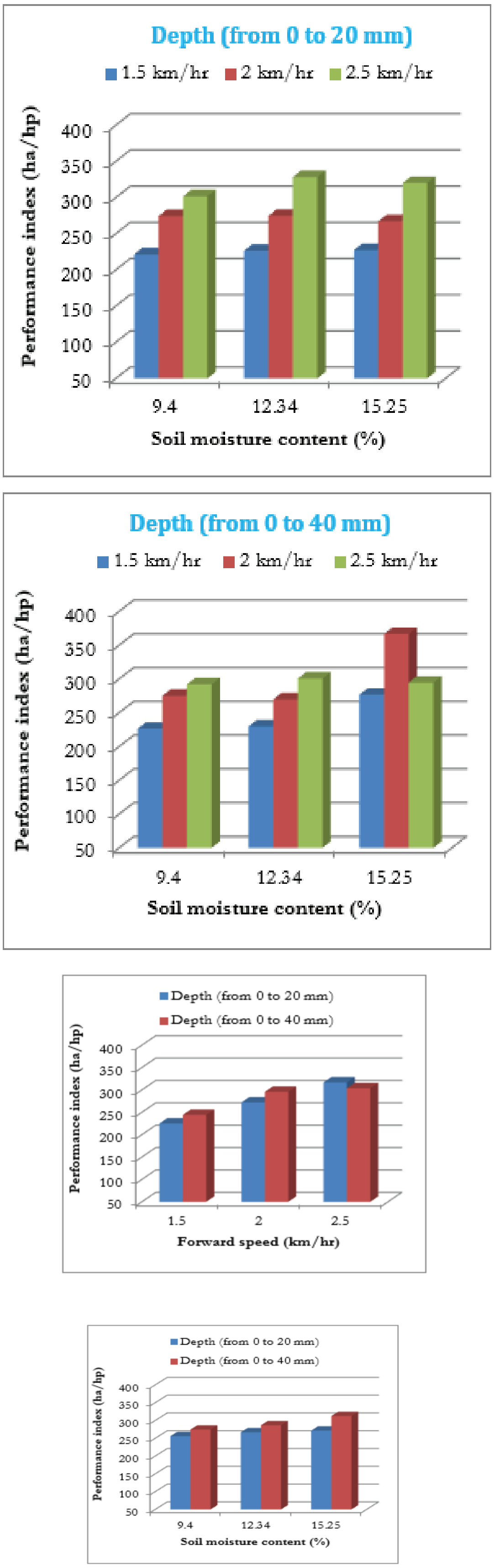


Figure 7: Effect of soil moisture and machine operational parameters on a performance index

at (P>0.05) level of significance. But there was a significantly different between higher and lower values of forwarding speed. From the ANOVA table, depths of operation (D) and moisture content (M) had a significant influence on energy consumption at (P<0.05) level of significance and each variable individually influenced the energy consumption and also significance was observed in the order of speed (S) followed depths of operation (D). The interaction effects of forward speed and depth of operation (S×D), forward speed and soil moisture content (S×M), depth of operation, and soil moisture content (D×M) on energy consumption are presented in Tables 4, 5, and 6 respectively. The results observed from the data revealed that the interaction effect of variables (Speed×Depth) and (Speed×Moisture) had significant effects on energy consumption at (P<0.05) level of significance. The interaction effect of variables (Depth×Moisture) had no significant influence (P>0.05) on energy consumption. The results of the combined effect of variables (Speed×Depth×Moisture) are presented in Table 7. Results revealed that the combined effect of depth of operation, forward speed, and soil moisture content had no significant effects on energy consumption at (P>0.05) level of significance.

Cost estimation of Engine Operated Weeder

The engine-operated weeder was evaluated for the estimation of cost of operation and compared with the traditional method of weeding. The total fabrication cost of the weeding machine was 11,409.92 ETB. The calculated results of fixed and variable costs were 8.638 ETB/hr and 33.058 ETB/hr respectively. The cost of operation for an engine operated weeding and traditional method were 758 ETB/ha and 1920 ETB/ha respectively as shown in Figure 7. The saved cost of weeding was 60.52% and the saved in time was 65.25% compared to manual weeding. Similar findings were reported by Sirmour and Verma (2018). Also, the cost and time of operation increased as the days after sowing increased. The dense canopy prevents the easy working of the weeder between the rows and increases the duration of weeding. As the duration of weeding increases, the field efficiency of the weeder decreases as a result of increased working hours

CONCLUSIONS AND RECOMMENDATION

This study was undertaken to evaluate the performance of an engine-operated weeder machine for the wheat crop. The engine-operated weeder machine was successfully evaluated. This test was conducted at different levels of operating parameters viz., depths of operation (from 0 to 20 and 0 to 40 mm), forward speed (1.5, 2, and 2.5 km/hr), and soil moisture contents (9.4, 12.34, and 15.25%). The performance of the developed machine was evaluated in terms of weeding efficiency, plant damage, effective field capacity, field efficiency, fuel consumption, performance index, energy consumption, labor cost, costs of owning and operating the machine is acceptable.

Based on measurements made and analysis carried out, the best-operating conditions were found. As a result, the following conclusions were drawn from the study:

Soil bulk density decreased from 1561±0.87 to 1385±0.31 kg/m^3 with increased soil moisture content from 9.40±0.11 to 5.25±0.26 percent. Bulk density decreased by 12.7% with an increase in soil moisture content from 9.40±0.11 to 15.25±0.26 percent. Weeding efficiency is increased with increasing depth of operation and soil moisture content and decreased with increasing weeder forward speed. It was optimum at 12.34 and 15.25 percent soil moisture as it gave a reasonably higher working range. Plant damage is low when operated at lower speeds, but high plant damage occurs when operated at high rates.

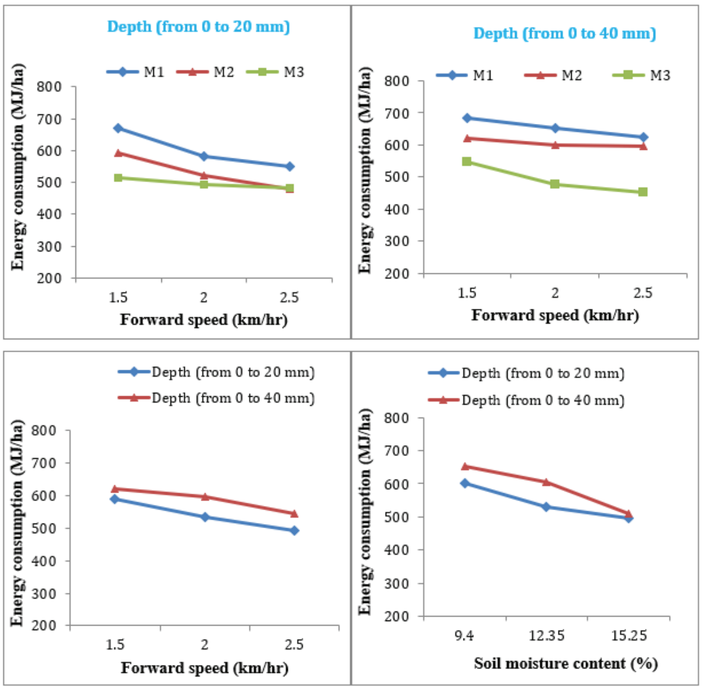


Figure 6: Effect of soil moisture and machine operational parameters on energy consumption

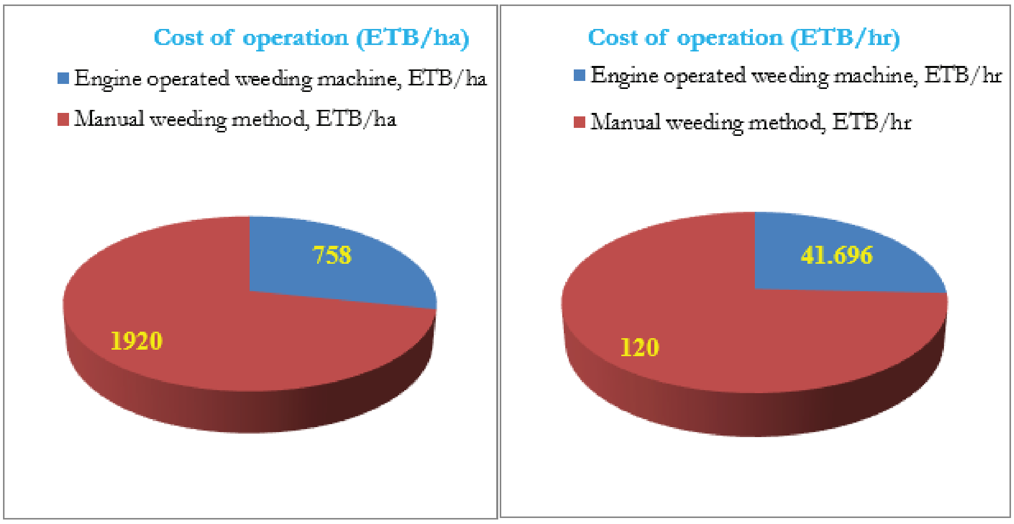


Figure 7: Diagram showing the cost of engine operated weeder and manual weeding operation

The maximum value of plant damage 7.56% was obtained with 2.5 km/hr at depth of operation ranging from 0 to 40 mm and 9.4 percent soil moisture content.

The maximum effective field capacity of 0.068 ha/hr was obtained at 2.5 km/hr weeder forward speed, a depth of operation ranging up to 20 mm, and soil moisture content of 15.25 percent. As the depth of operation increased, the effective field capacity decreased. The effective field capacity increased with the increasing forward speed, as a result of more area being covered in less time.

The field efficiency of the engine-operated weeder is higher when operated at low forward speed and low depth of operation within high soil moisture content. Fuel consumption increased as the forward speed and depth of operation increased and decreased as moisture content increased.

In conclusion, the performance of the weeder was found to be optimum at 15.25 percent moisture content with 0 to 40 mm depth of operation at a forward speed of 1.5 km/hr. Hence, maximum weeding efficiency of 90.1 percent was recorded with lower plant damage of 3.31 percent while the effective field capacity, field efficiency, fuel consumption, performance index, and energy consumption were found to be 0.052 ha/hr, 85.99%, 0.41 l/hr, 276.78 ha/hp, and 481.71 MJ/ha, respectively. The costs of weeding per hectare were observed as 758 birr/ha and 1920 birr/ha for engine-operated weeder and traditional weeding methods, respectively.

Based on the findings, it is concluded that the performance of the engine-operated weeder can be an efficient, effective, and economically possible option with the high prospect of extending technology for small and medium-scale farmers. However, this plenty of scope for improvement on the machine

RECOMMENDATION

The prototype weeder performance evaluation revealed that it can be used successfully on the farm for weeding operations. To make the weeder applicable and acceptable among farmers, the following steps are recommended for further study and improvement on the machine:

- The machine should be tested on different soil types,
- Different types of weeding blades should be designed and tested,
- Adaptation, modification, and performance test of the machine for multi-crops weeding operation should be done and
- Demonstration and scaling up of this machine should be undertaken at the farm level.

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