International Journal of Agriculture and Plant Science
www.agriculturejournal.in
Online ISSN: 2664-7664, Print ISSN: 2664-7656
Received: 26-06-2025, Accepted: 27-07-2025, Published: 11-08-2025
Volume 7, Issue 4, 2025, Page No. 101-104

Performance evaluation of mini-tractor drawn 5-tyne cultivator for small scale farmers

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Abstract
The performance evaluation of agricultural machinery greatly depends on utilization of time and efficiency of field operations. The objective of present study was to assess performance indicators such as actual field capacity (AFC), theoretical field capacity (TFC) and field efficiency (FE) of an agricultural implement (cultivator) with respect to different engine speeds. The evaluation was done on three different engine speeds of 1500, 2000 and 2500 rpm respectively. The reported forward speeds were 2.409, 3.636 and 4.878 km/h respectively with corresponding engine speeds. The corresponding increase in TFC (0.2409 to 0.4878 ha/h) and AFC (0.2313 to 0.4390 ha/h) represents a positive relationship between engine speed and area covered. The field efficiency for the corresponding above speeds was reported as 96.01, 91.99 and 89.99% respectively, the variation in field efficiency because of minimal turning and overlap which leads to less time losses and reported good field efficiency. The average specific fuel consumptions were reported as 0.58 L/h. The small difference in TFC and AFC at all engine speeds confirmed that the accuracy and precision of the machine was very high under ideal test conditions was observed. These results reported high work performance, less operating time with respect to different engine speeds.

Keywords: Mini-Tractor, Cultivator, actual field capacity, field efficiency and fuel consumption

Introduction

Tillage is classified as one of the simplest and extremely important ploughing operations among entire agricultural field operations. To prepare a good quality seedbed a precise and advanced equipment and machinery are required, during the process of seedbed preparation the braking of upper layer of soil horizon achieved and fertilizers mixing, weed control can also be achieved simultaneously. The process of tillage greatly enhances the porosity and voids space in soil, which supports the crop growth and development by proper aeration and water holding capacity (Hendrick and Gill, 1971a; Hendrick and Gill, 1971b; Du *et al*., 2021) [1, 2, 3]. From all tillage implements and equipment's, the cultivator is very important equipment because of its ability to do ploughing, pulverizing and mix the soil. It makes cultivators is very much essential in modern farming. The cultivator works by a tynes with shovel which is helpful to insert into the soil and break the clods and mix organic matter, manure and fertilizers into the soil thoroughly.

The labour availability during the peak season is very difficult and the agricultural operation by labour and draft animals are time consuming and leads to more expensive, the cultivator is important mechanized agricultural equipment it can perform tasks which will helps significantly reduce them labour shortage and save time. They are some estimations that an 70% of farm power was consumed by tillage operation. Right selection, matching and use of machinery or equipment reduces the overall operating cost, if cultivators are used properly, it will increase the field efficiency and reduces the operating cost their by a little increasing profit of farmers by reducing overall production cost.

Human farm power availability was only 0.091 kW/ha in 2016-17 and for draught animal it was decreased from 0.221 kW/ha in 1971-72 to 0.130 kW/ha (Mehta *et al*., 2019) [9]. Over the decades the farm equipment and machinery usage were increased as result the average farm power availability has significantly raised from 0.30 kW/ha in 1960-61 to 2.02 kW/ha in 2013-14 (Surendra Singh *et al.*, 2014) [13]. (Kanth *et al*., 2024) was analyzed the trends and patterns of farm mechanization in India. (Rahaman *et al*., 2025) [16] addressed various factors which are affecting mechanization index and farm power availability. The maintenance cost for draught animals and as well as the daily paying amount for agricultural workers has increased, identifying the need of further mechanization two main benefits of mechanization was need to follow, firstly intime field operations are essential for coordinating with crop calendars and secondly high-quality work, which leads to improved soil structure for better plant growth.

Indian agriculture are small and scatter land holdings, which have boundaries to economic feasibility of advanced machinery adaption or usage for mechanization increment. A mini-tractor drawn cultivator is the viable option under these circumstances. It is most appropriate and feasible for small and medium holding farmers because farmers can easily affordability for mini-tractor. Because simple design and easy to use it, high functional efficiency and more compact model, these mini-tractor drawn cultivators are becoming more popular. (Rahaman *et al*., 2024) also studied economic analysis and feasibility of self-propelled rotor power weeder. (Kanth *et al*., 2024) was studied various precision agriculture techniques and Technologies.

However, operation of cultivators somewhat difficult in Vertisols, because it is heavy black soils with clay percentage of various moisture conditions. A advanced and specialized equipment or machinery are needed for active tillage in diversified soil conditions (Kepner *et al*., 1978; Kumar *et al*., 2023a; Kumar *et al*., 2023b; Du *et al*., 2021; Kankal *et al*., 2016) [1, 4, 5, 6, 7]. A performance of a mini-tractor drawn cultivator was evaluated at the Aditya University, Agricultural Field Laboratory, Surampalem, aiming to assess field performance parameters such as field capacity, field efficiency and fuel consumption in the view of suitability to small and medium farms with efficient conditions.

Materials and Methods

1. Working principle of mini-tractor cultivator

A small cultivator is a type of soil tillage equipment used with mini-tractor with low horsepower, usually between 15 to 25 hp. In small farms holdings, it is used for weed control, seedbed preparation and intercultural activities, however it is mostly used for seedbed preparation. The action of tynes fixed on a horizontal frame, the tynes makes the soil to cut and pulverize thoroughly during operation. The tynes of the cultivator break the soil clods and incorporate crop wastes, as well as weeds into the topsoil. The depth of ploughing was regulated by hydraulic system of tractor provided at the end of the cultivator. In the small and marginal fields, a mini-tractor cultivator is more useful and helpful for farmers to carry out the operation on economic mode. The following Table 1 provides the technical specifications of the mini-tractor-drawn cultivator.

Table 1: Particulars of mini-tractor drawn cultivator

S. No	Component and Material	Specifications
1.	Number of Tynes	5
2.	Overall Width	1 m
4.	Tyne Spacing	220 to 250 mm
5.	Depth of Operation	100 to 150 mm
6.	Frame Type	Box type
7.	Tyne Material	High Carbon Steel
8.	Shovel Type	Single Point
9.	Weight (approx.)	100–130 kg
10.	Hitch Type	3-point linkage
11.	Power Requirement	15 hp

2. Performance evaluation of mini-tractor drawn cultivator

The performance evaluation of mini-tractor drawn cultivator is important for determining the theoretical field capacity, effective field capacity, field efficiency and fuel consumption with respect to the varied engine speeds such as 1500, 2000 and 2500 rpm. This assessment was necessary for every implement, equipment and machinery for suitability to type of soil, crop and size of farm for best use of resources which leads to save production cost for farmers. The numerical formulas for the evaluation of cultivator were presented in the following sub-sections.

2.1 Field efficiency

Field efficiency (F_e) defined as ratio of Actual to theoretical field capacity and expressed as a percentage. It was calculated using Eq.1**.** (Nagesh *et al.,* 2014) [10].

$$\text{Field efficiency (\%)} = \frac{\text{A.F.C}}{\text{T.F.C}} \times 100 \qquad \text{... (1)}$$

Where, A.F.C = Actual field capacity, ha/h and T.F.C = Theoretical field capacity, ha/h.

2.2 Theoretical Field Capacity

Theoretical field capacity is calculated by using Eq.2. (Patange *et al*., 2015) [11]. The cultivator width was considered as 1 m.

$$\text{TFC (ha/h)} = \frac{S \times W}{10} \qquad \text{... (2)}$$

Where, S = Forward speed, km/h and W = Width of the implement, m

2.3 Actual Field Capacity

Actual field capacity is usually expressed as hectare per hour. It is calculated by using Eq.3. (Manjunatha *et al.*, 2014) [8].

$$\text{AFC (ha/h)} = \frac{A}{T_P + T_{NP}} \qquad \text{... (3)}$$

Where, A = Area of coverage, ha T_P = Productive time, h and T_{NP} = Non-productive time, h.

2.4 Fuel consumption

Fuel consumption (F_t) measured by top-fill method. firstly, fuel tank is filled to its full capacity before testing on levelled surface. After the test, amount of fuel required to re-fill the tank gives amount fuel consumption for given test run and it is expressed in litre per hour. Fuel consumption is calculated by using Eq.4. (Raghavendra *et al.,* 2013) [12].

$$\text{Fuel consumption (L/h)} = \frac{V}{t} \qquad \text{...(4)}$$

Where, V = Volume of fuel consumed, L and t = Total operating time, h

Results and Discussion

1. Performance evaluation of mini-tractor drawn cultivator

After the experimental data collected, it was calculated by using standard formulas, analyzed and presented with graphical representation. Table 2 displays the results of calculations for important operational characteristics, including field efficiency, theoretical field capacity (TFC), actual field capacity (AFC) and fuel consumption.

Table 2: The calculated performance parameters of the mini-tractor drawn cultivator

S. No	Engine Speed (rpm)	Time Taken (h)	Working Width (m)	Area (ha)	Speed (km/h)	TFC (ha/h)	AFC (ha/h)	Field Efficiency (%)	Fuel consumption (L/h)
1	1500	0.0083	0.96	0.00192	2.409	0.2409	0.2313	96.01	0.41
2	2000	0.0055	0.92	0.00184	3.636	0.3636	0.3345	91.99	0.59
3	2500	0.0041	0.90	0.00180	4.878	0.4878	0.4390	89.99	0.75

1.1 Different engine speed with respect to time taken

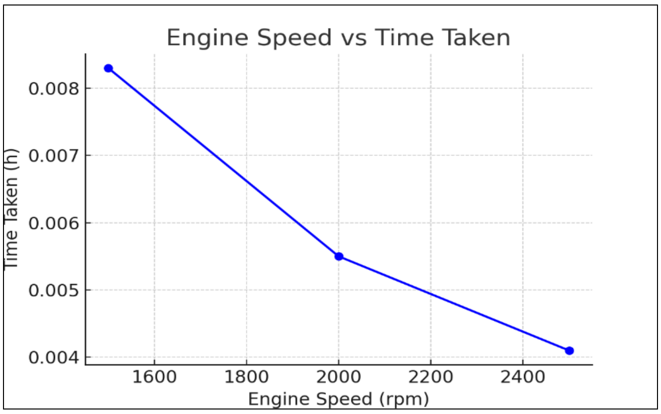

Fig 1: Different engine speed with respect to time taken

The above graphical representation depicts the three different engine speeds with respect to the time taken for the operation. The time required to cover to area decreases from 0.0083to 0.041 hours as the tractor engine speed increased from 1500 to 2500 rpm. The tractor engine rpm increased, more engine power was transferred to cultivator, which resulted in decreasing of the time required to cover the area as the engine rpm increased. A regression analysis was applied for statistical analysis, a high negative correlation was observed between tractor engine speed and time taken to cover area. It was reported that $R^2 > 0.95$ which indicates regression analysis holds goods for the obtained data. Operating a engine speed at a higher speed range at all time is not possible, because it results in higher fuel consumption their by it increasing in high cost of tillage operation. Form the analysis, it was suggested to operate the tractor engine speed below 2000 rpm to have good seedbed preparation.

1.2 Different engine speed with respect to forward speed

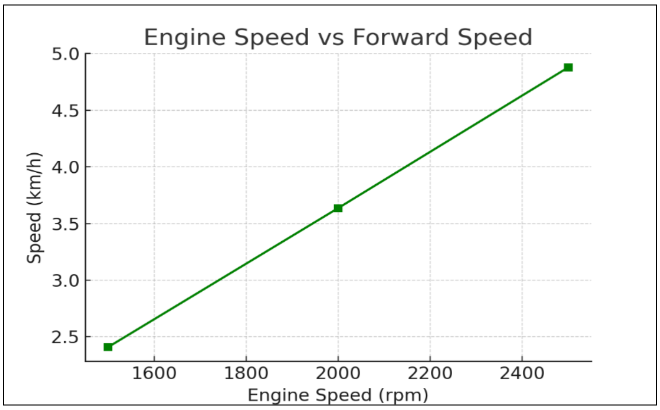

Fig 2: Different engine speed with respect to forward speed

The Figure 2 shows a graphical representation among the different engine speeds with respect to forward speeds. As the engine rpm increases a linear increase of forward speed was observed with all the three-engine rpms. as the engine rpm increases from 1500 to 2500 rpm, corresponding forward speeds also increased from 2.409 to 4.878 km/h, which results in 100% forward speeds was increased, which means double the time speed increased. As the speed increased time required to cover the area also increased, which resulted in saving time of operation. A regression analysis was applied for statistical analysis, a strong positive correlation coefficient was observed between tractor engine rpm and forward speed, which is $R^2 = 0.99$. Higher speed are not feasible in the view of economic point and some other factors such as type of soil, soil moisture content also need to consider for performance assess of cultivator or any other tillage equipment.

1.3 Different engine speed with respect to actual field capacity

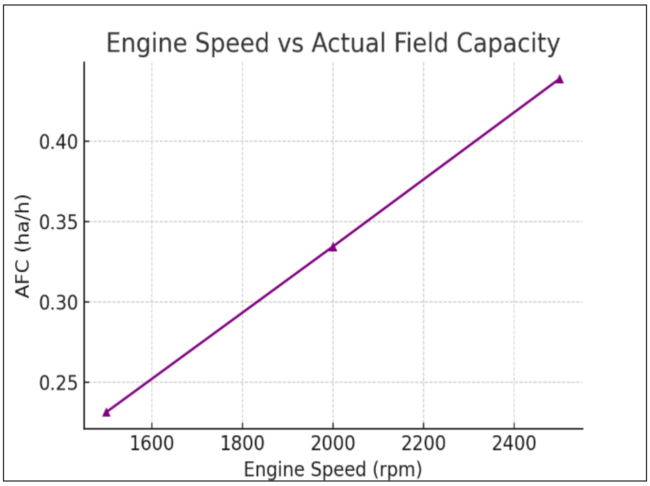

Fig 3: Different engine speed with respect to actual field capacity

The above graphical representation Figure 3 depicts the various engine speeds with respect to actual field capacity. The actual field capacity of cultivator at 1500 engine rpm was 0.2313 ha/h and at 2500 rpm the corresponding actual field capacity was 0.4390 ha/h, as a result of 89.79% actual field capacity was increased when the engine speed increased from 1500 to 2500 rpm. The actual field capacity was calculated based on the cultivator working width, speed of operation and actual area covered. Time taken for the operation also considered it includes the productive time and non-productive time, a non-productive included the breakdown of the cultivator, repair time, fuel fillings and operator rest pass time etc., a statistical analysis also carried out, a highly positive correlation coefficient was observed with R^2 value of 0.99 which represents as the engine speed increased simultaneously actual field capacity also increased.

1.4 Different engine speed with respect to fuel consumption

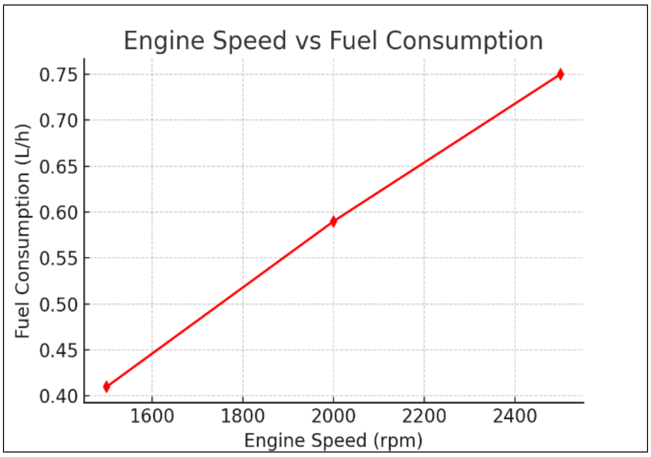

Fig 4: Different engine speed with respect to fuel consumption

Figure 4 represents a linear relationship between various engine speed with respect to the fuel consumption. The fuel consumption increased considerably from 0.41 to 0.75 L/h when the tractor engine speed increased from 1500 to 2500 rpm. The lowest fuel consumption was observed as 0.41 L/h at 1500 rpm, a moderate fuel consumption was recorded as 0.59 L/h at 2000 rpm and highest was reported as 0.75 L/h at 2500 engine rpm. The average specific fuel consumptions were reported as 0.58 L/h. The highest fuel consumption was not appropriate as it results in the high-cost operation which leads to higher overall crop production cost.

Conclusion

A cultivator was evaluated under different field conditions at three engine speeds such as 1500, 2000 and 2500 rpm. it was reported the that forward speed increases with increase of engine speed from 2.409 km/h at 1500 rpm to 4.878 km/h at 2500 rpm. The obtained results of theoretical filed capacity are increasing from 0.2409 to 0.4878 ha/h with engineering of engine speed, the actual field capacity of cultivator at 1500 engine rpm was 0.2313 ha/h and at 2500 rpm the corresponding actual field capacity was 0.4390 ha/h. The field efficiency for the corresponding above speeds was reported as 96.01, 91.99 and 89.99% respectively. The fuel consumption increased considerably from 0.41 to 0.75 L/h when the tractor engine speed increased from 1500 to 2500 rpm. The average specific fuel consumptions were reported as 0.58 L/h. The highest fuel consumption was not appropriate as it results in the high-cost operation which leads to higher overall crop production cost.

Acknowledgements

Author(s) acknowledges financial support from Department of Agricultural Engineering, Aditya University, Surampalem, Kakinada.

Competing Interests

The authors have declared no conflict of interests exist.

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