Performance Evaluation and Cost Analysis of Tractor Mounted Four Bottoms Moldboard Plow for Effective Tilth

Author's Details:
Bilal Ahmad[1,*], Usman Ali[2], Fazal Ahmad Jamal[3] Sidrah Ashfaq[4]
[1]Department of Farm Machinery and Power, University of Agriculture, Faisalabad, Pakistan
eabilal@yahoo.com
[2]Department of Engineering, Dalhousie University, Canada
usman.ali@dal.ca
[3]Department of Structures and Environmental Engineering, University of Agriculture, Faisalabad, Pakistan
ranajamal.nns@gmail.com
[4]Department of Farm Machinery and Power, University of Agriculture, Faisalabad, Pakistan
sidrah708@uaf.edu.pk
[*]Correspondence: eabilal@yahoo.com

Abstract:
Moldboard Plow is one of the oldest agricultural implements in the history of agriculture. It is considered as a necessary tillage implement because it carries the nutrients to the root zone of plants by turning the soil. This study focused on finding the optimal efficiency of Moldboard Plow in the field. For this analysis, we used a tractor mounted four bottoms Moldboard Plow. The theoretical and actual field capacities along with the efficiency were calculated at different engine rpm and depths (depth of cut). The maximum theoretical and actual field capacities were observed 0.55 and 0.33 (ha/hr) respectively when the engine speed was 1700 rpm, and the depth of cut was 6 cm. The maximum 68.65% field efficiency was observed when the engine speed was 1700 rpm and the depth of cut was 18 cm. In the current study it was observed that the efficiency greater than 65% can be achieved at the depth (depth of cut) of 14-18 cm and engine speed of 1700 rpm, it will cost 2022 PKR/ha. The Breakeven point can be reached after 8.33 days of use at a rate of 9 hours per day and it means that the owner could get back its original investment within 8.33 days of operation.
Keywords: *Moldboard, Theoretical Field Capacity, Actual Field Capacity, Field Efficiency, Breakeven analysis*

1. Introduction

Pakistan is an agricultural country and most of its population is directly or indirectly involved in agriculture. The agricultural sector of Pakistan involves 43.7% of the labour force [1] and contributes 19.3% of the country's GDP [2] but this percentage can be increased by adopting mechanized agricultural technologies.

The agricultural sector is fulfilling the food demand as well as the fibre demand of Pakistan. About 75 % of foreign exchange is due to agriculture [3]. Agricultural mechanization is essential for boosting Pakistan's foreign trade. Mechanization is defined as the use of agricultural machines for the betterment of agriculture [4], [5].

These statistics can be improved by adopting modern technologies with an effective way of mechanical operation. By adopting effective methods of farming, we can face food insecurity problems. Effective methods of farming can minimize the economical losses during the whole cropping season. To reduce crop production costs and to increase profit, we must operate the agricultural machines at their best operating conditions.

A Moldboard Plow is a primary tillage implement and it is used after harvesting the crop to loose and invert the soil in the form of furrow slices with a degree of pulverization, the degree of pulverization depends upon the type of Moldboard Plow, type of soil and speed of ploughing. The specific functions of Moldboard Plow are in the following

i) To cut the soil
ii) To break the soil
iii) To lift the soil
iv) To invert the soil
v) To pulverize the soil
vi) To bury the weeds, trash and manure in the field

Moldboard Plow consists of different types such as stubble bottom, high speed and general purpose.

The basic parts of Mouldboard plow are share, shin, gunnel, landslide, frog, brace, moldboard, frame, beam and attachments like coulter. These parts are shown in the Figure 1.

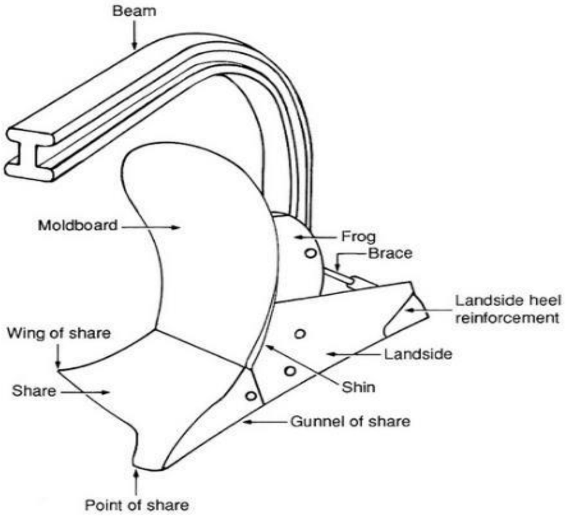

Figure 1: Parts of Moldboard plow

Moldboard Plow can be equipped with various attachments such as rolling landslide, jointer or rolling coulter and tail wheel. Tail wheel trails behind the plow and it can be adjusted to increase or decrease the pressure of landslide on the furrow wall. A rolling coulter is a disk having a sharp blade which is attached to cut the residue of previous crop to make smooth face of furrow.

Moldboard Plow is available in both animals drawn as well as tractor drawn categories. It penetrates into the soil by cutting it, lifts the soil upward along with the moldboard, and turns it on the surface in the form of furrows. The number of the furrow is dependent on the bottoms and size of a plow. The size of the plow is decided according to the need and the size of the farm.

The soil must be turned to bring nutrients into the upper surface, where plants can efficiently utilize these nutrients for their growth. A significant advance for this type of plow is a Moldboard Plow. A coulter was also added to cut vertically into the ground just ahead of the share (in front of the frog), there is wedge-shaped cutting edge at the bottom of the Moldboard Plow with the frame's landside supporting the frame under share (below-ground component).

The study was carried out on the Moldboard Plow evaluation, and the specific goals of this study are:

1. To find out the optimal depth of cut and engine rpm for achieving the maximum field efficiency of the Moldboard Plow.
2. Cost analysis of Moldboard Plow.

2. Materials and Methods

The Moldboard Plow was tested and evaluated to determine the best suitable operating conditions and the following parameters were considered during the evaluation process. Figure 2 shows the actual view of the field while testing and evaluation.

Figure 2: Actual view of the field

2.1 Depth of Cut

The depth of cut is the depth up to which the plow was penetrated and it was determined by placing a meter rod horizontally over a furrow opened by a bottom and measured vertically the depth of furrow from the lower surface of the horizontally placed rod to the bottom of the furrow. It was measured in cm.

2.2 Forward Speed

Forward Speed is the speed at which the operation was performed it was measured by the following formula

$$FS = D/T \quad \text{(Eq. 1)}$$

Where, FS = Forward Speed (km/hr), D = Traveled distance (km) and T = Time (hr).

2.3 Theoretical Field Capacity

The prediction of the value of the machine in the lab is known as theoretical field capacity. It is dependent on the operating width and operating speed of the machine. The machine which has greater operating width will have a greater value of theoretical field capacity. By increasing the operating speed the theoretical field capacity increases. [6], [7] performed work on different machines and calculated their theoretical field capacity. The theoretical field capacity of the plow was calculated by the following formula

$$TFC = (Ow \times Os)/10 \qquad (Eq. 2)$$

Where, TFC = Theoretical field capacity (ha/hr), Ow = Operating width (m) and Os = Operating speed (km/hr).

2.4 Actual Field Capacity

The value of the field which is actually plowed by the machine at a certain time is known as actual field capacity. [7], [8] checked out the actual field capacities of different machines. The following formula was used in this research to calculate the actual field capacity

$$AFC = Ac/Tt \qquad (Eq. 3)$$

Where, AFC = Actual field capacity (ha/hr), Ac = Cultivated area (ha) and Tt = Total time (hr)

2.5 Field Efficiency

Field efficiency is also called the efficiency of the machine. This is the percentage ratio between the AFC and TFC of the respective machine. [6], [7] determined the field efficiency by the same formula which is used in this research, the formula is in the following

$$FE = (AFC/TFC) \times 100\% \qquad (Eq. 4)$$

Where, FE = Field efficiency (%)

2.6 Cost Analysis

Machine maintenance is an important element of the budget. This element is greater than the price of the machine [9]. The following two types of costs were determined during the cost analysis

a) Fixed Cost
b) Variable Cost

a) Fixed Cost

Fixed cost is the sum of depreciation, interest, insurance, taxes and housing for the machine and it was calculated by adding all the above-mentioned expenses. Fixed cost is the sum of Depreciation cost, Interest, Insurance, Taxes and Housing [10], [11]

i) Depreciation

The cost for depreciation for a machine is calculated according to the expected life of the machine or implement. The value of depreciation was calculated with the help of the same equation used by [12], [13], [14], [15] in research.

$$D = (P-S)/L \qquad (Eq. 5)$$

Where, D = Depreciation, P = Purchase price, S = Salvage Value and L = Life of Machine.

ii) Interest

Interest is usually the opportunity fee for a machine and it was calculated by the following Eq. 6 [9].

$$I = ((P+S)/2) \times I \qquad (Eq. 6)$$

Where, I = Interest, P = Purchase value, S =Salvage and i = interest rate

iii) Insurance, Taxes and Housing

The values of insurance, taxes and housing are different in different regions of the world. Usually, insurance is about 2 %, taxes are about 1-2 % and housing is also 1-2 % of the total value of the machine [16].

b) Variable Cost

The cost which depends on the performance, maintenance and operating cost of a machine is known as a variable cost. It was calculated by adding the labour, fuel, lubricants, repair and maintenance costs of the machine.

i) Labor Cost

This cost is an important factor of variable cost. Labour cost is the cost that is required to hire the labour to operate the machine and this varies according to the region. This cost is paid to the hired labour according to the working hours.

ii) Fuel and Lubricants

The Moldboard Plow is a tractor-mounted implement and the tractor is powered by an internal combustion engine, this requires fuel and lubricants to perform work in the field. Fuel cost also varies in different regions and lubricant cost is considered as 15 % of the fuel cost [9].

iii) Repair and Maintenance

The cost is required in maintaining the machine and this cost is considered as 15 % of the average cost of the machine [9].

2.6.1 Break-even Analysis

Fixed cost and variable cost were determined to find the break-even point of the implementation.

3. Results

During the testing of Moldboard Plow the required parameters for the evaluation were recorded and forward speed, theoretical field capacity, actual field capacity and field efficiency were determined.

3.1 Depth of Cut

The plow was evaluated at four different depths of cut, mentioned in the following Table 1. The average width of the operating implement was 1.26 m, Figure 3 shows the actual view while measuring the width.

Table 1: Depth of Cut

Sr. No.	Average Depth of Cut (cm)
1	6
2	10
3	14
4	18

Figure 3: Actual view while measuring the width

3.2 Forward Speed

The plow was evaluated at four different engine rpm and at different engine rpm different forward speeds were recorded. The speed of travel was determined with the help of Eq. 1 as shown in the following Table 2.

Table 2: Results of Forward Speed

Sr. No.	Engine Speed	Depth of cut	Forward Speed
	(rpm)	(cm)	(km/hr)
1	1100	6	2.97
2		10	2.47
3		14	2.3
4		18	1.9
5	1300	6	3.41
6		10	2.85
7		14	2.5
8		18	2.3
9	1500	6	3.89
10		10	3.26
11		14	2.79
12		18	2.48
13	1700	6	4.34
14		10	3.88
15		14	3.49
16		18	3.11

The above data is represented graphically in the following Figure 4. The maximum value of forward speed was recorded at the engine speed of 1700 rpm and the speed was 4.34 km/hr.

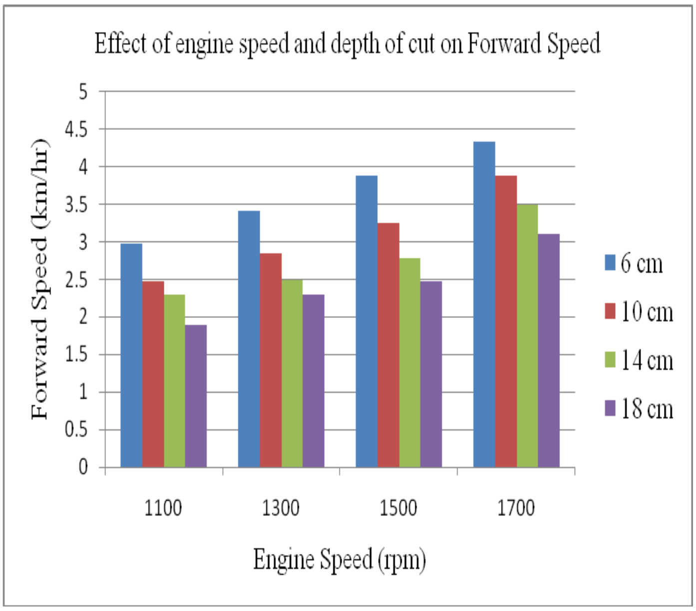

Figure 4: Effect of engine speed and depth of cut on Forward Speed

3.3 Theoretical Field Capacity

The theoretical field capacity of the implement was determined by operating width and operating speed as described in the Eq. 2 and the results are shown in Table 3.

Table 3: Results of Theoretical Field Capacity

Sr. No.	Engine Speed	Depth of cut	TFC
	(rpm)	(cm)	(ha/hr)
1	1100	6	0.37
2		10	0.31
3		14	0.29
4		18	0.24
5	1300	6	0.43
6		10	0.36
7		14	0.32
8		18	0.29
9	1500	6	0.49
10		10	0.41
11		14	0.35
12		18	0.31
13	1700	6	0.55
14		10	0.49

15		14	0.44
16		18	0.39

The maximum value of TFC was recorded at the engine speed of 1700 rpm and the minimum at the engine speed of 1100 rpm, at the depth of 18 and 6 cm respectively. The data is graphically represented in Figure 5.

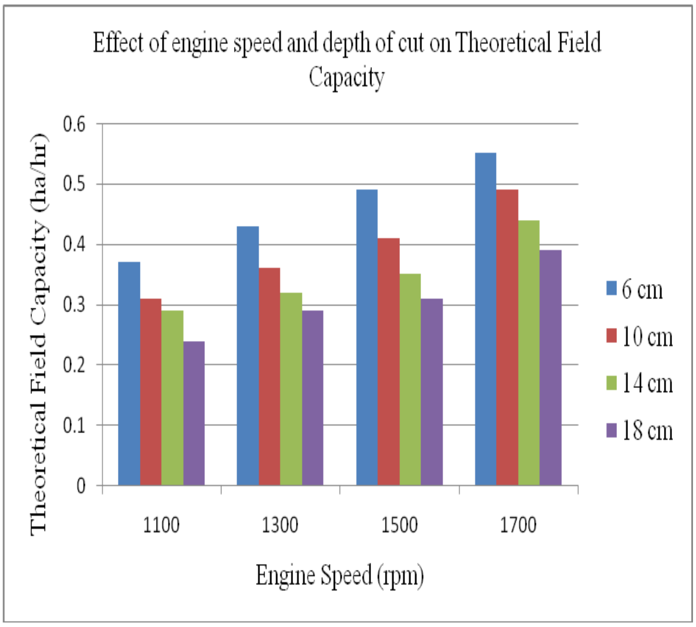

Figure 5: Effect of engine speed and depth of cut on Theoretical Field Capacity

3.4 Actual Field Capacity

In this research, the machine was evaluated at 16 different operating conditions in which there were different operating depths and different operating speeds were considered. So, to minimize the error theoretical and actual field capacities were determined separately for all 16 working conditions. The actual field capacity was calculated by using Eq. 3, the results are shown in Table 4 and graphically represented in Figure 6.

Table 4: Results of Actual Field Capacity

Sr. No.	Engine Speed	Depth of cut	AFC
	(rpm)	(cm)	(ha/hr)
1	1100	6	0.13
2		10	0.12
3		14	0.13
4		18	0.12
5	1300	6	0.20
6		10	0.19
7		14	0.18
8		18	0.17
9	1500	6	0.29
10		10	0.26
11		14	0.23
12		18	0.21
13	1700	6	0.33
14		10	0.31
15		14	0.29
16		18	0.27

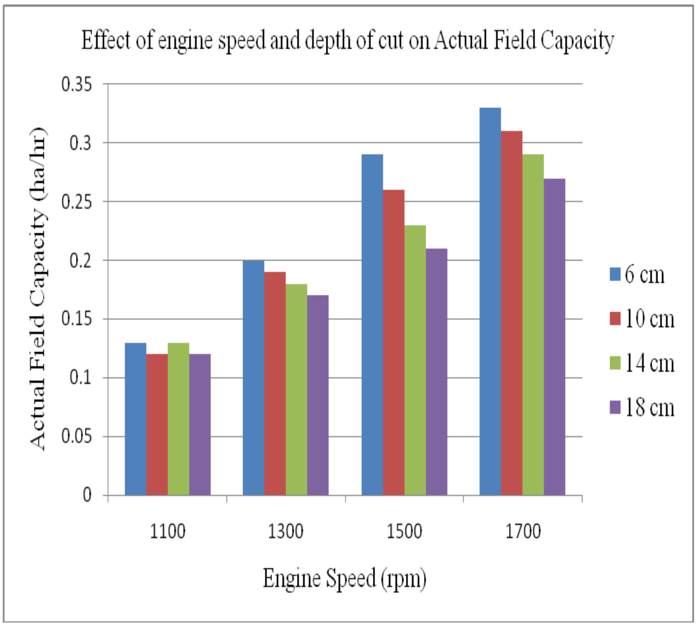

Figure 6: Effect of engine speed and depth of cut on Actual Field Capacity

3.5 Field Efficiency

Field efficiency was determined by using Eq. 4, the results are shown in Table 5 and graphically represented in Figure 7.

Table 5: Results of Field Efficiency

Sr. No.	Engine Speed	Depth of cut	FE
	(rpm)	(cm)	(%)
1	1100	6	33.40
2		10	39.84
3		14	44.17
4		18	49.71
5	1300	6	46.55
6		10	52.91
7		14	55.56

8		18	58.66
9	1500	6	59.17
10		10	62.81
11		14	65.43
12		18	67.20
13	1700	6	60.35
14		10	63.41
15		14	65.95
16		18	68.65

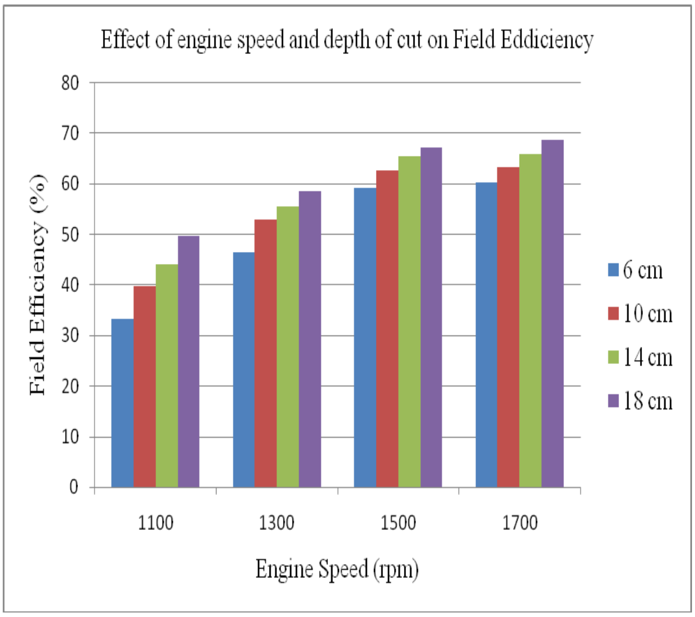

Figure 7: Effect of engine speed and depth of cut on Field Efficiency

3.6 Cost Analysis

To perform the detailed cost analysis the general information about the implementation is given below

i) General Information about implement

Price of Moldboard Plow, P = 1,55,000 PKR

Salvage Price, S (10 % of P) = 15,500 PKR

Expected life of machine, years = 12 years

Annual working hours, h = 800 hours

ii) Fixed Cost

Depreciation = (155000-15500)/12 (Eq. 5)

= 11625 PKR

Interest @ 13% = ((155000+15500)/2)×7% (Eq. 6)

= 11082.5 PKR

Insurance, Taxes and Housing @ 2 % = 3100 PKR

Total Fixed Cost = 11625+11082.5+3100

= 25807.5 PKR/year

= 32.25 PKR/hr

iii) Variable Cost

Labor Cost @ 1400 per day = 155.55 PKR/hr

(9 working hours per day)

Repair and maintenance @ 15 % = 23250 PKR/year

= 29.06 PKR/hr

Diesel Cost per hour @ 3.2 L/hr = 384.12 PKR/hr

Lubrication Cost @ 15 % of fuel price = 57.62 PKR/hr

(Diesel @ 120.05 PKR/L)

Total Variable Cost = 155.55+29.06+384.12+57.62

= 626.35 PKR/hr

iv) Total Operating Cost

Total Operating Cost =Total Fixed cost+Total Variable Cost

= 32.25 + 626.35

= 658.6 PKR/hr

3.6.1 Breakeven Analysis

A point that focuses on the profitability of a machine is known as its breakeven point. This analysis helps us to determine the point at which the total income will equal the total cost. The breakeven point of tractor-mounted Moldboard Plow can be achieved after 8.33 days of use at the rate of 9 hours per day. The breakeven analysis is shown in Figure 8.

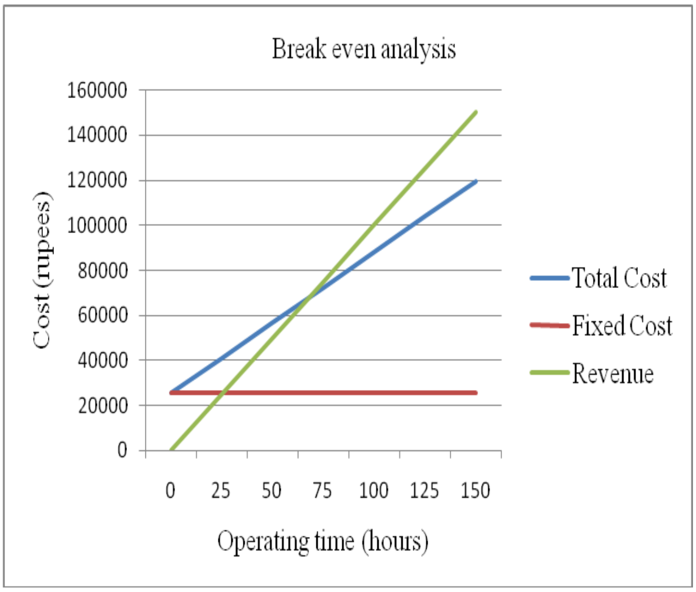

Fig. 8: Breakeven Analysis

4. Discussions

In the present study, it was observed that an increase in the engine speed from 1100-1700 rpm causes an increase in the forward speed of the tractor as well as the implement (Moldboard Plow). By increasing the depth of cut at the constant engine speed causes a decrease in the forward speed of the tractor. The minimum value of theoretical field capacity was observed at the engine speed of 1100 rpm with 18 cm depth of cut and the maximum was observed at 1700 rpm with 6 cm depth of cut. The minimum actual field capacity was observed at two working conditions with an engine speed of 1100 rpm, the depth of cut was 10 cm and 18 cm. The maximum value of actual field capacity was observed at an engine speed of 1700 rpm at 6 cm depth of cut. As the performance of any machine can be calculated by the efficiency of the machine, the maximum field efficiency was observed at the engine speed of 1700 rpm with 18 cm depth of cut. The increase in engine speed at the constant depth causes a positive change in the forward speed of the tractor while the increase in the depth of cut at the constant engine speed causes a decrease in the forward speed. While calculating the field efficiency it was observed that there is an increment in the values of field efficiency by increasing the depth of cut and engine speed which causes the increase in the forward speed. The calculated operating cost of the implementation at the maximum value of field efficiency was 2022.14 PKR/ha.

5 Conclusions

The research concluded that while evaluating the tractor-mounted Moldboard Plow at different engine speeds and different depths the maximum value of efficiency can be achieved at the engine speed of 1700 rpm with 14-18 cm depth of cut. While operating the implement at these operating conditions (engine speed 1700 rpm, 14-18 cm depth) the efficiency greater than 65 % can be achieved and it will cost 2022 PKR/ha. The field operation at engine speed lower than 1700 rpm decreased the efficiency of the machine and it will result in an increment in the cost of operation of the machine.

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